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Joseph Sarkis
*Editor*

# The Palgrave Handbook of Supply Chain Management

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With 155 Figures and 116 Tables

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# Preface

Supply chain management, although practiced in early human civilizations, did not become part of the parlance used by practitioners and academics until the 1980s. Thus, the term and the study of supply chains is a relatively recent, but growing phenomenon. And until more recently, the study and understanding of supply chains was under the purview of specialized academic experts and practitioners. With the recent COVID pandemic, we saw supply chain management as a term and practice enter the popular mindset.

When this handbook – a Palgrave Major Reference Work – was first conceived, it was conceived with this practitioner and academic specialist and student community in mind. Currently, it may be of interest to a much broader community beyond university academics and students and practicing supply chain managers. In fact, journalists, policy makers, and even community leaders may find value in understanding the supply chain field and related phenomena.

In an era characterized by global interconnectedness, rapid technological advancements, sustainability concerns, and an ever-evolving business landscape, the importance of supply chain management has never been more profound. Each of these topics along with COVID have caused an evolution of thought from efficiency and cost management to risk and resilience. As organizations strive to meet the demands of a dynamic marketplace, it is both efficiency and resilience of their supply chains that have become critical factors in achieving success. Agility, lean, green, and integrated are terms that appear throughout the book in various chapters.

This handbook is a comprehensive guide designed to assist professionals, students, and enthusiasts in understanding and mastering the art and science of supply chain management. Understanding supply chains requires an acknowledgment that supply chain management is not just a functional silo within an organization; it fuels the heart of modern commerce. It connects sourcing (upstream), production, distribution (downstream), and logistics into a seamless, coordinated system that strives to optimize operations, reduce costs, and enhance customer satisfaction – and even meeting basic human needs.

It also goes beyond the typical business issues – you have environmental sustainability, closed-loop supply chains, humanitarian, circular economy, and national security that are included in the supply chain discourse. Many of these non-traditional topics are covered in this volume of over 60 chapters.

Supply chain management is a field that encompasses a diverse array of topics, and this book attempts to cover the complex and ever-expanding terrain. The topics and chapters are generally positioned into six major categories – with significant overlap along each. Here is a summary of the parts.

**Strategic Issues** – These chapters cover concerns that have broader and longer-term implications. The issues cut across functional disciplines. The topics range from financial and human resource concerns to broader environmental and social sustainability issues. The topics would be of interest to all in the organization from the boardroom (C-suite) to the individual on the shop floor or consumer. Although these chapters take the perspective of a focal company, they are also likely to imply strategic relationships to outside stakeholders. Under strategic issues, the goal is to consider broader economic and business concerns and then evolve to social and environmental issues in the supply chain.

**Operational Issues** – These chapters focus on internal activities that are shorter term and more concentrated on specific projects and issues. These topics may be the concern of a few or singular functions within the organization. Many are related to traditional operational concerns and focused on operational efficiency and effectiveness of programs and projects. Typically, these topics would be considered under the purview and primary control of a single focal company. Subjects include a variety of continuous improvement projects and programs. Within the operational concerns, the evolution is from programmatic and philosophical operations concerns, such as lean and agility philosophies, to more specific optimization and planning of resource concerns, such as costing, risk, and inventory and human resources management.

**Logistics and Transportation** – In supply chain management, one of the most important ways of managing flows, especially materials flows, within and across boundaries is through logistics and transportation. This categorization is a separate part since the topic has received significant emphasis and sometimes represents core but separate fields within supply chain management. The subjects relate to materials management and materials movement; although each includes strategic and operational contexts, they will be focused on management of these specific functions and processes. These activities and functions occur upstream, downstream, and within organizations. The activities are often outsourced supply chain support activities and have technological linkages. In this part, we begin with general transportation and logistics as chapters, and then get into more specific related topics such as modes of transportation concerns, reverse logistics, and warehousing. We also sought to incorporate some locational analysis and ownership concerns within this context such as outsourcing and insourcing or international location such as off-shoring and on-shoring.

**Upstream Management** – In some fields of thought, the supply chain is meant to focus on the upstream aspects of managing supply. These activities and functions include sourcing, purchasing, procurement, and vendor management activities. These are external linkages between a focal organization and its upstream suppliers. These chapters cover immediate (dyadic) upstream suppliers and multi-tier relationships. Upstream interorganizational collaboration and coordination are also important topics in this context. There will be generic upstream supplier and vendor management topics including selection, development, and auditing. In some cases, specific characteristics and aspects take hold, such as coordination in a specific industry, but generalizations are also made. We also include topics that can fit across multiple stages and categories, such as coordination and collaboration as generic practices which are placed here primarily because much of the research is focused on upstream aspects. These latter topics may easily fit into other parts depending on the perspective taken.

**Downstream Management** – This set of chapters includes post-product or service provisions and is customer facing – relative to the focal organization. The functional characteristics of marketing activities and functions play significant roles in this part. Most of the activities and topics here focus on satisfying external customer needs and requirements. Issues also include end-of-life management or products and after-sales services. The order of these chapters within this part ranges from the most generic topics such as industrial marketing and general marketing and supply chain relationships and do include design and slightly more strategic issues such as customer relationship management and distribution planning. Specific tools and approaches with consideration of after-sales services are included.

**Technology** – The role of technology in the supply chain has its own part because it is a critical resource with significant interest from researchers and practitioners. Information, logistics, product, process, and inter-organizational technologies such as Industry 4.0 are some of the many technologies and technology management topics relating to supply chain management. The management of technology, justification, diffusion, and specific technology roles of emergent and existing technologies are each included. Similar to the previous parts in the book, this part begins with overarching umbrella topics including general technology and innovation management issues within the supply chain. Then more specific aspects such as process and product design with a technological focus introduced including topics such as managing virtual teams in a technological setting. Major portions of contributed chapters likely focus on Industry 4.0 and other emerging technology roles within the supply chain. Some topics include motivation and leadership concerns and others are broader stakeholder and community engagement. These are only example issues covered, with many linking concerns to globalization, the pandemic, resilience, and topics in other parts.

Now that we have spoken about the content. A primary goal of this Major Reference Work is to serve as a valuable resource for those who seek to understand, improve, and excel in supply chain management. Whether you are a seasoned supply chain professional looking to enhance your expertise, a student embarking on your educational journey, or a business owner striving to create a resilient and efficient supply chain, this handbook is the ultimate comprehensive companion.

Key features of this Major Reference Work include:

Comprehensive Coverage: We explore the entire spectrum of supply chain management, from the basics to advanced topics, ensuring that readers gain a well-rounded understanding of the subject.

Real-World Insights: Our content is enriched with real-world case studies and examples to provide a practical perspective on supply chain challenges and solutions.

Expert Perspectives: We have drawn upon the expertise of supply chain professionals and thought leaders to provide valuable insights and cutting-edge strategies. These experts come from a broad range of geographical regions covering every continent. They also include emerging scholars, seasoned scholars, and professionals from industry with years of experience.

Practical Tools: Throughout the Major Reference Work, you will find tools and frameworks that can be applied directly to your supply chain planning and operations.

Global Focus: Supply chain management is a global endeavor, and we explore how to manage supply chains in the context of globalization and international operations.

Sustainability and Innovation: We examine the increasing importance of sustainability and the role of innovation in shaping the future of supply chain management.

As the world continues to evolve so does the field of supply chain management. This Major Reference Work is designed to evolve with it, ensuring that readers are equipped with the latest knowledge and insights. Chapters are structured in a way to provide a brief foundation for the topic of the chapter, some of the current practice and research, and eventually future directions that are expected to occur. Most chapters also include a comprehensive reference set from academic and practitioner literature. There are both managerial and research implications peppered throughout each chapter.

We hope you find this Major Reference Work to be an indispensable resource as you embark on your journey to initially understand and eventually master supply chain management. Whether your goal is to optimize processes, reduce costs, enhance sustainability, manage technology, or simply gain a broader understanding of this critical field, we are confident that the knowledge within these pages will be a valuable asset in your endeavors.

Worcester, USA
February 2024

Joseph Sarkis

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## Volume 1

# About the Editor

**Joseph Sarkis** is Professor of Management, former Head of Department of Management, and former Interim Dean within Worcester Polytechnic Institute's (WPI) Business School. His teaching and research interests include topics in supply chain management, business and the natural environment, sustainability, operations, logistics, technology, and information management. He has also taught courses on supply chain management, logistics, operations management, business analytics, management science, sustainability, and business and the natural environment.

He has published over 350 papers in peer-reviewed journals on topics ranging from transportation and supply chains to manufacturing and production technology to service, non-profit, and governmental settings, with the vast majority of publications in SSI/SSCI indexed journals. He has also published over 175 additional papers as chapters in books and in conference proceedings. Twelve of his books have been published. A number of his publications have been recognized with various publishing awards. His work has been cited tens of thousands of times based on Google Scholar citations, with an H-index above 135.

Dr. Sarkis is noted as the world's most productive scholar in the field of supply chain management for the years 1995–2015. He is recognized as one of the most highly cited scholars in the world by the Web of Science (Clarivate) for a number of years starting in 2016 until today; this recognition has been noted by Clarivate as the world's "most influential scientific minds."

Currently, he serves on a number of editorial boards for a broad variety of journals including sustainability, operations and manufacturing, technology management, production, and information systems journals. He has served as editor of *IEEE Engineering Management Review* and *Management Research Review*. Prof. Sarkis's departmental and associate editor duties include and have included the Models and Methodologies department and the Social Issues and Sustainability in Engineering Management department for *IEEE Transactions on Engineering Management*; *Resources, Conservation and Recycling*, *the Journal of Supply Chain Management*, and *Transportation Research Part E*. Dr. Sarkis has served as guest editor of dozens of special issues on Technology, Transportation, Innovation, Sustainability and Business topics in such journals as the *European Journal of Operational Research*, *Decision Sciences*, *Journal of Cleaner Production*, *Business Strategy and the Environment*, *Transportation Research E*, *International Journal of Operations and Production Management*, *International Journal of Production Economic*s, *Greener Management International*, and *Information Systems Frontiers*.

His dozen books include topics on Greening the Supply Chain and Strategic Sustainability. Dr. Sarkis' most recent books include edited volumes entitled *Greening Logistics and Transportation* and *Green Growth: Managing the Transition to a Sustainable Economy*. His most current book is *Green Supply Chain Management*, published with Yijie Dou and the *Handbook of Sustainable Supply Chains*. He is a Springer-Nature book series editor for the Greening of Industry Networks series.

He has served as a visiting scholar at various international locations including Cardiff University's BRASS center and Business School, the University of Oviedo in Spain, Hanken School of Economics in Helsinki, UCSI University in Kuala Lumpur, and a visiting scholar in the EU Erasmus Mondus MESPOM program. He has also been a Sea-Sky Scholar at Dalian University of Technology in China. He is an AT&T Industrial Ecology Fellow. He has given lectures and keynote addresses in a number of countries including Denmark, Egypt, Finland, France, Germany, Hungary, Lebanon, Sweden, Italy, Japan, China, Brazil, the UK, and the Philippines.

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# Part I

# Strategic Issues

# Strategic Management and Supply Strategy

Christine M. Harland

## Contents



**Abstract**

Strategic management has informed and enhanced the development of supply strategy. Supply strategy is a strategic, collaborative, and policy-oriented field of supply in complex interorganizational networks and systems connecting manufacturing and service, for-profit, and not-for-profit organizations. Originating in production and operations management, supply strategy has grown from its operational roots through building on and incorporating strategic management concepts and theories.

This chapter examines strategic management as content and process of strategies formulated and implemented by firms. Strategic management concepts relating to networks of collaborating organizations provide building blocks for developing supply strategy as a multi-organizational, value-adding, strategic

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endeavor. Supply strategy is conceptualized as relating to supply within organizations, buyer-supplier relationships, supply chains, supply networks, and supply systems. Competitive strategy, strategic fit, and strategic alignment are applied and adapted to supply strategy.

**Keywords**

Supply strategy · Strategic management · Supply networks · Supply processes

## 1 Introduction

This chapter provides an overview of strategic management and how this topic has informed and developed supply strategy thinking and practice. *Supply strategy* is used in this chapter to represent the various terms and brands of supply chain management, supply chain networks, supply networks, and purchasing and supply management – the terms and the development of the overall field are examined later.

Rather than discuss specifics of the content of business and supply strategies – such as sustainability, innovation, or quality-oriented strategies – this chapter explores how strategic management concepts and theories have gradually been adopted and, to a limited extent, developed by the field of supply strategy. As a result, supply strategy has transformed itself from an operationally focused field encompassing material acquisition, transformation, and flows in purchasing, production, and logistics within manufacturing and distribution, to a more strategic, collaborative, and policy-oriented field of supply in complex interorganizational networks and systems connecting manufacturing and service, for-profit and not-for-profit organizations.

The discussion of strategic management in the chapter is selective, exploring the main concepts and themes that have been imported by supply practitioners and researchers. These concepts and themes are core to strategic management, showing how strategic supply thinking has been closely aligned to the development of strategic management thinking.

Strategic management texts and research publications discuss the burgeoning debates and nuances of their field, including the many different schools of thoughts, their origins, and perspectives on strategy. To date, supply strategy has adopted more normative, rational, design approaches from within these schools of strategic management, rather than more processual, emergent approaches. However, an overview of strategic management approaches is provided in this chapter because the field of supply strategy is currently developing more behavioral, social, and emergent thinking. It is increasingly recognized that *softer* resources such as social capital, knowledge, reputation, and expertise are strategically important to supply decision making, in addition to the harder resources of equipment, information systems, and materials.

The chapter examines strategic management as content and process of strategies formulated and implemented by firms. Strategic management concepts relating to networks of collaborating organizations provide building blocks for developing supply strategy as a multi-organizational, value-adding, strategic endeavor. Supply strategy here is conceptually framed as relating to supply within organizations, buyer–supplier relationships, supply chains, supply networks, and supply systems. Competitive strategy, strategic fit, and strategic alignment are applied and adapted to supply strategy.

*Strategy as content* is interpreted in strategic supply as a set of strategic, structural decisions relative to the boundary of interorganizational thinking and influence. For example, which organizations should be within supply relationships, chains, networks, and systems, and how should this set of organizations be shaped and reconfigured?

*Strategy as process* is interpreted as strategic decisions relating to supply infrastructure, in terms of processes, flows, and activities within supply relationships, chains, networks, and systems.

Stage and maturity models of strategic management have been widely used in supply practice and research and have been further developed, specifically for the field. Structural and infrastructural decisions and implications for supply are considered in this chapter, as organizations, relationships, chains, networks, and systems mature and progress through development stages.

First, a brief history of the development of supply strategy is provided, examining the reasons why and how operations and supply chain management evolved from an internally focused concept to a more strategic, interorganizational, networked perspective. This chronological development path provides the line of trajectory of the field that, in some part, explains why supply strategy takes the perspective of strategy it does.

## 2 Development of Supply Strategy

In their *genealogy of operations management*, Meredith and Amoako-Gyampah (1990) traced the origins of operations management back to *factory management* at the time of the Industrial Revolution. The invention of machinery to replace human labor and the division of labor into organized tasks heralded the development of more scientific approaches to manage factories efficiently, leading to the invention of mass production. In the 1930s *production management* replaced *factory management*, as economic efficiency became the core focus of manufacturing.

During World War II, operations research techniques were introduced to manage manufacturing and support military troops and materials movements, giving birth to a new concept of *logistics*. Modern production and operations management (POM) did not come into its own until the late 1950s to early 1960s. From this time to the late 1980s, POM focused largely on operations inside manufacturing organizations. Core to POM thinking was the transformation of input resources, via a process, to produce outputs – the *input-process-output* model. Most early POM texts concentrated on the tasks performed by the POM manager, and these tasks were internally oriented within the manufacturing firm.

The concept of manufacturing strategy appeared in Wickham Skinner's (1969) ground-breaking identification of manufacturing as being *the missing link* in business strategy. Skinner identified that manufacturing operations, faced by competing demands for productivity, timeliness, quality, and customer service, could not be good at everything and that *trade-offs* had to be made. Wheelwright (1978, 1984) developed these trade-offs, proposing four *competitive priorities* – cost, quality, dependability, and flexibility – and the need for these trade-offs to be consistent with corporate strategy.

In *Restoring our competitive edge: competing through manufacturing* (Hayes & Wheelwright, 1984), patterns of structural and infrastructural decisions represented strategic capability of manufacturing organizations. These decisions were related to capacity, facilities, technology, vertical integration and sourcing, workforce, quality, production planning, materials control, and organization. It is at this time that POM first considered the strategic importance of activities external to the firm, asking questions such as "what boundaries should a firm form around its activities," "how should a firm construct its relationships with suppliers, distributors and customers outside its firm boundaries," and "under what circumstances should a firm change the boundaries of these relationships"?

The term *commercial chain* was used to conceptualize a firm as one link in a larger chain of organizations (Hayes & Wheelwright, 1984). The term *supply chain management* (SCM) predates *commercial chain*, as it was first used by Booz Allen management consultants to signify the internal value chain within a manufacturing organization from inbound to outbound ends of the business (Oliver & Webber, 1982), that is, integration of traditional POM processes. This first use of the term SCM was synonymous to the term *materials management* proposed by Dean Ammer (1962), later discussed more strategically as a profit center in manufacturing organizations (Ammer, 1969). However, the brand *materials management* did not gain traction, but supply chain management did.

Hayes and Wheelwright's (1984) *commercial chain* underpinned the development of operations strategy as an interorganizational strategic endeavor. Wheelwright and Hayes (1985) incorporated consideration of operations external to the firm in their development of the concept of manufacturing strategy.

Interestingly, the whole question of trade-offs that was central to the concept of manufacturing strategy was being challenged, based on learning from Japanese methods of manufacturing. In *Quality is Free*, Philip Crosby (1979) was one of the so-called *quality gurus* who interpreted from learning from Japanese manufacturing that some trade-offs were not necessary. Better quality was shown by the Japanese to be achievable without increased cost. However, these performance variables and their trade-offs remained central to manufacturing strategy thinking.

As manufacturing strategists developed these competitive priorities, or trade-offs, that drove strategic structural and infrastructural decisions, they had not identified how these decisions were integrated into a marketing and business strategy process. Terry Hill (1985) articulated competitive priorities as performance dimensions that won orders – *order-winning criteria* – or allowed the business to compete for orders – *qualifying criteria*. These order-winning and qualifying criteria were:

- Price
- Product quality and reliability
- Delivery speed
- Delivery reliability
- Responsiveness to demand increases
- Technical liaison and support
- Meeting a launch date
- Being an existing supplier
- Product and color range

Hill highlighted that the relative importance of these criteria would differ between companies and possibly between products within the same company and that they were likely to change over time. However, Hill's key contribution to manufacturing strategy was the process that connected corporate strategy with manufacturing strategy. Table 1 below summarizes this process.

Mason-Jones et al. (2000) highlighted how order-winning and qualifying criteria differed across sectors. For example, in the fashion sector, quality, price, and lead time were qualifying criteria, whereas service level was an order-winning criterion. In contrast, quality, lead time, and service level were qualifying criteria for commodities, and price an order-winning criterion.

While Skinner (1974), Hayes and Wheelwright (1984), and Hayes et al. (1988) did identify vertical integration and sourcing as important to manufacturing strategy, relatively little of their texts were devoted to this topic.

From Harvard, David Garvin's text on *Operations Strategy* (Garvin, 1992) did not address upstream and downstream supply issues, focusing on issues internal to

**Table 1** Framework for reflecting manufacturing strategy issues in corporate decisions. (Adapted from Hill, 1985)

| Corporate objectives | Marketing strategy | How do products win orders in the marketplace | Manufacturing strategy – process choice | Manufacturing strategy – infrastructure |
|---|---|---|---|---|
| Growth<br>Survival<br>Profit<br>Return on investment<br>Other financial measures | Product markets and segments<br>Range<br>Mix<br>Volume<br>Standardization vs. customization<br>Level of innovation | Price<br>Quality<br>Delivery speed and reliability<br>Demand increases<br>Color range<br>Product range<br>Design leadership<br>Technical support being supplied | Choice of alternative processes<br>Trade-offs embodied in the process choice<br>Process positioning<br>Capacity – size, timing, location<br>Role of inventory in the process configuration | Function support<br>Manufacturing planning and control systems<br>Quality assurance and control<br>Manufacturing systems engineering<br>Clerical procedures<br>Payment systems<br>Work structuring<br>Organizational structure |

manufacturing. The big leap forward in understanding the importance of upstream and downstream supply issues in manufacturing and operations strategy was made by Hill (1989) where he further developed the strategic concept of positioning, relating this to process positioning. He devoted a chapter to exploring "the width of a firm's internal span of process, the degree and direction of vertical integration alternatives, and its links and relationships with suppliers, distributors and customers." He examined five strategic alternatives to manufacturing in-house:

- Joint ventures where two or more firms co-developed the application of technology and research
- Non-equity-based collaboration involving a longer-term cooperation between firms on a particular project or venture without the formal ownership structure of a joint venture
- Long-term contracts with suppliers to provide added predictability and increased assurance which helped both parties make and achieve long-term plans
- Customer–vendor trust-based relationships over time and over a number of projects
- Just-in-time production requiring coordination between suppliers and manufacturers across various parts of the manufacturing and inventory management process.

Womack et al. (1990) changed manufacturing, operations, and supply strategy thinking by providing two chapters on external aspects of operations strategy, one titled "coordinating the supply chain" and the other "dealing with customers." They moved manufacturing strategy forward by considering:

- Organizational modes other than vertical integration
- The concept of a network of suppliers, suppliers' suppliers, and so on upstream
- The concept of a network of customers, customers' customers, and so on downstream
- The significance of the ultimate consumer (which until then had received almost no attention in operations strategy)
- How relationships with suppliers and customers could be managed
- Performance implications of external relationships
- How this thinking connected with the work in marketing on channel management
- The importance of information technologies in managing external relationships

Womack et al. (1990) coined the term *lean supply*. For the first time, substantial consideration of the management of organizational modes other than vertical integration was provided. Supply-side scholars, notably Richard Lamming (1993) and Toshihiro Nishiguchi (1994) who were both involved in the International Motor Vehicle Program (IMVP) research project on which Womack et al.'s (1990) book was based, developed more fully a strategic approach to forming and managing supplier relationships.

Christopher (1992) took a more strategic, holistic perspective that incorporated downstream distribution channel organizations, leading ultimately to end customers. This upstream and downstream perspective of firms' span of strategic operational concern is embodied in the conceptualization of SCM as a field encompassing traditional internal operations management and connected relationships with suppliers, suppliers' suppliers, customers, and customers' customers, operating at multiple systems levels of internal supply chains, dyadic relationships, external supply chains, and wider supply networks (Harland, 1996).

In parallel, but with little overlap with POM scholars, purchasing and supply management (PSM) focused on how companies should purchase materials and components required for manufacturing, from suppliers (Webster & Wind, 1972; Leenders et al., 1980). The Five Rights – right quality, quantity, delivery, price, and service – were balanced, or traded-off, in operational purchasing decisions to decide with which supplier to place purchase orders. These multiple, parallel strands of thinking of PSM and SCM have been developed and intertwined into today's conceptualization of supply strategy as a far more strategic, interorganizational concept (Ellram et al., 2020), operating at multiple systems levels (Harland, 2021).

## 3 Aligning with Strategic Management

As the field of supply practice and research developed to be more strategic and externally oriented, many of the strategic concepts were drawn from the field of strategic management. The most adopted concepts by the field of supply strategy are summarized below.

To form strategy for an organization, first its strategic environment is examined as this provides the context within which an appropriate strategy is designed.

### 3.1 Strategic Environment

The strategic environment for any organization, or function within it, can be considered at three levels (Narchal et al., 1987).

1. Macro environment is the context within which organizations operate, over which they have little or no individual influence. Traditionally this was characterized as PEST factors – political, economic, societal, and technological factors. There are many different categorizations of macro environment factors, and, more recently, these have included factors such as demography, religion (van Buren et al., 2020), ecology, legal systems, and culture. The macro environment organizations should consider relates to the level of strategy they are forming. For example, the macro environment of a global business might be considered for each region the firm operates in, whereas the macro environment of a small- to medium-sized enterprise might focus on factors within the local economy, government, and society.

2. The sector or industrial environment relates to the specific sector an organization operates in – for example, bioengineering, fashion, or local government. Forces and factors relevant to that sector should be considered when understanding the strategic environment within which the strategy is to be formed. For example, within the food sector, food safety, traceability, and recycling have become important factors driving organizations.
3. The competitive environment is the set of competitors with whom the organization directly competes and their strategies and actions.

Most organizations are not able to influence the macro and sector environments within which they operate, so these become contextual for their strategy formulation and implementation. Typically, only large, powerful organizations can influence governments, industry groups and associations, or changes in legislation and regulation. However, many organizations may be able to influence some factors relating to their competitors.

Michael Porter's (1979) five forces model is commonly used by organizations to understand their competitive environment, but it also considers factors relating to the sector or industry. As an industrial economist, much of the thinking underpinning Porter's concepts and frameworks stem from the industrial organization perspective of Bain (1959) that focuses on economies of scale and scope of organizations within sectors or industries. Porter's approach to *strategic positioning* is about how an organization can position itself to achieve competitive advantage over other organizations in the sector. Organizations seek competitive advantage through an economies-of-scale-based *cost advantage* or through differentiating themselves from the rest of the competitive pack – a *differentiation advantage*.

Rivalry among existing competitors is at the center of Porter's five forces model and considers factors including the number and diversity of competitors, industry concentration, industry growth, brand loyalty, barriers to exit, switching cost, and quality variability of offerings. The other four forces considered are threat of new entrants, threat of substitute products, bargaining power of suppliers, and bargaining power of buyers.

When formulating supply strategy, the bargaining power of suppliers and buyers is highly relevant. Upstream on the supply side, to assess the bargaining power of suppliers, supply chain managers might consider the number and size of suppliers, the uniqueness of each supplier's product, and the ability of the firm to substitute in another component or service from another supplier. Downstream on the customer side, to assess bargaining power of buyers, factors including the number of customers, the size of each customer order, differences between competitors, price sensitivity, buyer ability to substitute, buyer information availability, and switching costs are considered.

It is important to define the boundary of influence when considering the strategic environment, placing those factors that are outside the control of the organization as external influencers on the organization's strategy.

Strategic positioning is also about an organization's position in the *value chain* and *value system*. Strategic management scholars, notably Porter (1980, 1985, 1987), Johnston and Lawrence (1988) and Kogut (1985), identified the strategic significance of managing the chain of value-added for the production and supply of products and services. Porter (1980) described the value system as the sum of value chains of suppliers, manufacturers, distributors, and end customers. Each value chain comprises primary activities from inbound to outbound ends of the business, supported by the firm's infrastructure and support activities, including procurement.

Porter identified that managing beyond the company boundary could improve output performance and cost management, by influencing the configuration of supplier value chains and improving coordination between a firm and its supplier and channel value chains. Kogut (1985) discussed how different firms in the same market choose to own different amounts and parts of the value chain; for example, Dell direct were able to gain competitive advantage of speed and range flexibility through owning downstream sections of their value chain to be closer to end customers.

Upstream, Kogut (1985) also examined *comparative advantage* (originally conceived by the British nineteenth-century economist, David Ricardo) that a firm could gain by having links in its supply chain in particular international locations; for example, dyeing of textiles is often cheaper in Asia than Europe, energy is relatively cheaper in Canada than in many other countries. In strategic management, Johnston and Lawrence (1988) described *value-adding partnerships* as independent companies working closely to manage the flow of goods and services along the entire value chain.

While the most common type of relationship discussed in strategic management historically was vertical integration, or ownership of links in the value chain, intermediate types of relationship between market and hierarchy were identified by Richardson (1972), Blois (1972), and Williamson (1975), based on the original work of Coase (1937). Vertical disintegration was reported as occurring across automotive, machine tools, robots, domestic appliances, and medical equipment manufacturing from the mid-1980s (Thackray, 1986; Porter, 1988).

It can be seen, therefore, that strategic positioning takes an *outside-in* approach to strategy formulation, considering the strategic environment and how an organization tries to achieve competitive advantage over others in the same sector, or industry, to maximize profits. Having considered strategic positioning, the content and process of strategy formulation occurs within this strategic, competitive, environment, to achieve *strategic fit*.

## 3.2 Strategy Content and Process

There are many schools of strategic management including, for example, strategic planning, design, strategic positioning, and cultural schools; for overviews of the various strategic management schools, see Mintzberg (2009) and Pettigrew et al.'s handbook (2006). There have been tensions between two main groups of strategic management schools relating to perceiving strategy as *content* or *process*.

The more normative, planning- and design-oriented strategic approaches that consider strategy as structure and content can be traced back to Chandler's "visible hand" (1977) and Ansoff (1965), while the process-oriented, more emergent perceptions of strategy align with the thinking of Mintzberg (1979). Heated debates on the relative merits of more normative, ordered approaches to strategic management leading to *well-tended gardens* vs. those favoring the more organic development of strategies as in a *weed patch* (Pfeffer, 1993, 1995; van de Ven, 1989; van Maanen, 1995) are now being replaced with greater acceptance of blended strategies.

The boundary between these distinct schools of strategic management thinking have blurred as blended strategies bridge the two main camps (Chakravarthy & White, 2006). Furthermore, the dominance in strategic management of for-profit business strategy has also been questioned as increasing attention is being paid to public sector, not-for-profit and so-called *third sector* organization strategy (Ferlie & Ongaro, 2015).

## 4 Achieving Strategic Fit and Alignment

Functional strategies, such as purchasing and supply chain management and finance strategies, should align their goals with those of the business strategy. This alignment requires consistency between customer priorities that the competitive strategy is trying to satisfy and capabilities of suppliers within the supply strategy.

When there is a greater fit between functional purchasing and supply chain strategies and business strategies, firms achieve higher performance (Baier et al., 2008; González-Benito, 2007). Organization studies and strategic management scholars often promote that *structure follows strategy* and that structural decisions within purchasing and supply chain management strategies should align with the strategy. Misalignment or misfit can impact adversely on purchasing cost and innovation performance (Ates et al., 2018).

Cousins et al. (2008) provided a strategic supply wheel showing five main elements of decision making that should be aligned with corporate and supply strategy, namely, organizational structure, the portfolio of relationships with suppliers, total cost–benefit analysis, skills and competences, and performance measurement. Harland (2002) provided a more detailed picture showing how supply operations, management, strategy, and policy, and their constituent elements, should be aligned, as shown in Fig. 1.

Supply operations, management, strategy, and policy choices should be internally aligned within the supply function, and the strategy and policy choices should *fit* with those of the overall business. To achieve this *corporate coherence*, Rozemeijer et al. (2003) argued that centralized or center-led purchasing is required; decentralized purchasing and organizations with lower purchasing maturity are less likely to make decisions coherent with the business strategy. This *structure follows strategy* argument aligns with strategic management thinking.

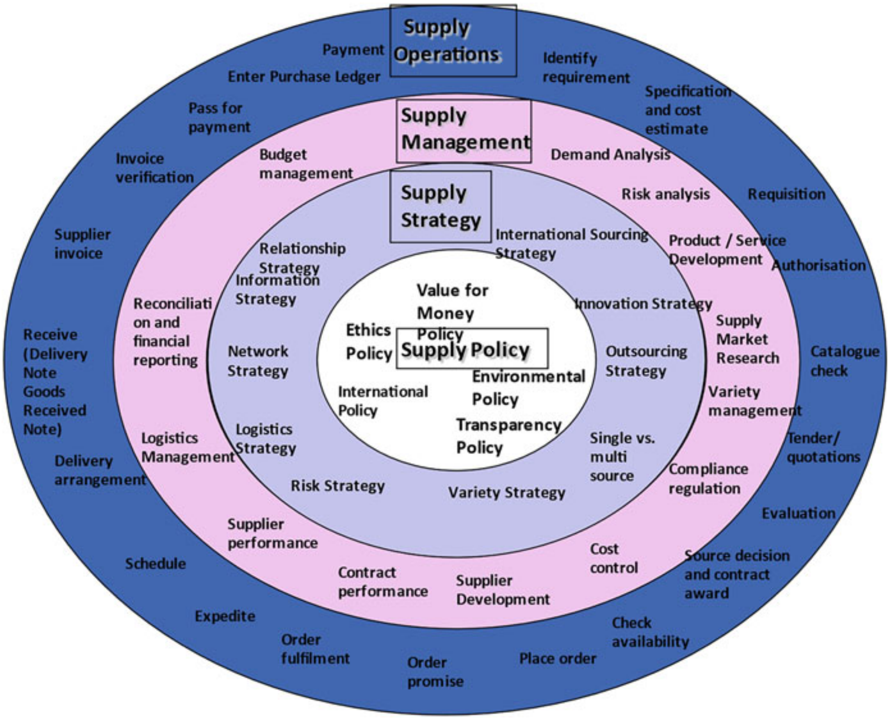


**Fig. 1** Supply operations, management, strategy, and policy

## 5 Supply Structure Decisions

Internal business function organization structure alternatives, including centralized, decentralized, or hybrid organization structures, have been considered in the supply strategy POM and SCM fields. However, there are more strategic structural decisions to be made, beyond internal departmental organization structures. This chapter examines the strategic decisions about choosing which organizations should be in a firm's supply network, how a firm might strategically position itself in a value chain, and the implications of strategic structural decisions.

Supply networks have been conceptualized as comprising a *focal firm*, often depicted in the center of a network of upstream suppliers, suppliers' suppliers, and so on to original source of raw materials and downstream customers, customers' customers, and so on to ultimate *end customers*. Every firm has its own unique supply network; from its individual vantage point, a firm sees a unique upstream and downstream network of organizations.

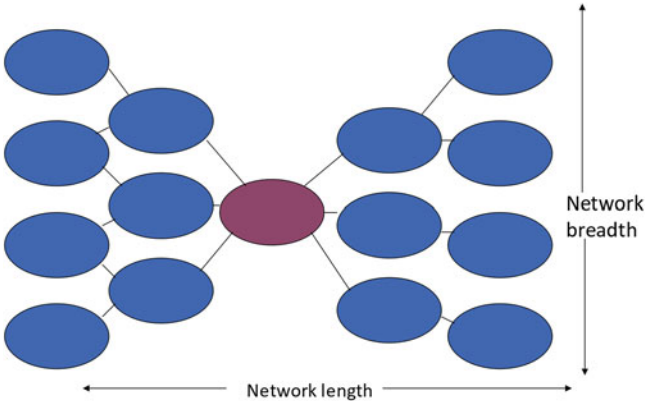


**Fig. 2** Simple supply network structure

Supply networks differ in shapes and sizes according to:

- The breadth of the network – the number of immediate suppliers, suppliers' suppliers, and customers and customers' customers
- The length of the network – the number of echelons or tiers in the network
- The firm's position in the network

Figure 2 shows a simple supply network structure.

## 5.1 Supply Network Breadth

The use of multi-sourcing encouraged price competition among more suppliers, leading to broader networks. However, learning from Japanese manufacturing methods, supply base reduction swept across manufacturing during the 1980s and 1990s, with an increased use of *single sourcing*. For example, Rank Xerox had almost 5000 suppliers in 1981, but reduced this number to around 300 by 1987 (Morgan, 1987).

Lamming (1989) reported that Japanese lean producers involved fewer than 300 suppliers in new product development compared to typical Western manufacturers who used 1000–2500 suppliers. In the service sector, Barnes (1987) discussed "reshaping the supply chain" in healthcare delivery systems, by reducing the number of distributors used to fulfill a service provider's requirements. However, the use of single sourcing was often misunderstood. It was common in Japanese automotive manufacturing to single source a particular component, such as a left taillight, while multi-sourcing the technology and manufacturing capability for all taillights, enabling switching between suppliers. This misunderstanding led to some Western firms exposing themselves to risks of single sourcing capability.

The impact of concentration in supply networks bears various risks. Narrow supply networks can cause individual suppliers to become over-reliant on certain customers. Sabel et al. (1987) discussed how this risk could be hedged through setting limits on the percentage of a supplier's business that a firm should demand. They also identified that dealing with more suppliers, including those dealing with your competitors, can improve access to innovation, learning, and knowledge.

Strategic supply decisions that impact on network breadth and length include modular design of vehicles enabling manufacturers to source modules, rather than components. Economies of scale benefits of modularity include reduced communication and transport costs between firms and their suppliers (Lamming, 1989).

In *Strategic Sourcing*, Nishiguchi (1994) analyzed the supply networks of Japanese automotive manufacturers, and how they had been organized into hierarchies, where first-tier suppliers provide modules to original equipment manufacturers and source components from their suppliers. *Kieretsu* were strategically created complex networks of suppliers involving equity ownership and interlocking directorships (Nishiguchi, 1994). This effectively lengthened supply networks, increasing the distance of a focal firm from its suppliers.

Longer supply networks may suffer more from noise and distortion in the system through the industrial dynamics Forrester or bullwhip effect (Forrester, 1961). Some firms work to get closer to sub-suppliers in their supply networks by reaching around immediate suppliers to form contacts with second- or third-tier suppliers; Patrucco et al. (2022) identified different archetypes of relationships firms have with their suppliers and sub-suppliers in triadic relationships.

There are relative merits of broader and narrower supply networks, as summarized in Table 2 below.

The number of supply connections may differ in the upstream and downstream sections of a supply network. Figure 3 shows how some firms are in supply networks that are highly concentrated upstream but less concentrated downstream. The example shown is the supply network for a precision castings manufacturer that supplies a wide variety of different industries but sources from a limited number of raw material suppliers.

Position in the supply network – whether a firm is located further upstream or downstream – has strategic and operational implications. Most research attention has been paid to relatively centrally positioned, high-volume, low-variety

**Table 2** Relative merits of broader and narrower supply networks

| Advantages of more supply relationships in a broader supply network | Advantages of fewer supply relationships in a narrower supply network |
|---|---|
| More adaptable to changes in the environment<br>Increased switching ability<br>More knowledge sharing through more and different contacts<br>Reduction of dependency and uncertainty of supply<br>Greater price competition in multi-sourcing | Reduced transaction costs<br>Rigid and strong<br>Dense flows of information<br>Ability to maintain confidentiality<br>Trust in relationships<br>More intense development of social capital |

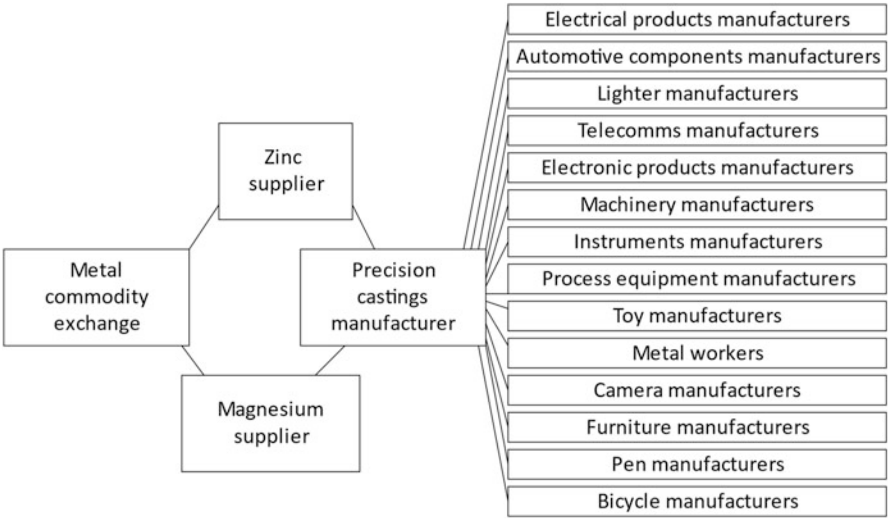


**Fig. 3** Example upstream concentrated supply network

manufacturers, such as many automotive or electronics manufacturers. However, being positioned upstream is very different to being downstream.

Upstream material processors may be quite large-scale, equipment-intensive organizations, such as in oil refining, but there are many other types of upstream businesses, such as food processors or metal processors, as examples. Life in that position in the network is very different. These firms may have a small number of suppliers, but their products may end up in a vast array of sectors. Buyers in these firms could be highly specialized and knowledgeable of their supply markets, but marketing and sales functions would have to deal with a wide range and number of target customer markets. Examples of downstream positioned firms are distributors and retailers.

Competitive advantage can be gained through harnessing the resource potential of the network more effectively than competitors. Supply network dynamics are interesting in networks where there is a powerful, downstream positioned firm, such as Walmart, and a powerful upstream positioned firm, such as Nestle. Each powerful firm may seek to dominate decision making and information systems in the network, possibly causing tensions for smaller firms in the network, caught in the crossfire.

## 6 Types of Supply Relationships

The type of relationship most discussed in the strategic management and industrial organization literature historically was vertical integration or ownership. This was the case until the mid-1980s when the topic of vertical integration started to decline. Stable trading relationships with suppliers were seen as a viable alternative to ownership of the supply chain (Dore, 1983). Buy, rather than make, became the dominant strategy as contracting out, or outsourcing became the new trend (Kumpe & Bolwijn, 1988; Child, 1987). Partnerships, alliances, and cooperative agreements were proliferating rapidly across many industries and countries, representing a global trend (Porter, 1985). However, the trend was nuanced as different variables impacted on the type of relationship being chosen. For example, continuous process operations such as petrochemicals, aluminum, zinc, and paper production still tended to remain vertically integrated (Christopher, 1985; Williamson, 1985, 1986). Growing and maturing firms were less likely to remain vertically integrated (Porter, 1988).

In those industries where information systems were available to control the supply chain, non-owned relationships were more likely (Child, 1987). Focused manufacturers (Skinner, 1974) chose to focus on a manageable set of products and vertically disintegrate their supply chains (Miles & Snow, 1986). Closer, more trust-based relationships were favored over traditional adversarial relationships in organizations seeking to improve product quality (Frazier et al., 1988; Lascelles & Dale, 1990). Risk was also being considered in strategy formulation and firms became concerned about the risk of becoming locked into technologies through ownership in the supply chain (Hayes & Abernathy, 1980). Vertical integration and disintegration decisions swing back and forth like a pendulum; downstream vertical integration becoming more popular again recently (Guan & Rehme, 2012).

An implication of vertically integrated supply chains and networks is the need to balance capacity of each link in the supply chain to match downstream demand. An alternative to this matching is to source in additional capacity requirements of individual firms in the supply chain or supply competitor supply chains with excess capacity.

## 7 Supply Processes and Activities

At an operational level, supply can be conceptualized as an aggregation of all the flows between the various dyadic relationships that make up supply chains and networks. The exchange relationship is core to marketing; Kotler (1991) identified five conditions that must be satisfied for an exchange to take place – there must be at least two parties, each party has something that might be of value to the other party, each party is capable of communication and delivery, each party is free to accept or reject the offer, and each party believes it is appropriate or desirable to deal with the other party.

A transaction takes place if agreement is reached between the parties; transactions are therefore the basic unit of exchange. A transaction could be a single event which, when completed, ends the exchange between the parties. However, continued transactions can lead to the building of an exchange relationship between the parties, which ties them economically, technically, and socially. The original search, negotiation, and agreement formation costs to set up the transaction can be spread over repeated transactions leading to an economies of scale argument in favor of longer-term relationships between the parties.

While much of the focus of attention in the marketing field has been on consumer relationships, business-to-business relationships account for a greater volume and value of business. Industrial buying and marketing differ from consumer buying and marketing in that industrial sellers usually face a more concentrated downstream customer market, industrial buyers have greater resources available to them than consumers have so they are usually able to make more informed, professional decisions, and there is more interaction between industrial buyers and sellers than between consumers and product and service providers. These differences lead to an understanding that industrial buyer–seller supply relationships are more symmetrical and balanced than consumer–seller relationships.

Supply flows in exchange relationships are summarized in Table 3 below.

There is a spectrum of relationship types from short-term exchanges through to vertically integrated organizations. Table 4, provides information on what is exchanged in different types of relationships and examples of each relationship type.

This spectrum of relationship types originates in industrial economics, notably Coase (1937); this was developed later by Williamson (1975, 1985, and 1986) linking relationship type as a form of market structure to market conduct and performance. Ellram (1991) defined supply chain management as an intermediate market form. Others conceptualize supply chain management focused more on operational flows of materials and decisions on inventory positioning.

The shift from short-term, adversarial relationships between buyers and suppliers enabled long-term relationships to be formed, giving rise to institutionalization and adaptation (Hakansson, 1982). The most significant adaptation is moving the relationship to a more strategic sharing of resources and decisions, as shown in Fig. 4.

As Fig. 4 shows, an important activity in forming these relationships is selecting a partner. Establishing and operating the relationship then involve the activities of resource integration, information processing, knowledge capture, social coordination, risk and benefit sharing, shared decision making, conflict resolution, and motivating. Partnerships between buying and selling organizations have become key types of relationships within supply chains, networks, and systems and can operate as "vertical quasi-integration" (Contractor & Lorange, 1988), where

**Table 3** Supply flows in exchange transactions

| Supply flows and exchanges | Description and examples |
|---|---|
| Materials | Raw materials, processed materials, components, finished products, packaging |
| Equipment | Tools, templates to enable the supplier to produce the item |
| Administrative information relating to exchanges from requisition to payments | Enquiries and invitations to tender, purchase orders, delivery schedules, transportation and tracking documents, goods receipts, invoices |
| Technical and quality information | Specifications, drawings |
| Payment | Currency, or goods in reciprocal arrangements, rebates |
| Social | Social interaction between buyer and seller |

**Table 4** Exchanges in different types of relationships

| Relationship type | Exchange elements | Examples |
|---|---|---|
| Integrated hierarchy | People, materials, goods and services, technologies, information, investment, equity | Single product firm, for example, paper or aluminum producer |
| Semi-hierarchy | People, materials, goods and services, technologies, information, money, equity, centralized control, divisional reporting | Multi-divisional firm, holding company, for example, chemicals, food producer |
| Co-contracting | Medium/long-term contract, technologies, people, specifications, materials, goods and services, knowledge | Co-makership, joint venture, for example, automotive |
| Coordinated contracting | Specifications, payment, operations planning and control information, materials | Projects, for example, construction |
| Coordinated revenue links | Contract, performance measures, specification of processes and products/services, brand package, facilities, training | Licensing, franchising, for example, fast food chains |
| Long-term trading commitment | Reservation of future capacity, goods and services, payment, demand information | Single and dual sourcing, blanket orders/framework agreements, for example, electronics |
| Medium-term trading commitment | Partial commitment to future work, reservation of capacity, goods and services, specifications | Preferred supplier, for example, defense equipment |
| Short-term trading commitment | Goods and services, payment, order documentation | Spot orders, for example, stationery purchases |

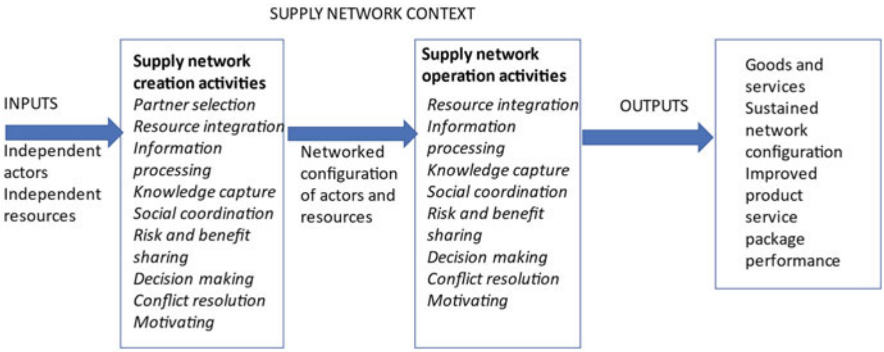


**Fig. 4** Process of moving from individual actors to integrated supply networks. Source: Harland et al. (2004)

boundaries between the organizations become blurred, replacing arms-length, or market, relationships with a "quasi-organization" (Lamming, 1993).

A shift in thinking occurred in the 1990s from considering supply chain management as the study of interconnected organizations in dyadic relationships and linear chains of organizations to appreciating the complexity of supply as a networked activity. Christopher (1992) defined the supply chain as "the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customer."

Harland (1996) categorized the various definitions and approaches to supply chain management using a systems-level approach, as relating to the internal supply chain within an organization, the dyadic relationship, external supply chains, and supply networks. Extending the systems thinking to consider organizations such as the United Nations that comprise networks of networks, and sector-level supply issues (Harland, 2021), an additional level of the supply system was added, as shown in Fig. 5.

As organizations move from focusing on dyadic buyer–supplier relationships to considering beyond these immediate relationships to other links in supply chains and networks, they may consider who in the network plays strategic roles such as innovation sponsor, advisor, coordinator, information broker, relationship broker, and network structuring agent (Harland & Knight, 2001).

Film and TV productions are highly networked activities, as is evident in the increasing credits of stakeholders shown before movies start. Each of these organizations plays different operational and strategic roles. For example, the director brings with them their own network of actors and creatives that they use for different film projects, and producers tap into their networks of finance and resources. These social networks are residual between projects as they contain and nurture social capital which is "The set of resources, tangible or virtual, that accrue to organizations through social structure, facilitating the attainment of organizational goals" (Leenders & Gabbay, 1999). There are certainly benefits for those within strong social networks, in that they are more likely to be engaged in the next film or TV

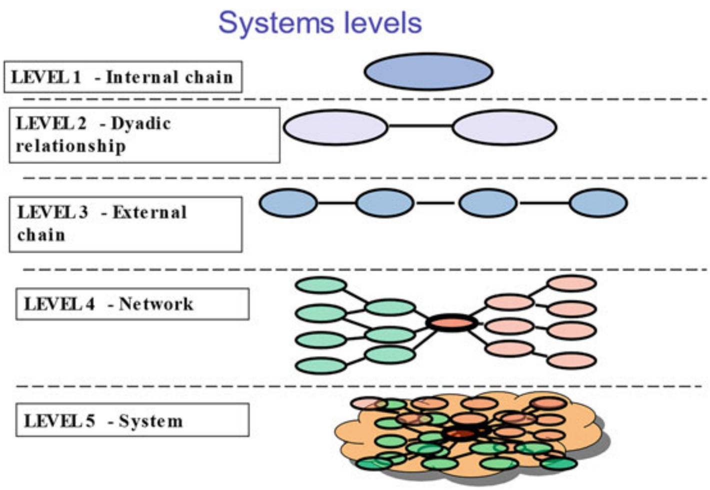


**Fig. 5** Supply systems levels. Source: Developed from Harland (1996)

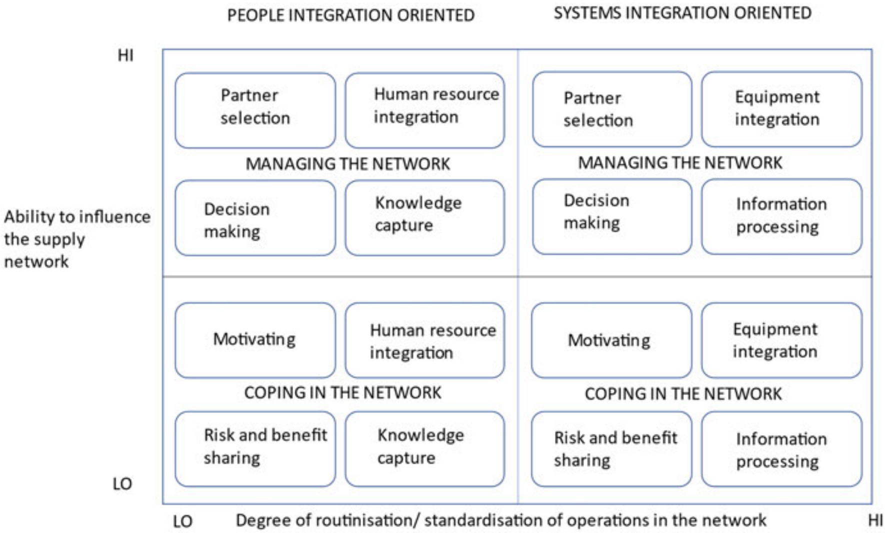


**Fig. 6** A taxonomy of supply networks. Source: Harland et al. (2001)

project and work with colleagues with whom they are familiar, but social capital and strong network connections can raise barriers to entry into these networks (Grugulis & Stoyanova, 2012).

The strategic choice of organizations on the roles and activities they will perform in supply relationships, chains, and networks depends upon their type of supply network. Figure 6 shows a taxonomy of supply networks (Harland et al., 2001).

The empirical research behind this taxonomy found that the two main drivers of difference between types of supply networks were the degree of dynamism or routinization of the network, and the degree of influence the focal firm had in its network. Highly dynamic, innovative networks where the focal firm had little influence over the network (in the top left box) led them to focus on motivating, trying to integrate human resources, share risks and benefits, and capture knowledge; these are all softer, more behavioral activities.

In contrast, dominant firms in quite routinized supply networks, such as automotive networks – in the bottom right box – focus on harder, more tangible activities such as equipment integration and information processing (such as imposing the implementation of enterprise resource planning systems). These firms dominate decision making and can choose their partners.

It is evident that as supply has developed strategically – beyond the boundary of the firm into relationships, chains, networks, and systems of supply – the need for a greater variety of concepts and theories to deal with this complexity has increased. Researchers in the field of supply have turned to strategic management for appropriate concepts and theories.

## 8 Value of Strategic Management Concepts and Theories for Supply Strategy

Researchers in purchasing and supply, supply chain management, and supply strategy have been criticized for insufficient use and development of theory, leading to conclusions that the field of supply cannot yet be recognized as an academic discipline (Harland et al., 2006; Chicksand et al., 2012; Spina et al., 2016). Despite this traditional lack of theory consideration, recently top academic journals have demanded theory contributions, whether they be theory building, combining, elaborating, testing, or application. For a comprehensive guide to theories used in supply, see Tate et al. (2022). In this section, a summary of maturity and stage models is provided, followed by a summary of theories used in strategic management that have been used in the field of supply.

### 8.1 Maturity and Stage Models

As manufacturing, operations, supply chain, and supply strategy concepts have developed, they have been influenced by models from strategic management and marketing strategy, notably maturity and stage models. While often being referred to as *models*, they are frameworks that convey ways of conceptualizing strategy development over time.

Strategic management maturity models are based on the principle that product classes have a *life cycle* akin to biological life cycles from birth through maturity to decline and death. Stage models are based on principles of continuous improvement, proposing that organizations, business functions, or teams can progress from one stage up to the next, aiming to reach the highest stage possible. While not necessarily *theories*, maturity and stage models have featured in manufacturing strategy from the mid-1980s. The conceptual building blocks of these models can be traced back to manufacturing in the Total Quality Management movement and even further back in Taylor's Scientific Management (1911) highlighting an inherent strategic drive for improvement throughout the development path of the field of supply strategy.

The most used maturity model in operations and supply has been the Product Life Cycle (PLC). The Marketing Product Life Cycle – M-PLC – was first proposed in the 1950s and was represented in the form we know today by Levitt (1965), shown below in Fig. 7.

The main principle of the PLC is that classes of products are designed, developed, and introduced to the market, they grow in sales volume until the market for them matures, and eventually demand and sales decline. There are many variations of PLCs and in practice firms try to avoid the decline of sales by relaunching and revamping products.

The principles of PLC stages are used in strategic management and other business functions as they differentiate between appropriate strategies for each stage; in strategic management, Anderson and Zeithaml (1984) examined differences between strategic variables at different stages of the PLC. There have been many


**Fig. 7** Product Life Cycle. (Adapted from Levitt, 1965)

criticisms of the PLC (notably Dhalla & Yuspeh, 1976), highlighting how products within product classes may behave differently, firms do reverse the decline by reinvigorating products, firms are not passive acceptors of PLC but rather their marketing strategies may determine the shape of the PLC, and PLC tends to promote new product introduction as a necessity. However, despite its critics, operations and supply chain strategists have defended its value as a useful tool within the armory (Hayes & Wheelwright, 1979).

In today's networked times, firm-based perspectives of a PLC have been challenged. Cao and Folan (2012) argue that the "extended product" to which value is added by many members of a value chain would not have a single PLC, as different firms in the value chain would have different perspectives relating to their value-adding contribution. Modern circular supply chains involving repair, remanufacture, and recycling also challenge the traditional view of the PLC which was formed at a time of a more *disposable* philosophy for products. Mass customization also challenges the PLC that is more appropriate to mass production and standardization. *Time pacing* is also a more modern introduction, where firms deliberately design and implement timed phases of product introduction, challenging the original, more biological definition of an organic life of a product (Lagnevik et al., 2003).

The PLC was brought into the realm of manufacturing and operations strategy by Hayes and Wheelwright (1979) who created a strategic framework that connected the competitive priorities of a business and marketing strategy with manufacturing strategy, creating differentiated manufacturing and process strategies for stages of a life cycle. Figure 8 provides examples of how competitive priorities may be translated into operations strategy priorities that then can be used to drive process design decisions.

In contrast to maturity models where decline is expected, stage models have been evident in supply strategy since the 1980s. Stage models involve continuous improvement with progression through stages of development. Hayes and Wheelwright (1984) proposed a four-stage model of evolution of manufacturing, shown in Fig. 9.

In this stage model, Hayes and Wheelwright proposed that if the operations function of a business is at stage 1, they are causing problems internally and need to sort themselves out so they no longer have a negative impact on the rest of the business. For example, the firm might have sales orders to satisfy, there might be

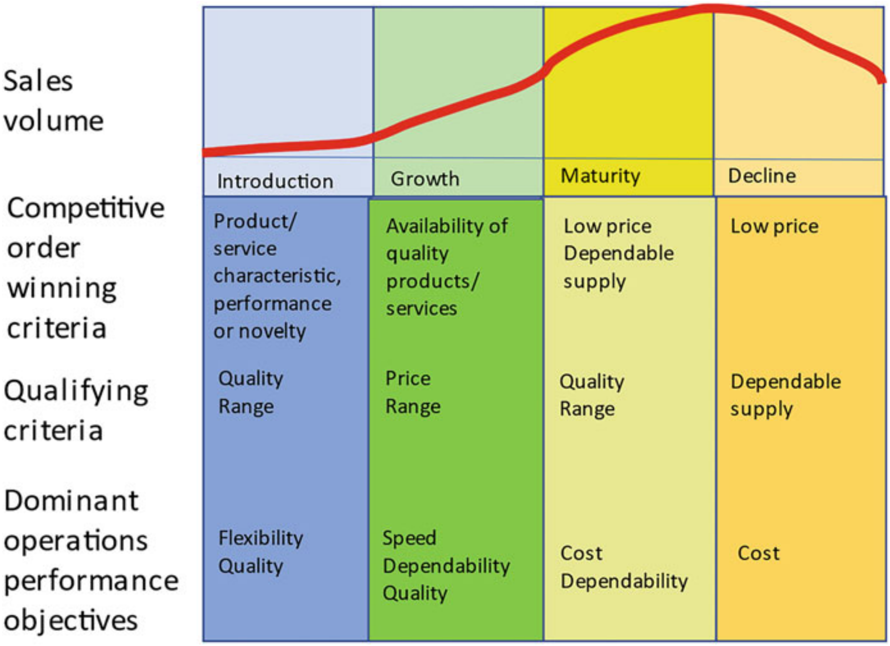


**Fig. 8** Application of PLC to supply

resources available to manufacturing but the operations function just cannot seem to organize themselves to produce on time.

The principles of the framework are that improvement occurs by progressing from one stage to the next, and not to try to jump from stage 1 to stage 4. Followers of the mantras of "world-class manufacturing," "best practice," and "benchmarking" have often failed to understand that aiming to emulate globally leading operations may not be feasible if their own operation is struggling in stage 1 or 2; first they must focus on solving internal problems.

From a purchasing perspective, Reck and Long (1988) also proposed a stage model (although they termed it a maturity model), shown in Fig. 10.

The field of supply chain management has tended to import more organizational and strategic oriented theories than individual or behavioral theories (Harland & Roehrich, 2022). Just as supply has evolved from focusing on flows of materials and associated information inside manufacturing firms to examine other units of analysis of dyadic relationships, chains, and networks of organizations (Harland, 1996), and systems of supply (Harland, 2021), there has been a parallel development in strategic management. Examples of theories used in strategic management and later adopted by supply researchers are provided in Table 5, indicating the system level at which they are appropriate.

The first two theories popularly used in manufacturing and supply chain management were Transaction Cost Economics (TCE) and Resource-Based View (RBV)

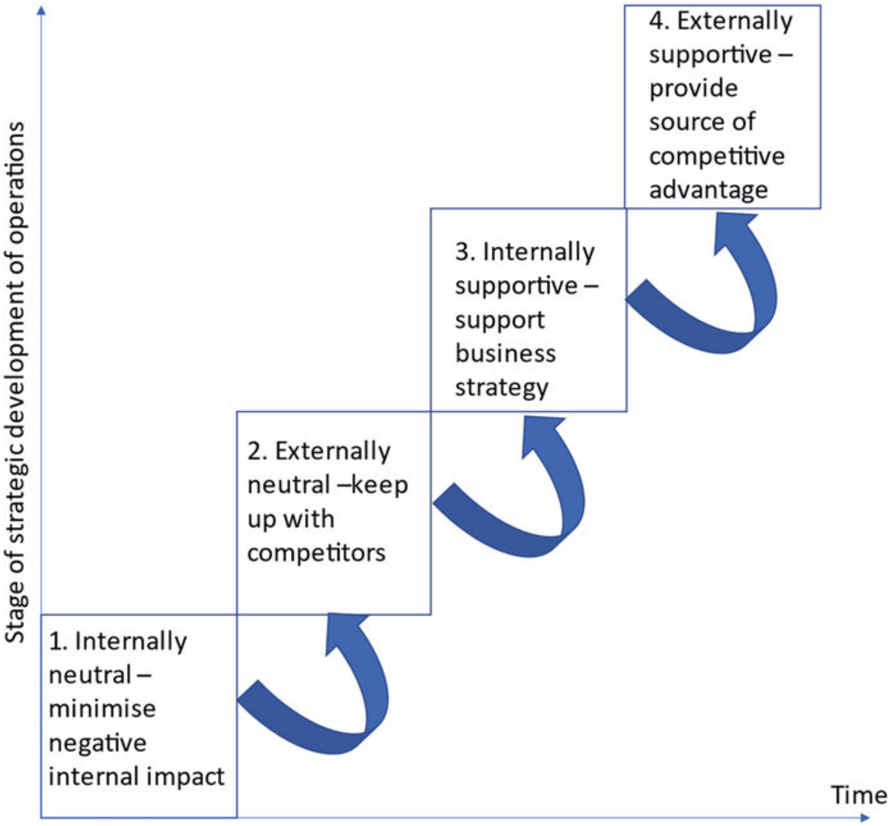


**Fig. 9** Four-stage model of manufacturing/operations strategic development. Adapted from Hayes and Wheelwright (1984)

of the firm. TCE was used to identify, through examining transaction costs, whether firms should make or buy, underpinning the development of theory application to decisions on strategic outsourcing (Williamson, 2008). RBV looked inside firms for the source of competitive advantage residing in valuable, rare, inimitable, and non-substitutable resources (Barney, 1991). RBV spawned a family of related theories including dynamic capabilities (Teece et al., 1997) and resource orchestration theory (ROT) (Sirmon et al., 2011). ROT parallels the strategic management development from firms competing with firms to interorganizational networks competing (Cook, 1977; Thorelli, 1986), appreciated in the burgeoning field of supply chain management (Christopher, 1992).

As strategic management in theory and practice has increasingly understood the competitive power of interorganizational networks of organizations, the field of supply strategy has also developed its thinking and use of theory to understand units of analysis and systems beyond the firm.

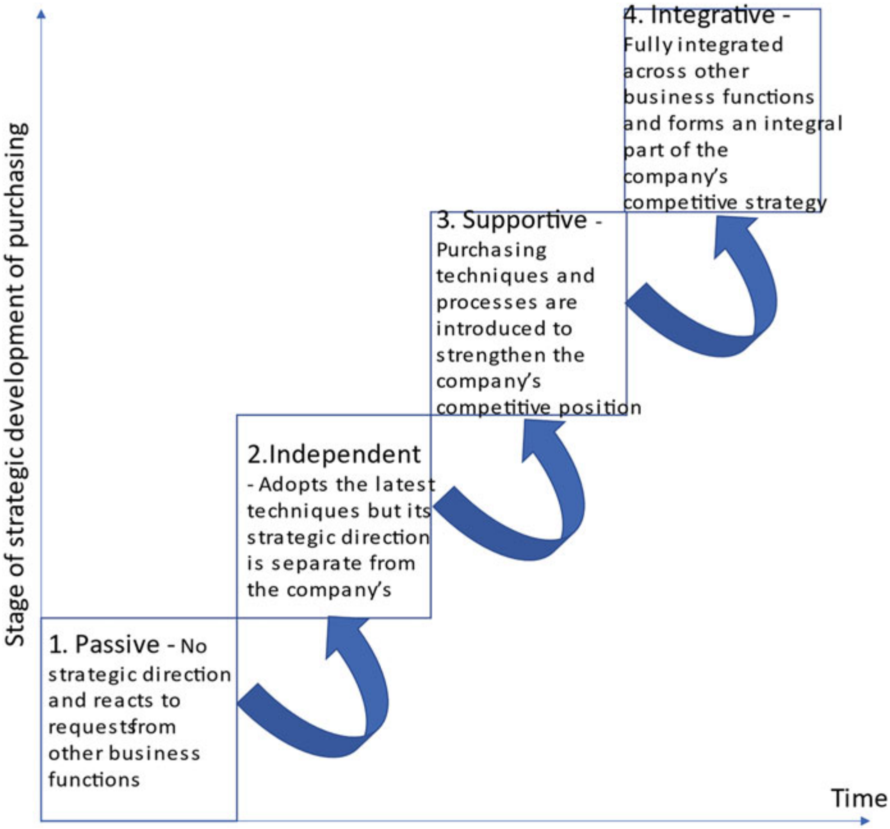


**Fig. 10** Reck and Long's maturity model. Source: Adapted from Reck and Long (1988)

## 9 The Future and Conclusion

The chapter has taken an historical, chronological perspective to explain how supply strategy has evolved over time, aligned with parallel development in the field of strategic management. To close, a glimpse into the future of continued complexity and networked businesses, economies, and societies is provided.

Complex problems, such as the COVID-19 pandemic and the unfolding, accelerating climate crisis, have given rise to calls within the field of supply strategy to seek theories outside the field to deal with this complexity (Craighead et al., 2020). More open, networked approaches and more holistic perspectives of management are required to be innovative in the future (Chesbrough, 2020). Appreciation and leverage of "interconnected" networks, rather than simpler connected supply chains of organizations, is required (Harland, 2021).

**Table 5** Strategic management theories used in supply. Adapted from Harland and Roehrich (2022)

| SCM systems level | Theories used in strategic management | Reference |
|---|---|---|
| Organization, internal supply chain | Transaction cost economics (TCE)<br>Resource-based view (RBV)<br>Dynamic capabilities | Coase (1937), Williamson<br>Barney (1991)<br>Teece et al. (1997) |
| Dyadic relationship | Agency theory<br>Power dependence theory | Eisenhardt (1989)<br>Emerson (1962) |
| External supply chain | Institutional theory<br>Resource orchestration theory<br>Stakeholder theory<br>Bullwhip effect | DiMaggio and Powell (1991)<br>Sirmon et al. (2007)<br>Freeman (1984)<br>Forrester (1984) |
| Supply network | Weak ties theory<br>Structural holes<br>Network organization | Granovetter (1973)<br>Burt (1992)<br>Miles and Snow (1986), Mintzberg (1979) |
| Supply system | Systems theory<br>Complex adaptive systems theory | von Bertalanffy (1951)<br>Holland (1995), Choi et al. (2001) |
| Supply market | Awareness, motivation, capability<br>Factor market rivalry | Chen (1996)<br>Markman et al. (2009), Ellram et al. (2013) |

In addition to greater appreciation and understanding of environmental complexity and interconnectedness, there are also developments within the field of supply that are leading to calls for change. Historically, purchasing and supply research has considered “softer,” behavioral approaches to management, but the dominance of operations management within the supply chain management space has led to more “hard” science approaches being favored; however, calls to increase the relational and “softer” approaches are being made (Caniato et al., 2020; Ellram et al., 2020).

Having originated in detailed operations within factories, the field of supply has passed through metamorphoses of production and operations management, supply chain management, and through to a broader concept of supply strategy and has embraced policy and strategy at different systems levels. Despite the thrust for hard scientific rigor from operations management, purchasing and supply management thinking has also pushed for more behavioral, psychological perspectives. Like strategic management, the field of supply strategy could be characterized as containing several different schools of thought. Senior practitioners of global organizations and academics working in larger systems levels of supply will continue to be influenced by strategic management concepts, theories, and practice.

In conclusion, the field of supply strategy or supply chain management is still evolving. Multiple perspectives are evident, each with their distinct focus on structures or processes, different systems levels, and different competitive drivers, challenging us to define the identity of the field. While not yet passing the tests required to be recognized as an academic discipline, as a field of practice and research, there is no doubt that supply strategy is maturing. Core to the trajectory of development is the more recent focus on supply strategy as a strategic, collaborative, value-adding endeavor, in contrast to the previous inward focus on efficiency and cost reduction. It follows, therefore, that strategic management is of increasing importance to supply strategy and supply chain management thinking and should feature more in supply chain research, teaching, and practice.

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# Maturity Tools in the Supply Chain Context: A Framework Proposal

Susana Garrido, Elisabete Correia, Marina Fernandes Aguiar, Daniel Jugend, and Helena Carvalho

## Contents



**Abstract**

The ability to recognize the gradual growth of a given supply chain considering a specific characteristic or factor by understanding its level of maturity is important for progress and benchmarking. These processes allow for a more effective and efficient identification of actions and directions to guide it toward excellence. This chapter aims to explore the theme of maturity tools for supply chain

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management by suggesting a framework to guide the construction. Addressing maturity models in an integrated manner, this chapter helps students, researchers, and managers in assessing the current level of performance of their supply chains and making decisions about what can be done toward continuous improvement. In addition, practitioners may go deeper and apply the model presented or even develop a maturity model using the framework proposed as a guideline.

**Keywords**

Supply chain · Maturity · Continuous improvement · Excellence · Measurement

## 1 Introduction

Maturity models provide a description and analysis of a current state of an organization or unit. It provides a structured way to analyze how a company meets certain requirements and which areas require attention to achieve better maturity levels (Aguiar & Jugend, 2022). Maturity models are a well-established practice in the management field, and increased global competition in the context of operations management is a motivating factor for the adoption of these tools (Yatskovskaya et al., 2018). Maturity models enhance the capabilities of firms who take a holistic approach to gaining competitive advantage.

Organizations have recognized the benefits of maturity models (Yatskovskaya et al., 2018). These tools function as a means for addressing organizational or process maturity levels when measuring a certain target (Groschopf et al., 2021). There are various maturity models in the literature covering different application contexts or objectives, such as the sales processes of industrial projects (Voss et al., 2023); processes of organizations that conduct state-commissioned studies (Analysis Capability Maturity Model (ACMM) (Covey & Hixon, 2005); business process management (Business Process Management Maturity – BPMM) (de Bruin & Rosemann 2007; de Bruin et al., 2005b); information technologies (Becker, 2009).

Furthermore, Uhrenholt (2022) states that maturity models enable the identification of the current state of the art in terms of operations and the future developments needed to improve them. According to the authors, this first task – the diagnosis – is of great relevance if maturity models are to sustain competitive advantage.

Researchers and practitioners from different backgrounds have gone to lengths to suggest mechanisms and frameworks to help supply chains improve their effectiveness and performance, through maturity models. Considering the context of supply chain management (SCM), some maturity models focus on assessing supply chain (SC) activities in an effort to achieve better results in an effective and efficient way (Santos et al., 2020; Groschopf et al., 2021). According to Jording and Sucky (2016), the SCM maturity model is formed from four elements that can be used independently or in conjunction, namely: high customer focus, management of the flow of goods, management of information, and inter-corporate coordination and collaboration.

Maturity models are applicable to different domains in the SC context (McCormack et al., 2008). They are variously implemented in the context of digital transformation (Groschopf et al., 2021; Hellweg et al., 2021), Supply Chain 4.0. (Frederico et al., 2020), for product fitting in retail SC (Gustafsson et al., 2019), to assess and improve supply chain operations (Garcia Reyes & Giachetti, 2010; Caiado et al., 2021), and for logistics processes in supply chains (Golinska-Dawson et al., 2023). These maturity models, among other applications, can also identify current situations and their progress toward SC sustainability.

Various frameworks aiming to evaluate sustainability in the supply chain context already exist. However, very few of them provide managers and other stakeholders with a comprehensive understanding of where companies and their supply chains stand in terms of sustainability evolution and what actions are required to continue progressing. Thus, an introduction of the concept of maturity in SC and the development of a maturity model that seeks to assess the current level of SC sustainability and give directions to reach higher levels of maturity could be of great interest. Managerial decision-making can use these tools to provide a structured path for the SC to follow (Reefke et al., 2014). Literature reviews show that maturity models in the context of SC addressing sustainability in a triple bottom line (TBL) approach are still scarce. As Reefke et al. (2014) point out, few models "connect maturity considerations in SCs with sustainability imperatives," so the development of such a model would help bridge this gap.

Several authors (Asah-Kissiedu et al., 2021; Dooley et al., 2001; Bititci et al., 2011; Chen & Fong, 2012) support the notion that properly operationalized maturity models have significant practical application and can enhance performance (Reefke et al., 2014). This relationship, although advocated (Lockamy III & McCormack, 2004; Söderberg & Bengtsson, 2010; McCormack et al., 2008; Aryee et al., 2008), has seen limited empirical evaluation (Söderberg & Bengtsson, 2010).

Thus, this chapter aims to contribute to the theme of maturity models for the supply chain. Initially, the concept of maturity models is presented. Subsequently, specific maturity models for supply chain management are presented and discussed. A framework to guide the construction of supply chain maturity tools is then proposed. Finally, the conclusions of the chapter are presented.

## 2 Maturity Models

The concept of "maturity" is often attributed to the quality movement in the 1930s and to Philip Crosby's Quality Management Maturity Grid (QMMG) (Crosby, 1979). The QMMG represented pioneering work in the development of upcoming maturity models (e.g., Estampe et al., 2013; Introna et al., 2014).

The concept of maturity is more prevalent today. It is associated with concepts such as competency, capability, or even level of sophistication (De Bruin et al., 2005a; Ferradaz et al., 2020). De Bruin et al. (2005a, p. 27) define the maturity of an organization as "a measure to evaluate the capabilities of an organisation regarding a certain discipline."

Several studies have examined the differences between the concepts of maturity and readiness. Pacchini et al. (2019) define readiness as the moment in which a company is ready to execute an activity, while maturity can be understood as the evolutionary level a company has achieved. In this sense, assessing readiness is a process that occurs before assessing maturity (Schumacher et al., 2016). When analyzing the use of technologies, Zoubek et al. (2021) argue that readiness models can be useful before implementing these technologies, by examining if a company is well prepared for its adoption and capable of fulfilling given prerequisites.

Maturity models encompass the description and capture of the *as-is* situation while a process of maturation occurs. Having investigated the factors crucial to industry 4.0 implementation in European countries, Castelo-Branco et al. (2019) state that readiness is how able a company is in developing the infrastructure of industry 4.0 and maturity is the ability to manage the information derived from this infrastructure.

Thus, maturity models are tools used to evaluate the capabilities of an organization in a particular domain (Becker, 2009; Introna et al., 2014). Similarly, for Kohlegger et al. (2009, p. 3), a maturity model "conceptually represents phases of increased quantitative or qualitative capability changes of a maturing element to assess its advances concerning focus areas."

The maturing element may be an individual, an object, or a social system, and the focus areas may be processes, digital resources, people skills (Kohlegger et al., 2009), an organizational function (Klimko, 2001), technology, or a product or a process (Jiankang et al., 2011). Bititci et al. (2014, p. 3065) understand a maturity model as a "matrix of practices that define, for each organisational area, the level of formality, sophistication, and embeddedness of practices, from ad hoc to optimising."

The maturity model adopted is a concept that can represent phases of increased capabilities, phases that reflect the development of an area of interest, or an evolution of the level of sophistication of practices. Either way, maturity models assume a path of development or evolution (Paes, 2011). For Klimko (2001), a maturity model constitutes a given application of the life cycle approach that each entity develops over time. The development path is traced through a sequence of levels, stages, or phases from an initial state to maturity (Becker et al., 2009). Reaching each maturity level allows for incremental and lasting performance improvements (Estampe et al., 2013).

Thus, high levels of maturity lead to high levels of performance. An immature organization, for example, will exhibit reactivity and improvisation (Ferradaz et al., 2020). In these immature situations, decisions aimed at improving processes only come after crises arising from a reactive approach to management. An evolution to a mature stage, involving increased awareness, includes factors such as whether an organization is proactive for learning, seeks to put into practice the lessons learned from mistakes, understands such mistakes as improvement opportunities, and promotes the involvement of the whole team in this process (Ferradaz et al., 2020). The relationship between maturity and performance is well supported by various studies (Dooley et al., 2001; Bititci et al., 2011; Chen & Fong, 2012).

In addition to including the characteristics of each maturity stage, effective maturity models establish a logical relationship between stages (Röglinger et al., 2012). In general, these models have the following characteristics (Klimko, 2001):

(i) The development of an entity is simplified and described as a limited number of maturity levels (usually between four and six);
(ii) The levels are characterized according to specific requirements that the entity must meet at that level; the levels are ordered from an initial stage to a final level;
(iii) The entity successively advances through the levels, none of which can be left out during development.

The ability to recognize the gradual growth of a given organization by understanding its level of maturity allows for a more effective and efficient identification of actions and directions to guide it toward excellence (Introna et al., 2014). But, to do so, it is necessary to determine the current stage of maturity, that is, to capture the perception of the situation in which an organization finds itself. For Maier et al. (2010), this is one of the main merits of a maturity model; and these models are used for several purposes (Pöppelbuß & Röglinger, 2011):

(i) As a descriptive tool to assess strengths and weaknesses (Neuhauser, 2004);
(ii) As a prescriptive tool to develop a roadmap for performance improvement, where the objectives of the next maturity and performance levels are established;
(iii) Companies can focus their resources (McCormack et al., 2008), that is, the models provide a path for improvement by recognizing capabilities, that is, skills or competencies that should be developed in a specific area in an organization (Paulk et al., 1993) to achieve a goal;
(iv) As a comparative instrument, which allows a company and its processes to be assessed and compared with standards and best practices of other organizations (Klimko, 2001; Demir & Kocabas, 2010), thus enabling internal and external benchmarking (Röglinger et al., 2012).

Regarding the last purpose, the study of Maier et al. (2010) points out some divergences between the concepts of a maturity matrix and a maturity model. A matrix is formed by cells encompassing behavioral patterns expected at each level; it can be understood as a grid, or a plateau, which can be applied to organizations in contrasting industrial sectors. A matrix is less complex than a model, which focuses on specific processes, uses structured checklists and questionnaires, and can even guarantee certification after benchmarking (Maier et al., 2010). In this sense, maturity tools can benefit organizations through their use with a process. Steps would include the description of a current state (as-is situation), identifying gaps and highlighting the areas that still require attention if more mature levels are to be reached, and an analysis of actions needed to put improvements into practice (Arekrans et al., 2021). In other words, more than just a diagnosis, these tools can function as a compass, showing the right direction toward improvement initiatives.

There are a number of milestones regarding maturity models. The model for process maturity (Capability Maturity Model – CMM) developed by the Software Engineering Institute (SEI) – at Carnegie Mellon – popularized the concept of maturity. CMM influenced the development of maturity models in different contexts (Dooley et al., 2001; De Bruin et al., 2005a; Bititci et al., 2014). CMM was developed focusing on the function of information systems, covering several processes (People Capability Development, Software Acquisition, System Engineering and Integrated Product Development). CMM allows software organizations to manage their processes through the description of each phase (Garcia Reyes & Giachetti, 2010), based on how they define, implement, measure, control, and improve their software processes (Paulk et al., 1993 in Bititci et al., 2014).

Five maturity levels are defined in CMM: Initial, Managed, Defined, Quantitatively Managed, and Optimizing. In CMM, higher levels of maturity means that companies are managing their processes better and, consequently, the projects they carry out will have fewer risks. More mature companies are more likely to deliver quality products that meet established budgets and schedules (Garcia Reyes & Giachetti, 2010).

The project management area has also developed and proposed maturity models based on the concept of continuous improvement. Among the most disseminated is that proposed by Kerzner (2002), which uses five levels: common language, standard process, singular methodology, benchmarking, and continuous improvement. Using these principles, the Project Management Institute (PMI) proposed the OPM3® maturity model, which is based on the following improvement steps: standardize, measure, control, and continuous improvement. These steps aim to assess and improve project management in companies (Fahrenkrog et al., 2003; Project Management Institute, 2003).

Since their development, maturity models have also been widely adopted and used (Bititci et al., 2014) in various areas of engineering and management (Pigosso et al., 2013; Ferradaz et al., 2020). Used as tools to achieve an informed approach to increase the capability of a specific domain or area within an organization (Paulk et al., 1993), they have been widely applied in information systems (Helgesson et al., 2012) – more than 70 maturity models having been identified in this area (Kohlegger et al., 2009). The application of maturity models is evident in numerous management fields, as can be seen in Table 1.

Beyond these specific management areas, there are also areas associated with sustainability issues, such as eco-design (Pigosso et al., 2013), industrial symbiosis (Golev et al., 2015), corporate sustainability (e.g., Amini & Bienstock, 2014),

**Table 1** Examples of management areas with a focus on Maturity Models

| Management areas | Authors |
|---|---|
| Management system integration | Poltronieri et al. (2019) |
| Knowledge management | Klimko (2001), Jiankang et al. (2011) |
| Quality, project management, risk management, new product development | (Panizzolo et al., 2010) |
| People management | (Introna et al., 2014) |
| Process management | (Bititci et al., 2014) |
| Performance management | (Bititci et al., 2014) |
| Project management | (Kerzner, 2002; Project Management Institute, 2003) |

circular economy (Sehnem et al., 2019), and circular product design (Aguiar & Jugend, 2022). The next topic of this chapter presents and discusses the concept of maturity applied to supply chain management.

## 3 Maturity Models in the Supply Chain

Companies with unique theoretical and technical knowledge or merely possessing the tools and resources needed for production do not guarantee success (Introna et al., 2014). For success to become a reality, a company must move along specific lines, build strategic alignment, develop adequate technical and organizational skills, provide the method for applying the acquired knowledge, and manage the capacity. By proposing systematized ways of representing the current level of these competencies and the means necessary for improvement, maturity models can help companies improve their performance.

Only a few models are aimed at supply chain management. Most of the maturity models proposed are not developed from an SC perspective (Srai & Gregory, 2005). Such models are function-oriented or dominated by financial measures rather than linked to a company's global strategy and directed to specific sectors of activity. These characteristics are also found in SC-based maturity models (Netland et al., 2007; McCormack et al., 2008), making the comparison even more difficult (Srai & Gregory, 2005).

A number of maturity models have emerged over time (Netland & Alfnes, 2008). For instance, Paes (2011) identified 28 maturity models in the literature, with logistics and SC as application domains, from 1998 to 2009. Based on this study (Paes, 2011), Table 2 presents the frequency with which the following items were investigated: the main focus of the maturity model, research approach, method for data collection, forms of application, presentation of results, and the number of maturity levels.

Table 2 shows the great diversity of the maturity model focus of analysis. Some examples of models applicable to the SC context include models for the maturity of SCM processes (e.g., Garcia Reyes & Giachetti, 2010; Lockamy III & McCormack, 2004; McCormack, 2001), models for the integration of the SC focusing on relationships and systems or technologies (e.g., Aryee et al., 2008), and models for the improvement of relationships in SC (e.g., Meng et al., 2011). However, models that take a broad approach to SC are still limited.

In developing these models, a slight predominance of the quantitative approach is observed. There is some diversity in data collection methods. Surveys directed at a more comprehensive set of respondents and the use of questionnaires represent the most used method. The degree of maturity is also highlighted as the preferred form of application in the maturity models whose results are fundamentally presented through charts. Maturity levels range from three to six, with five levels being the most common number.

Paes (2011) seeks to present a logical conceptual framework to assess and improve SC management in automotive companies. The study identifies 15 areas for maturity levels. These models were evaluated within three SC companies, to assess each maturity level and the degree of the strategic importance of each area. It can be seen from this approach that, even when developed from an SCM perspective, maturity models can evaluate similar and connected companies (e.g., Aryee et al., 2008; Netland et al., 2007): going beyond the observations of Rao and Holt (2005) that most studies on SCM focus on a single member or activity of the SC.

As Table 2 illustrates, there is a diverse range of critical areas or dimensions considered across the different models, even when the focus of analysis is similar. Most models assume the definition and evaluation of practices associated with such dimensions, but the type of practices considered and their number differ from model to model. For example, Foggin et al. (2004) proposed a diagnostic tool that helps identify potential problems and possible improvements in supply chains; and based

**Table 2** Maturity model diversity with logistics and SC as application domains – based on Paes (2011)

| Domains | % of studies |
|---|---|
| **Main focus of analysis** | |
| Logistics activities | 21.4 |
| SC processes | 10.7 |
| SC broad evaluation | 14.3 |
| SC relationships | 14.3 |
| Systems and technologies | 21.4 |
| **Research approach** | |
| Quantitative | 46.4 |
| Qualitative | 35.7 |
| Both | 14.3 |
| **Data collection method** | |
| Email survey/survey | 39.3 |
| Questionnaires | 39.3 |
| Interviews and visits | 35.7 |
| Data archive | 14.3 |
| Others/unavailable | 39.3 |
| **Forms of application** | |
| CMMI | 3.6 |
| Likert scale | 17.9 |
| Maturity grid | 57.1 |
| Others/unavailable | 21.4 |
| **Form of presentation of results** | |
| Graphic | 60.7 |
| Report | 21.4 |
| Not available | 17.9 |
| **No. of maturity levels** | |
| Three | 21.4 |
| Four | 28.6 |
| Five | 46.4 |
| Six | 3.6 |

on a supply network perspective using the case studies method, Srai and Gregory (2008) suggest a tool for maturity assessment.

Netgland and Alfnes (2008) point out that presenting the practices logically and simply helps categorize them. There is one challenge, the term "practices" used in maturity models can have different meanings. A practice can be a tactic or a method, depending on whether a tactic or method is chosen to perform a particular task or to meet a particular objective (Dooley et al., 2001). Practices can also be defined as an activity, as highlighted by the Project Management Institute (PMI). According to the PMI (2008), practice is defined as a specific type of management activity that helps execute a process by employing one or more techniques and tools (Pigosso et al., 2013).

Similarly, Paes (2011) considers practices as a set of activities performed by an organization to promote the effective management of supply chain processes. Practices can also be understood as processes. According to Netland and Alfnes (2011), a practice is an established organizational process that improves the way a business is run, ranging from teamwork and employee involvement to the use of techniques such as kanban.

These practice definitions are equivalent since a process can be separated into several activities – similar to the definition provided by the IS0 9001 standard. According to this standard, an activity or set of activities using resources and managed to transform inputs into outputs can be considered a process.

The transition from one maturity level to a higher level is usually associated with implementing best practices (Estampe et al., 2013). Best practices describe the state of the art for performing a business (Netland et al., 2007). Dooley (2001) follows the concept of Olsen et al. (1995) who define best practice as a tactic or method from real-life implementation that is successful; cross-functional development teams are a best practice example.

Garcia Reyes and Giachetti (2010) point out that some maturity models (e.g., Stevens, 1989) are theoretical frameworks with little empirical support. A recognized exception is Lockamy III and McCormack (2004), one of the most widely quoted maturity models in the literature (Netland et al., 2007). Lockamy III and McCormack (2004) developed a maturity model for SC processes, based on the SCOR model, and defined five levels of maturity (Ad-hoc, Defined, Linked, Integrated, and Extended). The maturity model for the SC is based on a model oriented to the management of processes (Business Process Orientation – BPO) (Söderberg & Bengtsson, 2010), see Fig. 1.

The SC maturity model (Fig. 2) realizes the characteristics of this BPO model, in which process maturity includes multiple levels. As the process matures, predictability, capacity, control, efficiency, and effectiveness increase (McCormack et al., 2008). Thus, as a SC maturity level increases, the definition and structuring of the SC and its practices increase, the SCM practices for its management are more advanced, and managers introduce a more strategic aspect to the SCM.

Processes progressively assume an inter-organizational nature, extending to the entire SC, also increasing the level of collaboration between SC partners. Although the maturity levels portray groups of practices that are employed at different levels of

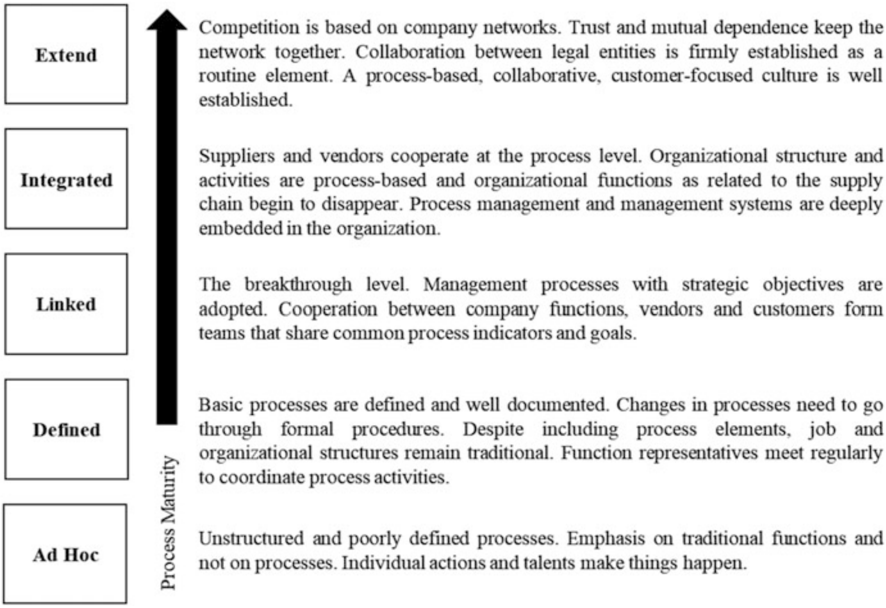


**Fig. 1** BPO maturity model. (Source: Adapted from Lockamy III and McCormack (2004))

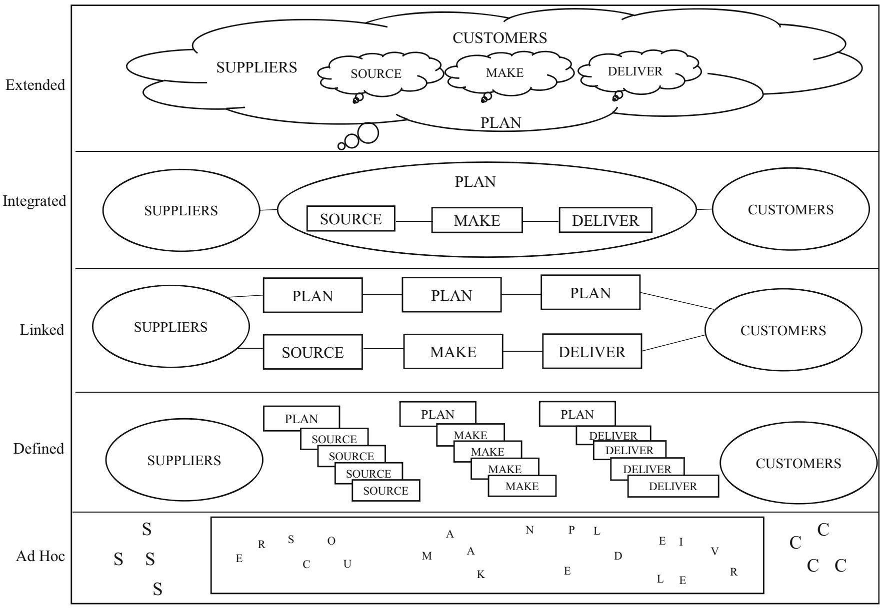


**Fig. 2** SC maturity model. (Source: Lockamy III and McCormack (2004))

process maturity (McCormack et al., 2008), these practices are not indicated in the model proposed by Lockamy III and McCormack (2004).

Progress to higher maturity levels means more predictable process performance, progressive reduction in SCM costs, and increased customer satisfaction. In addition to assessing the maturity of their processes, practices, and activities, many models also seek to establish a relationship between maturity and performance empirically.

In the case of Lockamy III and McCormack (2004), the assessment of the impact of these processes on SC performance was carried out through a survey of 90 companies. The relationship between SC maturity and SC performance was subsequently analyzed using regression analysis. The results indicated degrees of correlation in some of the performance measures (e.g., inventory levels).

The relationship between SC maturity and performance was further tested by McCormack et al. (2008) with 478 Brazilian companies, based on the previous maturity model and using a quantitative methodology. Using a survey and resorting to structural equation modeling, a positive relationship between SC maturity and performance was evidenced, highlighting a higher impact of the distribution process maturity (deliver) on overall performance compared to the impact of the remaining SC processes.

A number of other maturity models incorporate empirical insights and contributions from companies or experts (e.g., Netland et al., 2007; Garcia Reyes & Giachetti, 2010; Oliveira et al., 2011). For example, Garcia Reyes and Giachetti (2010) designed a maturity model describing competencies that a company must master to achieve one or more objectives. A Delphi method is used in their model. Based on this method, 80 experts from various industries contributed to the definition of five proposed maturity levels. Seven areas of competence (views) were defined (supply chain management and logistics; production systems; inventory management; customer relationship management; human resource management; information systems and technology management; performance measurement systems), and the experts define the best practices (including processes, procedures, projects, tasks) which translate into the competences necessary for the SC.

Once these practices have been defined for each maturity level and area, the intention is for managers to evaluate their implementation through an organizational questionnaire. A part of a questionnaire on the first competence area (supply chain management and logistics) is detailed. The model is validated using a pilot study in a Mexican company.

Many times, as is the case with this study, results are presented graphically using a radar plot, which shows the maturity levels and aspects for each area. These radar plots are represented by numbers corresponding to the questions in the questionnaire with the lowest values to be improved. The goal is to design a model that enables companies to assess the maturity of their SCM practices and constitutes a tool to assist in developing plans for the improvement of SCM practices.

Similarly, Aryee et al. (2008) developed a model to assess SC integration and used a survey with twenty-nine UK companies from various activity sectors to test their model. They developed a questionnaire covering several dimensions of analysis: supply chain process integration; manufacturing planning and control (MPC) systems; organizational performance; process and technological knowledge; and collaborative strategies. Several relationships were established between the various levels of collaboration and technological integration and organizational performance for each firm.

Netland et al. (2007) also test the validity of their maturity model in four Norwegian companies. They seek a model that assesses the maturity of SC activities based on the maturity assessment of 50 best practices. These practices are defined based on a literature review for each of the key areas considered in the model: strategy, control, processes, materials, resources, information, and organization. They are assessed considering five maturity levels, defined on a scale from 1 to 5 for each practice.

Another study (Oliveira et al., 2011) uses data from hundreds of companies across different sectors and countries (USA, Canada, United Kingdom, China, and Brazil). The authors identify 13 constructs or factors for maturity modeling including: demand management and forecasting, strategic planning team, strategic behaviors, procurement team, supply network management, production planning and scheduling, distribution network management, order management, process governance, foundation building, responsiveness, collaboratively integrated practices, and customer integration. They develop maturity scores as a continuous variable and a fixed number of 5 clusters in which each one represents a maturity level. They also develop precedence relationships among the 13 constructs, representing groups of SCM process capability indicators.

As mentioned earlier, there is an emphasis on the belief that an increase in maturity will lead to better SC performance, which will translate into an improvement in financial performance (Söderberg & Bengtsson, 2010). Although the existence of a positive relationship between maturity and SC performance is not a consensus (Estampe et al., 2013), it is advocated by several authors (e.g., Lockamy III & McCormack, 2004; Söderberg & Bengtsson, 2010; McCormack et al., 2008; Aryee et al., 2008). But this relationship is empirically proven in a few papers (Söderberg & Bengtsson, 2010).

Some studies (e.g., Aryee et al., 2008) have shown that performance improvement is associated with higher levels of maturity attributed to higher levels of collaboration and technology integration in a supply chain. There is solid evidence of a strong positive relationship between SC maturity and overall SCM performance for small and medium-sized enterprises (Söderberg & Bengtsson, 2010).

Several metrics are used for performance evaluation across different organizational functional areas: Customer service, Cost management, Quality, Productivity, and Asset reform management. Studies have also replicated each other, empirically strengthening these relationships. However, the study of Varoutsa and Scapens (2015) presented a different standpoint, investigating the in-between of the changing phases of a supply chain as it matures.

Recent literature on supply chain maturity has also shed light on emergent fields related to trending demands, such as digital transformation (Groschopf et al., 2021; Hellweg et al., 2023). Considering the term “Supply 4.0,” Frederico et al. (2020) proposed a framework encompassing the maturity level perspective to evaluate Industry 4.0 dispersion across the supply chain. Five constructs were listed as dimensions: managerial and capability supporters, technology levers, process performance requirements, and strategic outcomes. Under this domain, Gustafsson et al. (2019) adopted an innovative point of view, focusing on the challenges that retail supply chains face and exploring the potential outcomes that digitalization brings to the practice of product fitting.

More recent efforts have shifted to multidimensional sustainable supply chain maturity models and matrices (e.g., Chalmeta & Barqueros-Muñoz, 2021). For example, supply chain management can encompass a combination of quantitative and qualitative methods for sustainability assessment. In the qualitative sphere, open-ended interviews and questionnaires can be used. Quantitatively, an analysis of indicators can be used. An example of levels applied would be: Level 0 (no sustainability), Level 1 (partially sustainable in specific areas), Level 2 (sustainable in particular areas), Level 3 (partially sustainable), and Level 4 (totally sustainable).

Montag et al. (2021), based on a theoretical review, proposed a maturity model for the adoption of the circular economy in supply chain management that embraced three dimensions: organization, product, and process, further divided into four levels: linear, minimal developing, defined, and circular.

### 3.1 A Supply Chain Maturity Model Construction Framework

As the development and application of maturity models are critical, a process for doing so is necessary for its adoption by organizations and for future developments. To this end, frameworks for developing maturity tools have been introduced (e.g., De Bruin et al., 2005b; Maier et al., 2010). De Bruin et al. (2005b) developed a generic framework to guide the development of maturity models, taking an evolutionary approach through its six proposed phases: scope, design, populate, test, deploy, and maintain. The first phases are descriptive, starting with a diagnosis, followed by prescriptive and comparative aims. This model can be applied across multiple areas.

From a similar perspective, Maier et al. (2010) proposed a roadmap as a reference and guidance for developing new and evaluating existing maturity grids. The roadmap comprises four phases: planning, development, evaluation, and maintenance, listing decisions that need to be taken to develop such tools.

Exploiting these decisions within the supply chain field by establishing a link between de Bruin's model, Maier's roadmap and Table 2 of this chapter, and using the PDCA Cycle, a framework (Table 3) to guide the construction of supply chain maturity tools is proposed.

The framework proposed in Table 3 can guide users in the construction of a supply chain maturity tool through four stages, each corresponding to the activities that make up part of the PDCA Cycle of continuous improvement: Plan, Do, Check, and Act. In each of these stages, the corresponding phase designed by the authors referenced is identified, a set of suggested activities are to be performed, and the decisions that should be taken are also identified. For each phase, suitable SC contexts are highlighted.

**Table 3** Framework to guide the construction of supply chain maturity tools

| PDCA stage | Phases | Main decisions | SC context |
|---|---|---|---|
| ***Plan*** | Phase 1 – Planning<br>(Maier et al., 2010) | 1) Specify audience<br>2) Define aim<br>3) Clarify scope<br>4) Define success criteria | **Purposes**<br>Descriptive tool<br>Prescriptive tool<br>Path for improvement<br>Comparative instrument |
| | Phase 1 – Scope<br>(De Bruin et al., 2005b) | Focus of the model<br>Development stakeholders | |
| ***Do*** | Phase 2 – Development<br>(Maier et al., 2010) | 1) Select process areas<br>2) Select maturity levels<br>3) Formulate cell text<br>4) Define the administration mechanism | **Main focus of analysis**<br>Logistics activities<br>SC processes<br>SC broad evaluation<br>SC relationships<br>Systems and technologies<br>Specific aspects<br>**Research approach**<br>Quantitative<br>Qualitative<br>Both<br>**Data collection**<br>Email/survey<br>Questionnaires<br>Interviews/visits<br>Data archive<br>**Forms of application**<br>CMMI-type structured models<br>Hybrid models<br>Likert scale questionnaire<br>Maturity grid |
| | Phase 2 – Design<br>(De Bruin et al., 2005b) | Audience<br>Method of application<br>Driver of application<br>Respondents | |
| | Phase 3 – Populate<br>(De Bruin et al., 2005b) | Content of the model<br>Theoretical starting point<br>Identify sub-components<br>Instrument to conduct the assessment | |
| ***Check*** | Phase 3 – Evaluation<br>(Maier et al., 2010) | 1) Validate<br>2) Verify | Consult SC experts using diverse techniques, such as Delphi, a panel of specialists, and/or focus group<br>Apply the model in upstream and downstream firms of an SC using case studies or action-research |
| | Phase 4 – Test<br>(De Bruin et al., 2005b) | Check the validity, reliability, and applicability | |
| | Phase 5 – Deploy<br>(De Bruin et al., 2005b) | Improve the standardization/ acceptance of the model | |
| ***Act*** | Phase 4 – Maintenance<br>(Maier et al., 2010) | 1) Check maintenance<br>2) Maintain results database<br>3) Document and communicate the development process and results | Verify the tool usability and congruence among different SC from diverse industrial sectors |
| | Phase 6 – Maintain<br>(De Bruin et al., 2005b) | Track model evolution and development | |

Source: Adapted from Maier et al. (2010), De Bruin et al. (2005b), and Paes (2011)

## 4 Conclusion

Although maturity models are a contemporary theme, many companies have difficulty applying them. This chapter aims to help provide a better understanding and diffusion of such tools by presenting a concept of maturity models that can be applied, mainly to supply chain management. In addition, this work also proposes a framework for SC maturity model construction.

Different studies on maturity models in management have been analyzed, especially considering those that can be applied to the supply chain management context. Furthermore, the chapter presented a framework to build maturity models for supply chain management. It is envisioned that the content presented and analyzed here can be added to new theoretical reviews and studies in companies (qualitative or quantitative) on maturity models in supply chain management.

By presenting research on maturity models in an integrated manner, this chapter aims to assist managers assess the current level of performance of their supply chains and making decisions about what can be done toward continuous improvement. In addition, practitioners may go deeper and apply the model presented or even develop a maturity model using that proposed here as a guideline (Table 3). In any business, a higher level of maturity offers many advantages, such as diagnosing weaknesses in current processes; identifying ways, practices, and technologies for improvement; measuring performance; and improving management capability toward better performance levels.

As global demand for products increases and deadlines for orders decrease, companies face greater pressure than ever before and, thus, they need to establish fast, productive, and efficient supply chains. By using technology and information strategically, companies can use supply chain maturity models to benefit from a secure market position.

Despite the contribution of this chapter and the importance of the topic, limitations in terms of business process maturity models cannot be ignored. We could highlight the lack of studies and theoretical base, or the absence of certain crucial elements: human, cultural, and organizational factors among them.

Another limitation could be the confusing way of measuring maturity, a fact that suggests a lack of training and experience. Thus, the maturity model is a way to ensure supply chain security, knowing that the concept of process maturity comes from an understanding that a process has a life cycle/development stage that can be clearly defined and managed throughout.

## 5 Future Directions for Practice and Research

Given what has been presented in this chapter, future research in the area of maturity models should encompass the adoption of methods that in addition to providing an "as-is" diagnosis, could also include a "to be" scenario, such as action research, along with partnerships between academics and companies that are associated with certain supply chains.

The presentation and discussion of the results generated by applying these tools might be relevant to expand knowledge in the field and map opportunities to improve performance in different areas of the focused supply chain. An interesting research and development avenue might be to compare, both theoretically and in practice, the relationship between the concepts of resilience and maturity and how supply chains from different sectors address this issue. Furthermore, it would be desirable to examine the way in which industry 4.0 technologies, including blockchain, Internet of things, and big data, might contribute to supply chains in the search for their maturity. The theoretical development, proposal, and assessment of supply chain maturity models and matrices integrating such technologies might serve to update the current knowledge on the field and support practitioners interested in boosting the performance of supply chains.

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# Global Supply Chain Management

Andreas Norrman and Jan Olhager

## Contents



**Abstract**

Global supply chain management concerns the management of sourcing, manufacturing, and distribution that take place in different countries before a product is sold and delivered to the final buyers. From the view of the focal manufacturing firm, a global supply chain consists of three key parts: the upstream supply network, the manufacturing network of plants belonging to the focal firm, and the downstream distribution network. We discuss managerial perspectives on structuring the supply, manufacturing, and distribution networks

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as well as the structural aspects of entire global supply chains. In recent years, the number of global and local disturbances has increased, and the number of factors and issues to consider is constantly growing. We discuss considerations concerning restructuring with respect to offshoring and reshoring, tax, national culture, and supply chain risk management and the balance between global and local supply chains.

**Keywords**

Distribution · Manufacturing · Networks · Sourcing · Structure · Supply

## 1 Introduction

The globalization of supply chains increased in the 1980s and 1990s. New markets opened up, and companies were looking for global markets as well as new sources of low-cost manufacturing. The outsourcing and offshoring of manufacturing activities changed the global operations landscape, leading to more complex and diverse supply chains. In the beginning of the twenty-first century, manufacturers were beginning to experience problems in the widespread global operations and started to reconsider where production should take place. As a countermovement to offshoring and outsourcing, firms began to reshore and insource to regain control of the supply chain and improve resilience (Johansson & Olhager, 2018a). In the post-COVID-19 pandemic era, global trade has been undergoing a reduction caused by, for example, Brexit, the US–China Trade War, the replacing of the North American Free Trade Agreement (NAFTA) with the United States–Mexico–Canada Agreement (USMCA), and the Trans-Pacific Partnership (TPP). Many countries, such as China, India, France, the UK, and the USA, have moved from globalization to nationalism for public health, national security, and economic reasons (Tompkins, 2021). Manufacturing firms operating globally must pay careful attention to macro-level changes since such changes may have profound effects on global supply chains.

A global supply chain can be defined as a transnational network of suppliers, manufacturers, and distributors to produce and distribute a specific product to the final buyer. Global supply chain management is then concerned with the management of sourcing, manufacturing, and distribution that take place in different countries before a product is sold and delivered to the final buyers. All three key parts of the global supply chain – sourcing, manufacturing, and distribution – need to be managed and potentially restructured when global events occur. The configuration of the supply, manufacturing, and distribution networks is related to location, that is, geographical dispersion, and ownership. While the manufacturing network is owned by the focal firm, the supply and distribution networks are often dominated by external partners (suppliers and third-party logistics service providers, respectively) even though joint ventures are possible.

## 2 Global Sourcing, Manufacturing, and Distribution

The first step in becoming a global firm has traditionally been to set up a sales office or subsidiary in a new market at the time of entry. The purpose is to develop the foreign market, with the sales office acting as the extended arm of the headquarters. The second step is to establish manufacturing facilities in select markets to take advantage of local low-cost labor, to provide local responsiveness to product design customization needs, and to avoid high trade tariffs and export restrictions. Some markets employ local content requirements, which forces firms to have manufacturing operations in the market to be able to sell to that particular market. The next step can be to internationalize most or all types of resources by adding, for example, local responsibility for supply chain management and product and process development. The final step is to consider the global operations system as one capability network. The ways in which companies source, manufacture, and distribute to satisfy global demand differ. The globalization aspect concerns all three parts: sourcing, manufacturing, and distribution.

A manufacturing firm's perspective on global supply chains focuses on its own network of manufacturing plants, that is, those plants that are owned by the firm. Many firms produce a variety of products and potentially use many different technologies. Consequently, two plants of the same firm may have completely different products as well as different technologies – with very little in common. In this situation an analysis of the entire manufacturing network of the firm would not be able to provide detailed insights. Instead, to be able to understand the logic of the manufacturing network and its plants, it is advisable to look – not at the entire set of plants – but at a sub-network level or specifically at the product group level (Feldmann et al., 2013; Ferdows et al., 2016; Feldmann & Olhager, 2019).

The subset of plants involved in the manufacturing of a particular product group are connected via product design and development – since it is the same product group – and often via material flows between plants. Later, we will discuss when a firm divides an internal manufacturing network for a product group into two or more self-sufficient geographical regions; where the material flow connection may be minimal, while the product design unites the regions.

Many firms have a clear distinction between two types of plants – *component plants*, which are concerned with parts manufacturing and supply semi-finished goods; and *assembly plants* which finalize products before distribution to customers.

Figure 1 captures the distinction between the plant types for manufacturing of a particular product group and the other plants belonging to the same firm. Figure 1 illustrates that there are two component plants serving two assembly plants. Figure 1 also includes the upstream supply network and the downstream distribution network for the focal product group. Since the set of suppliers and distribution channels may differ between product groups, it is necessary to focus on the supply and distribution networks for the particular product group. Figure 1 emphasizes that the supply, manufacturing, and distribution networks for a particular product group are connected via the material flows.

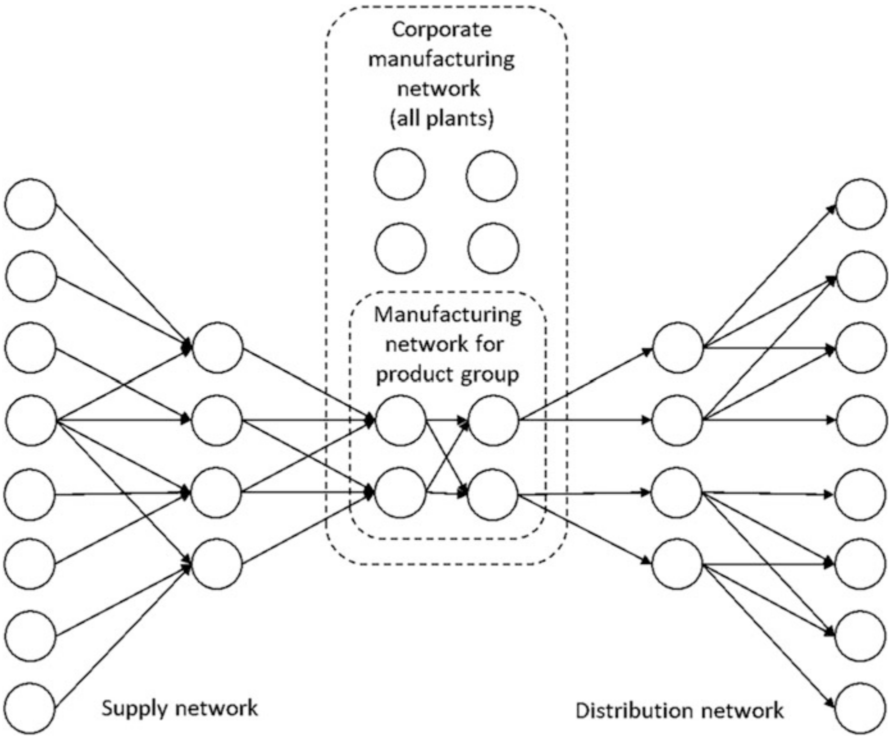


**Fig. 1** Supply, manufacturing, and distribution networks for a particular product group of the focal firm

## 2.1 Supply Network Issues

The supply network is concerned with the upstream suppliers and how they are connected (Fig. 1). For example, the number of suppliers per item, global or local suppliers, and what kind of partners to involve have to be determined. A key aspect in the supply network is the number of suppliers per item: single or multiple sourcing. During 1980–2000, supply base rationalization was commonly practiced by reducing the supplier base and selecting one supplier per item, which is single sourcing. The purpose was often to reduce the total transaction costs and distribute the total purchase value to fewer suppliers to enable volume increases and deeper relationships with the suppliers that remained. Since the millennium shift, risk management has often led to multiple sourcing – the use of two or more suppliers per item.

Recently, another alternative has become increasingly attractive to many firms – *make some and buy some*. An interesting example is IKEA and its internal manufacturer of wooden furniture, IKEA Industry. IKEA Industry accounts for approximately half of the wooden furniture supply to IKEA, which makes it the world's largest manufacturer of furniture. The *make some and buy some* strategy implies that IKEA first turns to external suppliers for new assignments for purchasing flexibility.

IKEA Industry is used for three reasons (Ferdows & Olhager, 2020): (i) to maintain knowledge about production processes to help its research and development [R&D], product design, exploit its scale to innovate, develop new concepts, and invest in new wood manufacturing technologies; (ii) to have updated information about production costs, which is useful in price discussions with external suppliers in the wood industry; and (iii) for contingency purposes if suitable external suppliers cannot be found. With its size, IKEA Industry becomes an excellent reference in the wood industry segment for both buying and manufacturing.

Global sourcing implies that the supply base is spread among many regions throughout the world. With increasing globalization, it has become easier and more relevant for firms to look for suppliers further away from their own facilities since world-class suppliers are probably not in the immediate vicinity. Some suppliers may be active in many regions – potentially in all regions where the focal manufacturing firm is operating – or only in one or a few regions. The geographical dispersion of supplier plants may influence the decision to buy from a particular supplier. For example, if the product is considered a global product – a product that is identical in all parts of the world – it is preferable to have the same set of suppliers close to all manufacturing plants in order to maintain a certain level of consistency in terms of product quality and performance.

The major advantage of a global supplier is generally considered to be low-cost manufacturing due to economies of scale. This aspect has led many firms to source from low-cost countries. However, a lower purchasing price must be weighed against longer transportation lead times, distances, and costs. If quick response is required, a local supplier in the geographical vicinity is more likely selected.

A complementary strategic sourcing aspect is whether the supplier should contribute with low-cost production or with flexibility. Fisher (1997) suggests that low-cost suppliers are required in physically efficient supply chains designed for products with stable demand, whereas flexible suppliers are needed in market-responsive supply chains for innovative products with volatile demand over potentially short product life cycles.

Typically, only the first tier is visible from the focal firm or plant, which implies that problems further upstream in the supply chains are hidden until a major issue occurs (Choi et al., 2021). Finding the constraints in terms of critical raw materials or suppliers has become increasingly important for managing global supply chains. The concept of a nexus supplier refers to a supplier in a multi-tiered supply network that potentially exerts a profound impact on a buyer's performance due to its network position (Yan et al., 2015). A nexus supplier may well be several tiers upstream in the supply network and hence very difficult to identify. Nevertheless, it is becoming increasingly important to identify these types of suppliers irrespective of where they may be positioned in the supply network.

## 2.2 Manufacturing Network Issues

As competition becomes global, and the complexity of the environment in which companies operate is increasing, managing an integrated international network has become an increasingly important task for managers (Ferdows, 1997, 2018). Global manufacturing implies that the manufacturing firm has plants in various regions across the globe. Important considerations for the structure of the global manufacturing network include location factors, plant roles in networks, and network–plant relationships.

## Location Factors

Location factors are related to the geographical dispersion of plants. There is a multitude of factors that can be relevant in specific situations and influence the decision on where to locate a plant; see, for example, MacCarthy and Atthirawong (2003) and Bhatnagar and Sohal (2005). Table 1 lists a few common factors. Some factors can be quantified in terms of costs, while others are assessed as qualitative factors.

There is a difference between component plants and assembly plants concerning the relative importance of certain factors. Proximity to transportation hubs may be important for both plant types, but component plants are more likely to search for proximity to raw materials and strategic suppliers, while assembly plants are typically located closer to customers and markets. The fewer and larger the plants, the more strategic is the location decision.

Ferdows (1997) found that three location factors dominate in terms of strategic importance, namely, access to low-cost production, access to skills and knowledge, and proximity to market. Johansson and Olhager (2018b) tested these location factors in the context of offshoring and backshoring and found that access to low-cost operations was the dominating location factor for offshoring, while development competences (including access to skills and knowledge, technology, and R&D) was the dominating factor for backshoring. Market proximity was not a strong driver of manufacturing relocation in any direction, suggesting that this factor per se did not motivate a change in manufacturing location.

**Table 1** Common site location factors

| Aspect | Factor |
|---|---|
| Proximity | . . . to raw materials<br>. . . to transportation hubs<br>. . . to customers and markets |
| Access | . . . to the right work force: low-cost labor (for low-cost manufacturing)<br>. . . to the right work force: skills and knowledge (for product and process development) |
| Legal | Local content requirements<br>Tax incentives<br>Trade barriers |
| Social | Culture<br>Quality of life |
| Situational specific | A number of factors can be added that are relevant and specific to the situation |

### Plant Roles in Networks

All plants in a manufacturing network do not have to be identical, perform similar tasks, or have the same set of equipment and competences. Instead, plants can take on different roles in a network. Ferdows (1997) identified six different roles with respect to the strategic reason for site location and the level of site competence. The ultimate plant type was called the "lead" plant – the global hub for product and process knowledge.

Feldmann and Olhager (2013) tested the framework in Ferdows (1997) with data from more than 100 Swedish manufacturing plants and found that the various site competences could be grouped logically into three bundles related to (i) production, (ii) supply chain, and (iii) development. Feldmann and Olhager (2013) further identified three plant types with different types and levels of the three competence bundles: one type having only production competences; another type having production and supply chain competences; and a third type possessing production and supply chain as well as development competences. The three plant types and their competence bundles are illustrated in Fig. 2.

The level of production competence increases with higher plant types, that is, when more competences are added to the site. This result suggests that supply chain competences require a solid base of production competences and that development competences require even more solid competences in production as well as supply chain competences. Plant type 3 exhibits the highest plant performance on cost efficiency, quality, and the rate of new product introduction, and significantly higher than plant type 1. This finding supports the idea of co-locating production and

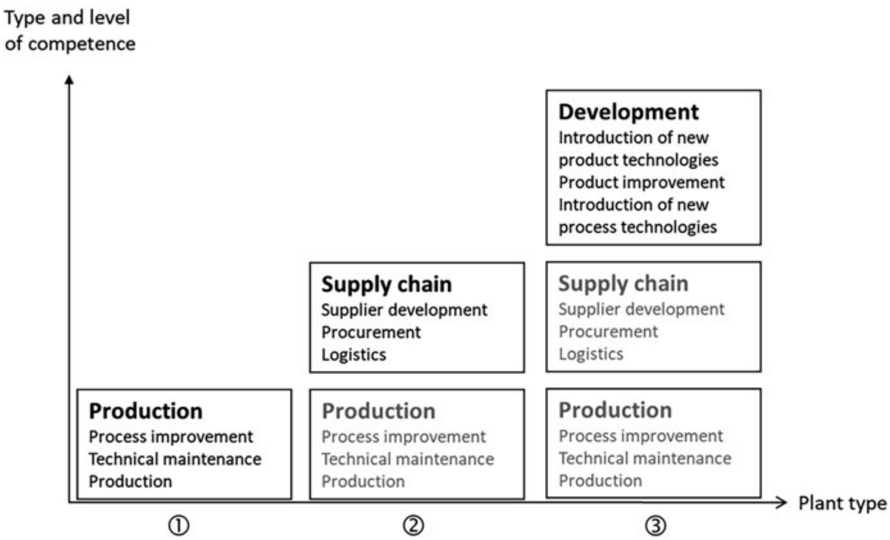


**Fig. 2** Three plant types with respect to type and level of site competence bundles (Based on Feldmann & Olhager, 2013)

product development to support the efficient industrialization of new products (Feldmann & Olhager, 2013).

## Network–Plant Relationships

Manufacturing networks can be looked at from two perspective: the headquarters view, concerning the entire network, and the plant view, focusing on the individual plant (Shi & Gregory, 1998; Cheng et al., 2011, 2015). A central aspect in manufacturing networks is that of the division of decision making between headquarters (the network level) and the individual plants (the plant level). The benefits and problems of using a centralized or decentralized approach for manufacturing strategy decision making include (Hayes et al., 2005): (i) centralized decisions can lead to the standardization of policies, procedures, and systems as well as common business practices that may improve communication and coordination across the network, while (ii) decentralized decisions can lead to greater responsiveness to customer needs and improved adaptability to local operating conditions. Companies can also operate "somewhere in between the two extremes" but finding the appropriate middle ground can be a source of intense disagreement between facility managers (who tend to prefer local autonomy) and corporate directors of manufacturing (who usually prefer a centralized approach) (Hayes et al., 2005).

The distribution of manufacturing decision making along the spectrum from complete centralization with no local influence to full plant decentralization, where all strategic manufacturing decisions taken at the plant, was evaluated by Olhager and Feldmann (2018) who identified three different approaches to the distribution of decision-making authority: centralized, decentralized, and integrated. The third approach means that decisions are taken jointly between headquarters and the plant concerning the strategic direction of the manufacturing operations at the plant. These three approaches align well with the discussion in Hayes et al. (2005) and are illustrated in Fig. 3.

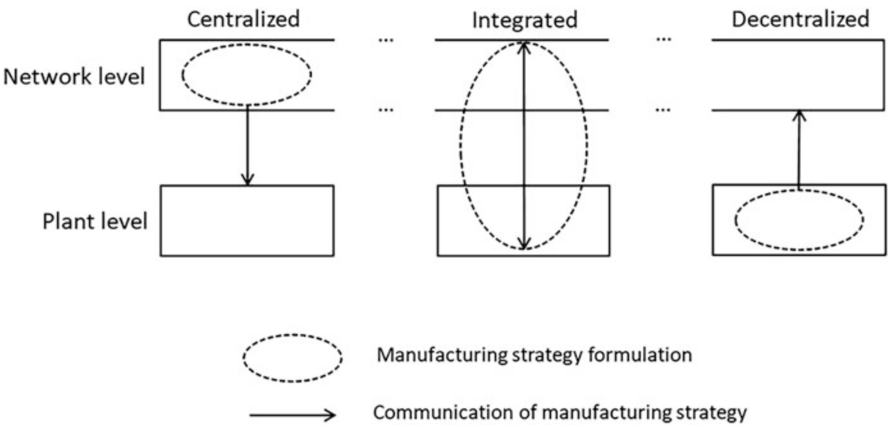


**Fig. 3** Three manufacturing strategy decision-making structures. (Source: Olhager & Feldmann, 2018)

Lohmer et al. (2021) conducted a complementary multiple-case study investigating the network perspective of four German-based multi-plant manufacturing firms. Lohmer et al. (2021) found that the centralized decision-making structures dominated, while integrated and decentralized structures were limited to certain decision categories such as short-term production planning and capacity decisions. The relationship between plant roles and decision-making structures can be grouped into two categories (Olhager & Feldmann, 2021): plants with only production competences have very little decision autonomy (i.e., decisions are located centrally at the headquarters), and plants with production, supply chain, and development competence are likely to have full local autonomy (i.e., a decentralized approach).

## 2.3 Distribution Network Issues

The distribution network implies decisions on how many tiers to use and the kind of actors who reach out to immediate customers and to end customers. In terms of ownership, a global firm can sell through its local sales subsidiaries or through independent distributors, wholesalers, and retailers. The number of actors tends to increase for consumer goods in contrast to industrial goods. An increased number in terms of ownership transfers leads to more independent decision makers, who often want to manage inventory by themselves and have their own warehouses. Other driving forces for more tiers in the distribution network are lead time requirements and the ability to leverage economies of transportation, both of which are characteristics of global supply chains.

However, since the 1990s, a trend toward the centralization of distribution networks has been observed, especially in the B2B context, where many local stock points were consolidated into larger distribution centers (Abrahamsson et al., 1998). This has led to leveraging economies of scale and specialization and improving information systems and transportation planning. This evolution has contributed to improvements including: inventory reductions by pooling inventories for demand from multiple regions; lead-time reductions by better order-to-delivery processes; and transportation cost remaining stable through consolidated and leveled demand.

Instead of having many local warehouses geographically positioned close to customers, one or two distribution centers could supply European demand in one to two days, for example. But for industries with much shorter lead-time requirements, more stock points are needed so they can be closer to customers. The current trend among consumers to require very short lead times (counted in hours), such as in omni-channel retailing (Kembro & Norrman, 2020), are strongly influencing a return evolution toward more stock points again and an increased decentralization of distribution structures. An important factor is whether new decision-making tiers will be introduced. That is, will decentralized decision making return which could increase the demand dynamics and lead to new bullwhip effects, or whether this could be mitigated by increased information sharing and coordinated decisions (e.g., through vendor-managed inventory).

The postponement boundary problem is also dependent on the manufacturing network design (Lee, 2010). The postponement boundary problem also concerns when and where certain value-adding and product differentiating activities (such as assembly and packaging) should be performed. If these activities could be postponed such that they take place at a distribution center, demand could be pooled to this location, potentially leading to a good balance between manufacturing, inventory, and transportation costs.

Increased direct distribution also includes concepts such as drop shipment and merge-in-transit. Drop shipment means direct deliveries from the supplier (or plant) direct to the customer without passing intermediate stocks. This concept is often practiced among on-line retailers today. Merge-in-transit is a more advanced setup, where multiple drop shipment flows from different suppliers are coordinated and merged during transportation to the final customer without passing through the warehouse of the selling firm. An important decision concerns who should operationally manage the required transportation and warehousing activities. Today, most transportation and many warehousing activities are outsourced to logistics service providers, which could be either large global players or smaller local firms. For a global distributions network, both distribution time and cost can be considerable for a product – favoring the use of specialized logistics service providers.

Distribution network may include multiple tiers, it is important to look beyond the immediate customer to identify and understand the industries the downstream customers belong to and the specific industry criticality. For example, are there customers in the early, middle, or late stages of a business cycle? A well-informed understanding of such positions can provide vital guidance in an early warning system for detecting how and when changes in the business cycle will affect the demand for the products produced by the focal firm.

## 3 Global Supply Chain Structures

There are different approaches for serving global demand in terms of how sourcing, manufacturing, and distribution in various parts of the world are constructed and interact. Figure 4 illustrates four basic supply chain structures – linear, divergent, convergent, and mixed – building on the manufacturing network structures in Feldmann and Olhager (2019). The geographical regions include – the Americas, EMEA (Europe, the Middle East, and Africa), and Asia (including Oceania). Taking the supply chain and geographical perspectives, the four structures show that the linkages between successive supply chain stages can be very simple or very complex.

The structures include suppliers, component and assembly plants, and retailers and customers. For simplicity, we include only the first-tier strategic suppliers and how they are connected to the internal manufacturing plant network. The letters A, B, and C in the box for the strategic suppliers refer to a category of components or to a specific component that is critical. Such critical components tend to be sourced from a single supplier, who may be the sole component supplier that can meet quality standards or other product properties.

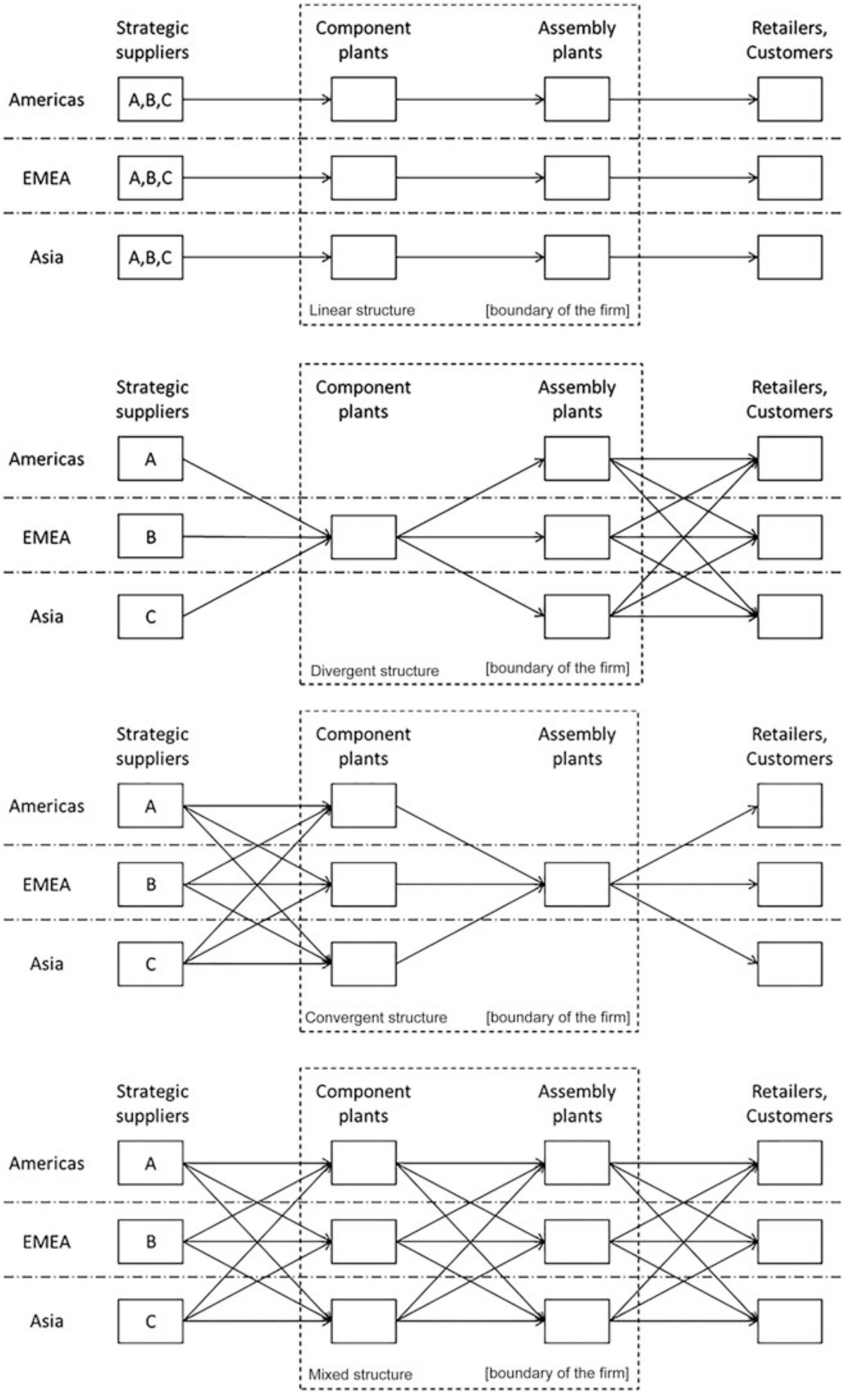


**Fig. 4** Four basic global supply chain structures, focusing on the manufacturing network; from top: linear, divergent, convergent, and mixed (based on Feldmann & Olhager, 2019)

The overall impression of Fig. 4 is that the four structures are distinctly different in how they connect to suppliers and customers as well as the internal relationships among plants. The number of internal plants is four to six for all four structures, which is rather typical for internal manufacturing networks for a particular product group (Feldmann & Olhager, 2019, pp. 167–168).

### 3.1 Linear Supply Chain Structures

The implementation of a linear supply chain structure is typically related to a division of the world into three regions: the Americas, EMEA (Europe, the Middle East, and Africa), and Asia (including Oceania). Figure 5 illustrates this approach. Some firms may even divide the supply chain for Asia into two parts: one for China and one for the rest of Asia. Each region has a complete supply chain, with regional sourcing, manufacturing, and distribution serving the demand in the same market region. The three supply chains work in parallel.

The product is typically of simple design with little intellectual property content and can therefore be produced locally at many locations near the relevant market areas. Typically, the product development responsibilities rest with one "lead" plant, while the other local assembly plants can be assigned responsibility for local product customization and potentially for local product designs (Feldmann & Olhager, 2019). With the

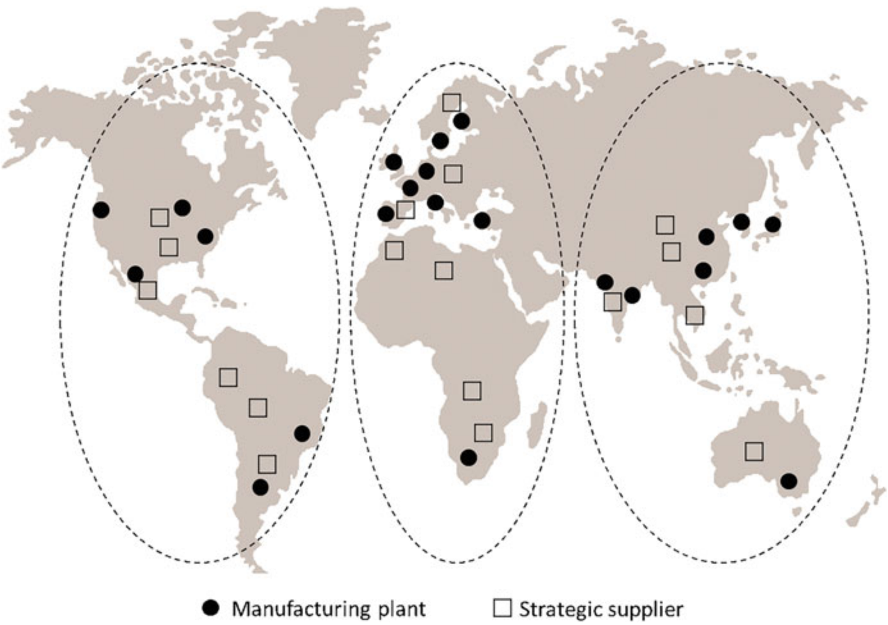


**Fig. 5** Dividing the globe into three regions with self-sufficient supply chains, regional sourcing, manufacturing, and distribution for regional markets

responsibility to serve a local region follows an economies of scope approach for each assembly plant, that is, offering a broad product range to the designated market area.

The advantages with linear supply chain structures include simplicity (few relationships), easy communication (same time zone), market responsiveness (short lead times), and low environmental impact (short transportation distances). With respect to running two or more supply chains in parallel, the following aspects can be added: resiliency (redundancy) and clear structures for sharing best practices (matching counterparts in parallel supply chains). However, there are a few disadvantages: limited supplier selection, restricted to regional suppliers, which are not necessarily world-class; and lower levels of economy of scale and specialization, since an assembly plant focus needs to be on economies of scope. A key managerial challenge is related to how R&D responsibilities should be distributed among the parallel linear supply chains, including this issue of coordination of product standardization vs. local customization across the parallel supply chains.

### 3.2 Divergent Supply Chain Structures

The divergent supply chain structure is connected globally through a core component plant, which typically is the "lead" plant of the entire network and co-located with an assembly plant. Such a "lead" plant has full responsibility for global product and process development, including the introduction of new technologies (Feldmann & Olhager, 2019). The component plant feeds a number of assembly plants that are located globally in reasonable proximity to each respective market. This situation implies that the overall material flow structure is divergent.

The key drivers are economies of scale at the component plant and the protection of intellectual property rights (IPR). If IPR issues concerning product designs or manufacturing processes are of paramount importance, it becomes necessary to keep them under tight control at the "lead" plant for that particular product group. Overall, divergent supply chain structures combine economies of scale at the component plant for critical components with market proximity at the assembly plants for quick response and low logistics cost for reaching customers.

The key managerial concern is how to serve the global demand from a set of assembly plants. If demand in a certain region increases, or if the firm decides to enter a new market, the question arises of where to locate a new assembly plant. The assembly plants may be responsible for sourcing complementary and less complex material in addition to performing the final assembly operations and delivering to the local customers.

### 3.3 Convergent Supply Chain Structures

The convergent supply chain is fundamentally a reverse copy of the divergent one. The core plant is the single assembly plant, which becomes the "lead" plant in the internal manufacturing network and is often co-located with a component plant. A predominant characteristic of the convergent supply chain is that the products and many components are highly specialized, with substantial R&D investments and high levels of skills and knowledge at both component and assembly plants (Feldmann & Olhager, 2019). The product is often a high-end one with high-quality performance. Hence, the control and testing of the finished product are important enough to centralize the function to one plant globally before the global distribution of the end product.

Economies of scale drive this structure at the assembly plant with related control of the finishing operations. There are two key managerial challenges – one strategic and one tactical. Since some R&D responsibilities are distributed to some or all component plants, it is important to maintain the central control and coordination of the product designs. In addition, operational excellence at the assembly plant depends on timely deliveries from component plants located elsewhere, wherefore the tactical synchronization of material flows is important.

## 3.4 Mixed Supply Chain Structures

The mixed supply chain structure exhibits the highest levels of complexity in terms of number of manufacturing plants and long cross-regional transportation. A greater number of plants involved in the manufacturing of a particular product group, means greater likelihood that the supply chain structure will be mixed. The material flow can connect all plants, at least connect all component plants with all assembly plants, which can include many trans-regional shipments on a regular basis.

This supply chain structure is typically related to the extensive division of production tasks among plants, often related to modular product designs (Feldmann & Olhager, 2019). Different product modules are manufactured at different sites (typically focusing on one module) and transported to various regional assembly plants. Even though modular product designs are considered to be highly favorable from a manufacturing and customer perspective – by producing a limited number of modules that can be combined into multiple end-product configurations – the global supply transportation consequences can be quite unfavorable. Therefore, modular product designs must be evaluated from a global operations network perspective (Pashaei & Olhager, 2015, 2017, 2019).

Configuration and coordination managerial challenges in this environment can be quite significant. The network is complex, with additional complex relationships among the plants, including many cross-border flows. A market change in one part of the world may affect the balance of the network, which in turn could require adaptation to the new situation. Hence, there is eventually a need to rebalance networks through expansion, consolidation, and relocation, which forms the essence of the managerial challenges associated with a mixed supply chain structure.

## 4 Current Concerns

Current concerns include interesting global supply chain management issues related to supply chain restructuring, tax considerations, national culture, and risk management.

### 4.1 Restructuring the Global Supply Chain

Restructuring the global supply chain can imply changes concerning who should be doing what and where in the world. The "who" question concerns ownership, the "what" question relates to the manufacturing tasks that are subject for redistribution, and the "where" question is a location issue. These three dimensions are not independent. The manufacturing that is to be relocated (i.e., what) is moved from a host plant (i.e., where) to another plant – either domestically or abroad, either internal or external to the firm. The following four concepts are of particular interest in this context:

- "Outsourcing" is the act of obtaining semi-finished products, finished products, or services from an outside company if these activities had been traditionally performed internally (Dolgui & Proth, 2013).
- "Insourcing" is the decision to reincorporate an outsourced activity within a company that had formerly been transferred to an external supplier (Cabral et al., 2014), in other words, outsourcing in reverse.
- "Offshoring" is concerned with relocating value-adding activities across the national borders of the firm (Roza et al., 2011).
- "Backshoring" refers to a relocation back to the domestic location of the firm (Kinkel, 2014), in other words, offshoring in reverse.

There are some related concepts to the previous four mentioned. A joint venture with co-ownership between the focal firm and a partner in (typically) another country is a mixed form of internal and external ownership. *Nearshoring* denotes repatriating value creation tasks from the foreign host country to a location closer to, but not within, the borders of the home country (Fratocchi et al., 2014). From a Western European perspective, nearshoring could refer to a move from a far-away location to a country in Eastern Europe. Similarly, from the US perspective, Mexico would be a nearshoring opportunity. The concept of reshoring is more general and refers to relocation from one location to another and not necessarily back to the original location or to a nearshore destination but to a third country in general. An example of further reshoring is when a European firm first offshores production to China and later moves this production to Vietnam.

Offshoring and backshoring are first and foremost a location aspect. A change of location can involve a change in governance. Hence, it is often important to include the perspectives of outsourcing and insourcing when considering offshoring and backshoring. Thus, relocation refers to a move of (some or all) operations for the

| | | Governance of host plant | |
|---|---|---|---|
| | | Internal | External |
| Relocation direction | Offshoring | Captive offshoring | Outsource offshoring |
| | Backshoring | Captive backshoring | Insource backshoring |

**Fig. 6** Shoring and sourcing alternatives: relocation direction and governance modes of the host plant

focal plant or firm to another location across the country's national borders, either internally (within the company's own production network) or to an external party (supplier or contract manufacturer). Backshoring refers to the reverse decision, that is, a relocation of production activities back to the company's domestic facility either from an external supplier or from another unit within its own network.

Figure 6 combines the perspectives of location and ownership and shows the main change options. These refer to the four basic shoring and sourcing alternatives that relate to off- and backshoring as well as out- and insourcing.

Offshoring has increased over the years and is expected to continue to grow in the near future, although there is no consensus regarding the absolute extent of the activity (Mihalache & Mihalache, 2016). As a counter-movement to offshoring, backshoring is lagging in time by definition (Stentoft et al., 2016). In addition, Johansson and Olhager (2018a) found that the amount of offshoring exceeded that of backshoring during the period of 2010–2015 in Sweden; the number of backshoring projects during the period was only 56% of the corresponding number of offshoring projects. The net effect is successive reduction of manufacturing activity in Sweden, as in many other European countries.

Research on reshoring in general has focused on drivers, contexts, effects, and creating conceptual frameworks (Stentoft et al., 2016; Boffelli & Johansson, 2020). Over time, a consensus view has been established on the main drivers for both offshoring and backshoring activities (Johansson & Olhager, 2018a, b; Johansson et al., 2019; Boffelli & Johansson, 2020); see Table 2.

The message from Table 2 is clear: The key drivers for offshoring are few and focus on cost and imitation (i.e., do what the competitors do), while the drivers for backshoring are many and diverse – where cost and imitation dimensions are absent. Even though the drivers in individual cases may be few and specific, the list in Table 2 includes drivers that have been cited in case and survey research, which encompass both offshoring and backshoring (based on Johansson & Olhager, 2018a, b; Boffelli & Johansson, 2020). It should be noted that most research on off- and backshoring concerns cases where the home plants are located in developed countries, predominantly in Europe.

The other dimension in Fig. 6, the aspect of governance was captured by Feldmann and Olhager (2008), who investigated the choice between internal vs. external sources. The dominating criterion for choosing internal

**Table 2** Typical offshoring and backshoring drivers

| Category | Offshoring drivers | Backshoring drivers |
|---|---|---|
| Competitive priorities | Labor costs<br>Price competitiveness (related to labor costs) | Quality (product quality)<br>Lead time<br>Flexibility |
| Development competences | – | Access to skills and knowledge<br>Access to technology<br>Proximity to R&D |
| Other aspects | Imitating competitors | Made-in-effect<br>Free capacity at home plant<br>Incentives<br>Cultural differences<br>Strategy change<br>Managerial mistake (to offshore in the first place) |

suppliers was "corporate decision," followed by quality and competence. Quality, cost, and delivery dependability factors dominated for external suppliers. Interestingly, "corporate decision" was the only criterion that was rated significantly higher for internal suppliers than for external suppliers, while many of the other factors exhibited significant differences in the other direction.

The following nine criteria were rated as significantly more important when choosing external suppliers: quality, cost, delivery dependability, volume flexibility, delivery speed, size of company, logistical solution, design flexibility, and geographical coverage. These results suggest that the choice of an internal supplier is largely based on the availability of an internal source – since the criteria for choosing an internal source is significantly lower for multiple aspects. Thus, if the firm has the possibility to source in-house, meaning within their own manufacturing network, they tend to do it. In addition, the results strongly suggest that a wide range of competences are requested from an external supplier (as opposed to an internal supplier) in order to be selected (Feldmann & Olhager, 2008).

Research on the interaction between location and ownership is still largely absent but would be a welcome addition to the understanding of offshoring and backshoring. Initial insights suggest that internal sourcing is preferable over external sourcing since the manufacturing activities and competence stay within the same firm, which is associated with more degrees of freedom. The two dimensions of location and ownership concern the shoring and sourcing decisions, with the ultimate goal being "rightshoring" and "rightsourcing." However, these decisions are complex and have many dimensions, which ultimately forces decision makers to weigh benefits against risks.

## 4.2 Tax Considerations

Supply chain globalization and the explosion of world trade means that raw materials, components, and finished products cross country borders many times. Changes in trading blocs (EU, USMCA, ASEAN, etc.), the World Trade Organization, geopolitical tensions, and differences in government regulations and customs tariffs make the location of value-adding operations a crucial factor in global supply chain network design. State and local governments also compete to attract companies to locate in certain areas by offering different "packages" of tax incentives.

Thus, for supply chain structures involving multiple jurisdictions, tax-related implications are increasingly relevant for practitioners (Cohen & Lee, 2020). How and where nodes are established and value-adding activities performed (manufacturing, assembly, packaging, etc.) influence customs duties as well as direct and indirect taxes. Practitioners from the legal, fiscal, and logistics domains design global product flows, including where and how products are sourced, value-added, and distributed (Norrman & Henkow, 2014).

Global product flows along with organizational and legal structures and financial flows determine the tax implications. Whether the tax structure or global supply chain is optimized first does not matter; changing either one will reciprocally impact the other. This interaction requires deeper analysis, but logisticians normally locate according to production and logistics costs, neglecting the role of taxation (Shunko et al., 2017), whereas fiscal experts seem to simply consider tax savings without addressing logistics complications from the cross-country setting (Adams, 2008).

Pre-tax operating savings from a pure logistics analysis may not necessarily transform into an actual cost reduction after taxes, while supply chains based on tax optimizing principles may become very strange from a logistics perspective (Balaji & Viswanadham, 2008). Cross-border transports may be introduced that are efficient for profit after tax but unnecessary from a logistics and environmental point of view, where local drop-shipment or merge-in-transit might be favorable (Henkow & Norrman, 2011).

The huge variety of tax structures, introduced by different jurisdictions, poses great boundary-crossing challenges for global firms (Cohen & Lee, 2020), where country specifics have clear implications for tax rates and import duties. Key tradeoffs between tax-related costs (e.g., duties, corporate income taxes, and value-added taxes [VAT]) and traditional logistics costs must be considered with careful evaluation of cross-border flows (Norrman & Henkow, 2014; Prataviera et al., 2020). Frictions may arise because the supply chain, legal, and fiscal domain analyses are often based on different principles.

Customs duties and compliance rules are applied to cross-border movement and value-adding activities, direct taxes are levied on the income, and indirect taxes are applied to the transfer of goods (Hsu & Zhu, 2011; Dong & Kouvelis, 2020). These fiscal elements are briefly described below, and then elements useful for the joint supply chain mapping and development of an operating model that could bridge the gap between the domains are suggested.

### Customs Duties and Compliance

Customs duties, trade tariffs, and customs requirements are important aspects of global supply chains and are generally meant to protect national competitiveness from foreign competition. These trade barriers are usually classified into tariff and non-tariff barriers (Adams, 2008).

Tariff barriers refer to paying taxes on the import and export of goods. Customs duties are taxes levied on the importation of certain goods into a customs jurisdiction (Cohen & Lee, 2020) and often computed as a percentage of the product value that crosses the border but may also be levied based on weight or volume. Duties depend on the origin of the imported goods and the associated goods classification (i.e., the tariff code). The jurisdiction of primary manufacturing activities is important. However, origin is sometimes determined by the location of the last substantial transformation. Transformation can include any operation that changes the product's tax code such as when a product gets a "new name, character, or use" that differs from the one that it possessed prior to processing.

The concept of substantial transformation is ambiguous, creating unclear legal boundaries. The product's complete bill-of-material should be examined and implications for component vs. product compared in relation to different trade agreements (Lee, 2010). The current servitization of products and software's increased role in defining a product's capability and capacity also increase the complexity in classification for tax codes and customs duties (Henkow & Norrman, 2011) especially as jurisdictions classify differently. As software upload and testing in many cases are easier to move than manufacturing, the postponement of such activities could change product class and with commensurate tax implications.

Non-tariff barriers include local content requirements, technical standards, quota restrictions, and complexity in the required documentation (Lee, 2010). Trade agreements may also entail lower customs duties or special treatment if specific requirements are met. Indeed, given changing trade agreements and customs duties, changes both in goods classification and in customs duties must be observed (Henkow & Norrman, 2011). Cross-border flows must be compliant with various administrative requirements and restrictions, such as formalities for export and import that could extend lead times. In certain cases, goods may be placed in specially designated areas where they are considered not to be imported, such as a free-trade zone, a bonded or customs warehouse, to avoid import duties in the country where the storage facility is located (Hsu & Zhu, 2011). However, these solutions may involve additional costs and nontrivial complexity due to special monitoring and auditing required by customs.

### Direct Taxes, Corporate Income Tax, and Principal Structure

Direct taxes are levied on the income. In cross-border situations, differences in tax legislation and tax rates between countries create several opportunities for global firms. Low tax rates become attractive for profitable products when tax savings are not offset by supply chain costs (Webber, 2011). For corporate income taxation (CIT), the legal basis of establishing tax consequences is the "principal approach" related to the fact that global firms often divide themselves into different legal units.

One way to reduce overall tax liabilities is to centralize high-value operations (and risks) into a "principal structure" (Bhutta et al., 2003) and then locate the principal in a low-tax jurisdiction (Shunko et al., 2017). This approach can consolidate profits but also increase tax and other fiscal considerations (Adams, 2008; Prataviera et al., 2020). Transfer prices between sub-units in a global firm can influence how profits are divided and how software versus content hardware is valued.

A jurisdiction's incentives could also require that physical operations be located in low-tax jurisdictions to justify the profits planned to be reported there (Hsu & Zhu, 2011; Joseph et al., 2017). Sometimes the relocation of operations seems to be more "on paper" than substantive. Thus, governments are asserting the "substance over form" principle to challenge structural changes perceived as merely tentative to reduce taxable income and shift profits to low-tax jurisdictions (Petriccione, 2007). Tax authorities require that any restructuring of existing operations should produce substantial operational changes and can introduce penalties when the "substance over form" principle is not respected (Adams, 2008). For global supply chain design, different jurisdiction assessment of activities considered for economic substance must be understood.

### Indirect Taxes, Value Added Tax and Sales Taxes, and Permanent Establishment

Indirect taxes – such as sales tax and VAT – are consumption taxes applied to the transfer of goods aimed at being neutral for companies and are indirectly levied on supplies of goods. While sales tax is levied at one stage – often at the retail stage in the USA – VAT is a multiple-stage consumption tax system in the EU.

A cornerstone of international taxation is the term "permanent establishment" (PE), which means a fixed place of business that typically gives rise to income or VAT liability in a particular jurisdiction (Petriccione, 2007; Norrman & Henkow, 2014). The PE mandates that the business be wholly or partly carried out through that fixed place. PE should reduce taxpayer uncertainty for cross-border activities and lead to a fair sharing of taxing rights among jurisdictions. While a subsidiary company does not necessarily constitute a PE of the parent company, it can trigger a PE – and the related CIT or VAT – through employee activity, business activity, or revenue creation in a fixed place of business. In some cases, even outsourced activities could trigger a PE.

Different approaches to combine hardware and software, and different country-specific regulations (e.g., in terms of PE creation), have different tax implications related to – for example – the postponement of value-adding activities. These approaches influence where and how much tax should be paid (Henkow & Norrman, 2011; Joseph et al., 2017). This situation is related back to economic substance, referring to whether its activity or role is for real or established only for fiscal reasons (Prataviera et al., 2020).

Therefore, to claim to pursue substantive activities and not only formal tax planning, some global firms move their warehouses to where their principals are located (Balaji & Viswanadham, 2008; Webber, 2011). If the principal is just a post box not aligned with the creation of a PE in the country, the "substance over form" principle is not respected, causing alarms and public scrutiny.

### Tax-Aligned Supply Chain Mapping and Operating Model

To facilitate communication and decision making between domains, a common iconographic platform could be useful (Henkow & Norrman, 2011). Traditionally, supply chain maps describe material and information flows by using icons such as arrows, triangles, and circles, which can be attributed with volumes, time, capital, costs, frequencies, uncertainties, and locations to illustrate the supply chain and identify improvement areas.

Within the legal and fiscal domain, this kind of mapping is not as entrenched. However, to make proper decisions, fiscal experts need to understand certain attributes of structure, processes, risks, and the management of material and financial flows. The different customs areas – direct taxes and indirect taxes – have different aims; see Table 3.

By adding icons (see Fig. 7) for other types of products (e.g., services); different kinds of territorial borders connected to custom procedures; and more abstract icons for payment flows, change of risk (ownership); and finally different kinds of legal persons (such as PE), a joint mapping could be facilitated, giving answers to the most relevant questions.

To further harmonize global procedures and provide guiding principles, some global firms define operating models (Henkow & Norrman, 2011), clarifying roles and responsibilities and tying together the supply chain structure with the legal and financial structure. An operating model combines definitions, principles, and maps illustrating different flow set ups – product, information, and financial flows – for different jurisdictions or trade blocs. An operating model can mitigate the many risks faced globally and help pursue overall tax optimization (Petriccione, 2007). Consequently, the operating model plans for and influences the creation of a company's PEs in different countries, the classification of goods (which can vary by country),

**Table 3** Structural questions to understand for tax aligned SCM

| Tax area | Key questions |
|---|---|
| Customs | Who is importing?<br>What type of product is it?<br>Where does the product originate? |
| Direct taxation (company income tax) | What kind of product (income item) is sold (e.g., good, service, or interest)?<br>Who are the buyer and seller, and what relationship do they have?<br>In which country is it sold?<br>In which country is the residence of the companies?<br>Economic substance of different legal person? |
| Indirect taxation (consumption tax) | What kind of transaction is it?<br>Who are the seller and buyer, and what type of relationship do they have?<br>What route does the product take (where do transports begin and end)?<br>In what territory is the product delivered?<br>PE or not (e.g., related to VAT registration)? |

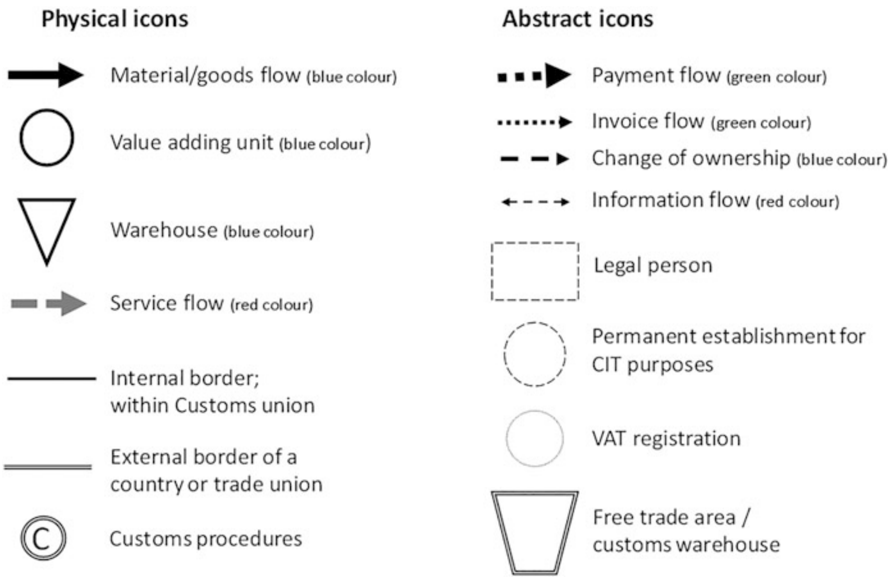


**Fig. 7** Icons for aligned mapping of supply chains and tax elements. (Source: Henkow & Norrman, 2011, p. 884)

the customs duties that should be paid where, and how much the different types of taxes require to be paid (Adams, 2008; Henkow & Norrman, 2011).

## 4.3 National Culture

An interesting question is whether managers in different parts of the world would, based on their heritage, make different supply chain decisions when faced with the same decision factors or whether there is a "globally correct" answer for supply chain problems. Managing an established global supply chain, or transforming and restructuring one, naturally involves global partners and colleagues that must be aligned. But people's origin and heritage have implications for how problems are understood, solved, and communicated and how decision making works.

People understand things differently – whether within a global firm or between different companies in a supply chain – which can create misunderstandings and tensions, decreasing the effectiveness of supply chain management. Griffith and Myers (2005) showed that firms were successful when using different strategies for information sharing with supply chain partners from different countries or cultures: for example, US firms performed better when they had low levels of information exchange with other US firms but high levels of information exchange with Japanese firms.

National culture could significantly explain international operations management behaviors (Pagell et al., 2005). Many managers have probably experienced the same – what works well in one's homeland might be less appropriate elsewhere. It can be frustrating to not understand why suppliers, remote plants, and customers are not responding as expected. To manage such situations in global supply chains, the first step is to identify and understand the factors to consider and then assess whether systematic differences could have implications for supply chain management.

A relevant lens to use is that of Hofstede (1980), who defines national culture as the collective mental programming of the people in a national context. He uses a quantitative classification scheme for measuring differences and similarities between national cultures (see https://geerthofstede.com). National cultures differ in their set of values, beliefs, ideas, attitudes, and morals, which guide the behaviors of individuals. The difference in national culture spans to the organizational culture, influencing the management and operations of daily processes performed and managed by local people. Studying regions (such as North America, Europe, Asia, Asia Pacific, and Africa) is not enough (Hofstede, 1980; Pagell et al., 2005) as different behaviors between national cultures can be observed. But not all countries differ notably, and many countries and their workers share common factors such as language, religion, customs, borders, beliefs, rules, and ethnic heritage. However, Hofstede (1980) points out the following various cultural dimensions as important to understand; see Table 4 for an explanation and examples.

- "*Power distance,*" which relates to authority.
- "*Individualism–Collectivism,*" which addresses the degree of interdependence between society and its members. The overall self-perception of one being an individual or being part of a group, referring to whether "I" or "we" dominates.
- "*Masculinity–Femininity*" describes what motivates people.
- "*Uncertainty avoidance*" is about the reaction to ambiguous events.
- "*Long-term vs. short-term orientation,*" which refers to orientation in life. It cultivates the adaptation of firms in aligning their objectives and plans to meet the needs of partner firms, with an aim to develop a long-term relationship being likely to nurture a collaborative relationship and deter the opportunistic behavior of partner firms (Wong et al., 2017).

Relating back to the previous example (Griffith & Myers, 2005), Hofstede's lens would tell us that the characteristics of the USA are to be individualistic, short-term oriented with small power distances. Japan's national characteristics are the opposite – collectivistic, long-term, and having high power distance. In the USA, information could be seen as power, and sharing could threaten one's position. In Japan, information sharing fits with aspects such as harmony, long-term collectivistic thinking, and where power follows authority.

Successfully managing and transforming global supply chains takes more than understanding that supply chain decisions might vary in different countries or regions. It is important to understand what issues make global supply management different and challenging, such as understanding how and what dimensions of national culture could influence supply chain decisions. Many of the aspects discussed would probably help explain how (well) cross-national supply chain work together by establishing integrated relationships. But culture is a multi-

**Table 4** Hofstede's cultural dimension (for more country examples, see https://geerthofstede.com)

| Cultural dimensions | Explanation | Example countries |
|---|---|---|
| Power distance | "*High-power distance*" means that one accepts positions and follows authorities, authority often is concentrated and centralized, and organizations often are hierarchical<br>"*Low-power distance*" means that the concentration of authority is avoided, power is decentralized, and fewer layers of management is used, leading to higher independence | *High power distance*:<br>Malaysia, Panama, India, France<br>*Low-power distance*:<br>Israel and countries in the Anglosphere or Northern Europe |
| Individualism–Collectivism | "*Individualism*" means that people place a high value on autonomy, individual achievements, and privacy and that one should take care of oneself<br>"*Collectivism*" indicates that the group (family, clan, organization) is highly valued as well as loyalty, devotion, and conformity | *Individualism*:<br>USA, UK, Canada, Italy<br>*Collectivism*:<br>Japan and many Asian and Latin American countries |
| Masculinity–Femininity | "*Masculinity*" is characterized by success being related to winning, the assertive acquisition of money/power, and achievement. Competition is how to solve issues<br>"*Femininity*" define success by quality of life. The equality of genders and caring for the disadvantaged are important, and issues are dealt with by compromises and finding consensus | *Masculinity*:<br>Japan, Austria, Mexico, China<br>*Femininity*:<br>Norway, Sweden, Thailand |
| Uncertainty avoidance | "*Low uncertainty avoidance*" means that people embrace unpredictability and have less adherence to rules, procedures, and hierarchies. People are more relaxed risk takers, and more informal actions such as ad hoc negotiation for the settlement of disputes will be accepted<br>"*High uncertainty avoidance*" indicates that people are threatened by the unknown and thus need more stable and predictable workplaces. In general, risk taking is avoided, and there is a reliance on rules | *Low uncertainty avoidance*:<br>Singapore, Denmark, UK<br>*High uncertainty avoidance*: Greece, Portugal, Belgium, Japan, Spain, Russia |
| Long-term vs. short-term orientation | "*Long-term orientation*" is the fostering of virtues oriented toward future rewards, perseverance, and thrift. Related to supply chain management, long-term (future) orientation emphasizes long-term relationships with partners<br>"*Short-term orientation*" is the fostering of virtues related to the past and the present, in particular, respect for tradition, preservation of face, and fulfilling social obligations | *Long-term orientation*:<br>South Korea, Japan, China, Russia<br>*Short-term orientation:*<br>Colombia, Morocco, Iran, Egypt |

dimensional construct, and countries may differ on one element but not on all. It is important to first understand one's own characteristics. Managers should, independent of their own origin and heritage, analyze both themselves and their supply chain partners to understand if and how national cultural differences influence the design, coordination, integration, and transformation of their global supply chain.

## 4.4 Risk Management

Supply chain risk management (SCRM) has been defined as "collaborating with partners in a supply chain to apply risk management process tools to deal with risks caused by, or impacting, logistics related activities or resources" (Norrman & Jansson, 2004, p. 436). SCRM has offered many useful tools for *identifying, assessing, managing*, and *monitoring* risks. The SCRM practice has developed over time, by increasing its scope (in terms of risk types focused on and supply chain length analyzed), developing capabilities (such as information systems and their integration), increasing cross-functional and inter-organizational work, balancing proactive and reactive work, and getting a risk culture in place (Norrman & Wieland, 2020). Compared to a more local supply chain, a global network means both more potential risk sources to identify and assess but, alternatively, more potential mitigation strategies to use. Finally, the fact that national cultures differ – such as uncertainty avoidance and long-term orientation – influences how easy it will be to get a joint global risk culture in place.

*Risk identification* means discovering all relevant risks and uncertainties (Fan & Stevenson, 2018). Given that organizational resources are normally limited, it is necessary to have a structured risk identification approach (Kern et al., 2012). This will surely mean more work the more global the supply chain. Companies with global supply chains must have a global scope when identifying risks, consider various supply chain partners, and how the environment in their countries might differ from the focal firm's environment (Manuj & Mentzer, 2008).

In a general, a cross-functional supply chain mapping over many tiers should be the starting point. This mapping can help understand how finished goods, products, and customers are connected to different components and raw material and where bottlenecks (e.g., single sources upstream; cf. Fig. 1) and critical locations (e.g., due to natural hazards, geopolitical developments, transportation problems) exist.

First looking into larger risk areas and then going deeper into different risk types and associated factors would support a systematic review of traditional supply chain risk sources (see Table 5). Such a "list of potential risks" would complement the supply chain mapping and other tools for risk identification such as the Kraljic matrix, cause-effect diagrams, fault tree analysis, event tree analysis, SWOT analysis, brainstorming, and supplier audits and scorecards (Norrman & Jansson, 2004; Jüttner, 2005; Norrman & Wieland, 2020). Contemporary tools for information intelligence can increase a company's reactive capability to spot risks from such things as natural hazards – earthquakes, storms, and flooding – early on.

**Table 5** Examples of risk sources that can support risk identification

| Risk area | Risk types | Risk factors |
|---|---|---|
| Macro risks | Economic | Exchange rate fluctuations, changes in interest rate, changes in the overall economic situation |
| | Environmental | Natural disasters, man-made disasters, weather, pandemics, security, sabotage, terrorism |
| | Infrastructural | Poor infrastructure, port congestion, customs delays, security check delays, changes in transportation network, infrastructure security |
| | Legal | Uncertainty in external legal environment, (potential) new regulations |
| | Political | Changes in government policies, changes in export or import regulations, tariff changes, administrative and bureaucratic issues, political instability, sanctions, wars |
| | Social | Changing social demands, labor strikes, boycotts, social riots |
| Networks risks | Network behavior | Chaos in system, opportunistic behavior, lack of ownership, supply chain inertia |
| | Supply market | Production/capacity constraints on supplier market, limited available suppliers, market failures, commodity price fluctuations, geographic concentration of suppliers |
| Supply risks, internal risks (in/between plants) | Commercial | Supplier-specific price escalations |
| | Corporate fit | Cultural differences, poor communication, reluctance to share information, poor alignment and coordination, relationship issues |
| | Financial | Supplier's financial health, credit risk, tax evasion |
| | Legal | Contracts and agreements regarding liability, bribery, false claims, patent infringements, antitrust claims, price fixing accusations |
| | Logistical | Delivery reliability issues, problem with unloading facilities |
| | Operational | Breakdown in equipment(s), improper product handling and storage, internal accidents, skills of workforce, poor forecasting, planning and inventory management, supplier stock-outs |
| | Quality | Product quality does not conform to specifications, lack of quality control |
| | Security | Security breaches |
| | Sustainability | Poor product material, design, and safety, contamination and degradation of resources, unhealthy, unsafe, and unhygienic working environment, excessive labor worktime, unfair wages, child labor, discrimination, exploitive hiring policies, unethical treatment of animals, biological risks |

(continued)

**Table 5** (continued)

| Risk area | Risk types | Risk factors |
|---|---|---|
| | Technology | Incompatible IS/IT systems for information sharing, unreliable IT systems, unfinished transformation initiatives, inability to follow rapid technological development |
| Demand risks | Demand | Demand variation, sudden large demand fluctuations, bullwhip effects, systematic forecasting errors |
| | Market and competition | Market changes, competition changes, new product introductions |
| | Customers | Risks affecting customers, branding issues |

In global supply chains, transportation and lead time normally increase, which in general increases uncertainty and risks. Currency fluctuations become more important to handle as does exposition for geopolitical issues such as trade wars and tax-related changes. Cultural differences could increase uncertainty, and supply chains become harder to monitor and control. But while globalization makes some supply risks more important to consider (such as macro and network supply risks), many supply risks' importance remain, in general, the same, but the *variation* of supplier performance levels normally increase. More global supply chains imply increased work and complexity to obtain the information needed for risk identification.

The main purpose of the *risk assessment* step is to determine the criticality of the identified risks and prioritize risks that require additional attention (Manuj & Mentzer, 2008). Usually, one tries to understand the probability and the impact of different risk sources. This logic is not changed by globalization, and similar tools and methods can be used, such as the frequently used risk matrixes, Delphi techniques, or failure modes and effects analysis.

When risks are assessed and evaluated, relevant *risk mitigation strategies* should be applied. Risk mitigation strategies are created with the purpose of reducing the probability of losses associated with risk events to an acceptable level or to reduce the impact of the risk source. Effective risk mitigation requires close collaboration between the supply chain actors and support from top management. Many different supply chain risk mitigation strategies have been proposed over time and structured differently (Norrman & Jansson, 2004; Jüttner, 2005; Manuj & Mentzer, 2008; Fan & Stevenson, 2018). In general risk management strategies revolve around accepting risks, buffering against uncertainty, collaborating with partners, using contracting to transfer or share risks, decreasing risks through supply network design, improving planning, securing different flows, and standardizing elements of the supply chain (see Table 6).

For global supply chains, strategies related to network design are important. Factors such as the number of plants and suppliers and their locations, insourcing vs. outsourcing, offshoring vs. backshoring, and transportation each can contribute to risk. However, the implications of other strategies, such as how to buffer, with whom to collaborate, and understanding how to improve secure flows – which could imply leaving certain risky geographical locations – need to be analyzed and understood.

**Table 6** Examples of risk mitigation strategies

| Risk mitigation strategy | Example | Explanation |
|---|---|---|
| Accepting | Accept risk | "Do nothing strategy" to passively accept the risk with no mitigation strategy |
| Buffering | Excess inventory | Add extra inventory (e.g., by increasing safety stock levels) to reduce stock-out risks |
| | Excess capacity | Add excess capacity in production, storage, handling, and/or transport to make the company more flexible for unplanned changes |
| Collaboration | Information sharing | Share key information with supply chain partners to increase visibility and enable more effective and efficient decision making |
| | Supplier development | Invest in supplier development for critical suppliers/ components to gain performance improvements |
| | Early supplier involvement | Include suppliers earlier in the product development process to avoid problems at later stages |
| | Supplier scorecard/ audits | Use supplier audits and scorecards to gauge and monitor the development of supplier performance |
| | Supply chain partner education | Educate supply chain partners to make them aware of how their decisions have an impact on the overall supply chain |
| | Supply chain coordination | Coordinate decisions and actions across company borders in the supply chain to improve overall supply chain performance |
| | Jointly developed mitigation strategies | Develop mitigation strategies jointly with supply chain partners to ensure alignment |
| Contracting | Insurances | Use insurance contracts to transfer part of the risk to insurance companies |
| | Inventory liabilities | Use contracts to transfer inventory liability to supply chain partners |
| | Delivery agreements | Change delivery agreements to transfer part of the risk to supply chain partners |
| | Dynamic contracts | Make contracts dynamic to the external environment and behavior of the involved parties to share risk with the supply chain partners |
| | Financial hedging | Use financial contracts to mitigate currency fluctuation risk |
| | Contract enforcement | Enforce contracts to reduce transaction costs and supplier opportunism |
| | Negotiate long-term contracts | Use long-term contracts to mitigate price increases from suppliers |
| Network design | Multiple sourcing | Use multiple sourcing to hedge against risks from individual supplier performance |
| | Geographically diversified sourcing | Use a geographically diversified sourcing network to hedge against location-specific risks |
| | Local sourcing | Use local sourcing to, e.g., minimize lead time risks |
| | Source from responsive suppliers | Source from responsive suppliers to maintain flexibility |

(continued)

**Table 6** (continued)

| Risk mitigation strategy | Example | Explanation |
|---|---|---|
| | Source from creditworthy suppliers | Source from creditworthy suppliers to ensure the financial performance of suppliers |
| | Outsourcing | Outsource non-critical activities to transfer the risk to supply chain partners |
| | Insourcing/vertical integration | Take control over critical suppliers/activities to control the risk |
| | Choose strategic stocking locations | Locate the inventories wisely to minimize costs and increase service level |
| | Flexible transportation | Have a flexible transportation network using multiple modes, carriers, and routes to avoid mode/carrier/ route specific risks |
| Planning | Postponing | Delay actual commitment of resources and costs to maintain flexibility |
| | Speculating | Take decisions based on anticipated customer demand to be better prepared |
| | Pricing and promotion planning | Incentivize customers to act in ways using pricing and promotions to limit supply risks of certain components and products |
| | Assortment planning | Make assortment decisions with supply situation in mind to limit supply risks of certain components and products |
| | Silent product rollover | Avoid informing customers about new product launches to avoid specific product demand |
| | Supply-demand synchronization | Make supply and demand decisions jointly to avoid supply-demand mismatch |
| | Improved forecasting | Improve forecasting techniques to allow for better decision making |
| | Develop contingency/ security plans | Develop contingency/security plans to be better prepared and facilitate the recovery |
| Securing | Improve data security | Improve data security to protect against data and information losses from external threats, e.g., cyber risks |
| | Improve inspection routines of goods | Improve inspection routines to easier identify security threats |
| | Avoid risky locations | Avoid risky locations when choosing locations of suppliers, warehouses, offices, using information to avoid location-specific risks |
| Standardization | Standardize processes | Standardize processes to remove complexity and allow more flexibility in operations |
| | Standardize products and components | Standardize products and components to remove complexity and allow more flexibility in operations |

## 5 Emergent Concerns and Future Directions

Globalization and global supply chains are being reconsidered with respect to new emerging types of global disturbances and more frequently occurring traditional disturbances. Some researchers expect that the combined effect of the increased global risks and decoupling of economies (through heightened nationalism and protectionism) will lead to a decline in or retreat of globalization (Ajami, 2022; Belke & Gros, 2021). Others argue that the new risks are only marginally higher and can be managed by global firms through alternate cross-border strategies and emerging technologies (Contractor, 2022). Ciravegna and Michailova (2022) proposed that although increasing globalization is needed in the post-COVID-19 era, the reconfiguration of global value chains will nevertheless result in a less globalized and more regionally fragmented world economy.

The alternative to a global supply chain is a local supply chain that is self-sufficient within a predetermined geographical area. If the ambition is to capture and satisfy global demand, a number of such local supply chains are needed; see Fig. 5. The drivers for creating global vs. local supply chains differ. Depending upon the situation, some aspects may dominate over others and influence the firm to move in a particular direction. Table 7 summarizes some key drivers for deciding on global versus local supply chains.

A global supply chain is characterized by aiming for the best options for every aspect of "who should be doing what and where" along the supply chain. This options analysis means trying to find the best suppliers globally for each component, locating its own production in locations that are well suited for the particular manufacturing processes, supplying the global markets through efficient distribution channels, and connecting these parts via good infrastructures. There are several arguments for having global supply chains, and include:

- Economies of scale in that each individual plant can serve the entire global demand

**Table 7** Drivers for global versus local supply chains

| Global supply chains | Local supply chains |
|---|---|
| Efficiency<br>  Economies of scale<br>  Relative advantages of countries<br>  Inventory pooling between markets | Market proximity<br>  Follow market changes<br>  Local responsiveness<br>  Short lead times and quick response |
| Suppliers<br>  World-class suppliers<br>  Global suppliers active in many regions | Environmental impact<br>  Shorter transportation distances |
| | Risk management<br>  Control<br>  Communication<br>  Cultural similarities<br>  Resilience regarding trade wars |

- Competent suppliers, searching for the best suppliers for all individual components
- Utilization of the comparative advantages of countries with respect to low-cost manufacturing, cheap labor, manufacturing clusters, and innovative product and process development
- More degrees of freedom in designing the global system for suppliers, production, distribution and markets as more options are available

A local or regional supply chain is characterized by having suppliers, manufacturing, and distribution in the same region and serving a geographically concentrated market. These considerations are a valid alternative even when the markets are global. In that case, a number of regional supply chains are needed that are self-sufficient in each region. Overall, it can be seen as having a number of parallel systems with suppliers, production, and markets. Arguments for such an approach include the following:

- Better adaptation to local needs as the facilities are adapted to produce the local market's complete product range.
- Less capital tied up through increasingly shorter lead times.
- Less environmental impact through shorter transports and no transcontinental transports.
- Lower risks in the supply chains in that the supply chains are independent and self-sufficient. Earthquakes, tsunamis, hurricanes, storms, volcanic eruptions and forest fires often affect a limited area, leaving other local supply chains unaffected.
- Less risk of "bullwhip" effects through greater transparency and flexibility as all actors are in the same region.
- Minor cultural differences between the various actors in the chain through concentrated geographical coverage.
- Barriers to trade and requirements for local processing (production and suppliers) may constrain the options.

The negative aspects of global and local supply chains are fundamentally the absence of the drivers for the other supply chain types. Besides the risk aspects discussed above for global supply chains, poor communication due to cultural dissimilarities and long lead times resulting in higher total inventory investments are often cited as problems. There are also some difficulties in creating efficient local supply chains, which have to do with operating in a limited geographical area, as follows:

- Limited supplier competence. It can be difficult to find sufficient suppliers for all component types within the region. This may require an adaptation of product designs or active supplier development.
- Difficult to create a balance between supply and demand, especially in a dynamic market. If demand increases, it can be difficult to get all suppliers to adjust supply volumes to align with demand volumes or, alternatively, find new suppliers.

- Cost inefficiencies through higher labor costs in certain regions, which possibly can be compensated by higher levels of automation, robotization, and digitization.

The total investment in setting up a number of local supply chains is probably higher but must be weighed against the potential savings in distribution, transportation, and inventory costs. However, it is not clear which setup will have the overall lowest cost for running the system, wherefore the balancing decision between global and local supply chains is far from trivial.

How can the supply chain take advantage of economies of scale with global operations and a global supplier base and simultaneously maintain an ability to adapt product designs to local conditions and needs? Girod et al. (2010) advocated that the most important activities and capabilities should be identified and assessed before determining the global and local challenges associated with them, implying a granular approach. In essence, the choice of position in the spectrum between global and local supply chains is to strike the optimal balance between global efficiency and local responsiveness.

However, changing the global operations footprint takes time. While individual manufacturing tasks and processes can be transferred to other facilities in the short term, entire manufacturing facilities are not easily moved due to great inherent inertia. Since changes in the marketplace tend to be much quicker than any manufacturing system can adapt to, decisions on how to supply specific markets and find new suppliers are necessary to adjust to such market changes.

## 6 Summary and Conclusion

The core perspective of managing global supply chains is to decide on "who should be doing what and where" along the global supply chain. Two additional perspectives can be added in terms of "how" (first and foremost related to the type and level of technology) and "with how much capacity" (i.e., "rightsizing" with respect to the balance between cost efficiency and flexibility). Every manager of global supply chains or global operations aims for a well-balanced or optimal global network but acknowledges that the number of factors and issues to consider is constantly growing.

The recent events of the COVID-19 pandemic and the war in Ukraine have exposed the limitations (or inability) of the global supply chains to be proactive. For example, the risks with lean supply chains have been exposed, and many firms have drawn the conclusion that more inventory is needed along the supply chain. Inventories are generally considered to be a "necessary evil," but the question for the future is whether the emphasis will be on "necessary" – as a motivation to maintain high inventory levels – or on "evil" – as a motivation to reduce and minimize inventories along the supply chain.

With respect to the inherent dynamism in the global environment, pendulum movements are likely to continue in the future between free trade and protectionism as well as between global and local supply chains. The risk dimension of decision making on global supply chains is likely to grow in importance for decisions on the location and number of facilities and inventory investments in the supply, manufacturing, and distribution networks, while potential costs advantages, access to rare materials, and market opportunities will drive further globalization.

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# Africa and Supply Chain Management

Ronakeh Warasthe

## Contents



**Abstract**

The vast majority of 55 nations on the African continent are considered emerging economies. In conjunction with this classification, supply chain management (SCM) and logistics in Africa are prone to particularities such as the different levels of infrastructural development and political instability. Yet, there is an underrepresentation of Africa in SCM literature. This chapter adds to the scarce research on SCM in the African context by presenting both the perspectives of emerging and developed economies in empirical studies. A Delphi study conducted during different stages of the pandemic gives insight into risks and

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vulnerabilities of supply chains (SCs) in Africa and presents restoration and resilience building measures named by the expert panel. The second study on the expected impacts, risks, and opportunities of the German Act on Corporate Due Diligence in Supply Chains elaborates on German firms with SC ties to Africa. The use of secondary data from global non-profit sources and research papers allows a comprehensive assessment of how SCM is carried out in the African context. Disruptions of the fragile supply chains such as the ongoing COVID-19 pandemic continue to challenge the economic stability and growth while acting as potential incubators for developments such as digitization and reshoring. In depicting frame conditions of supply chains in Africa such as macroeconomic factors, infrastructure, and material flows to identify SC risks and measures to build SC resilience, this chapter aims to provide results that might also be applicable for emerging economies in different regional contexts. Readers find insight into challenges and opportunities of SCM with regard to African operations and gain valuable understanding for related decision-making. Practitioners my gain new perspectives and helpful guidelines for doing business in Africa.

**Keywords**

Supply chain management · Africa · Sustainability · Risk management · Resilience

## 1 Introduction

For several decades, managing supply networks has become a key success factor for industries and economies worldwide (Ohmayer & Kilimann, 2008) and an increasingly relevant topic of scientific research (Min et al., 2019). Researchers have studied supply chain management (SCM) mainly from the perspective of industrialized regions while neglecting the view from emerging economies (EE) and developing countries (Svensson et al., 2008; El Baz et al., 2018). Only very recently have SCM scholars started broadening the geographical scope of their analyses to (sub-Saharan) Africa (Nnamdi & Owusu, 2014; El Baz et al., 2018) or studying operations and logistics at the base-of-the-pyramid (Gold et al., 2013; Khalid et al., 2015; Seuring et al., 2019).

Given the large economic growth potential of Africa and the particularities of logistics and SCM in this continental region, it is surprising that related SCM research still is in its infancy. Characteristics of the economic and cultural environment need to be considered when studying SCM in Africa (Georgise et al., 2014). Specific factors include a lack of hard currencies, qualified personnel, cultural aspects in logistics, and efficiency impacts of personal relationships between supply chain (SC) actors (El Baz et al., 2018). Scientific analyses mainly evaluate product-specific SCs and (third-party) logistics operations, risk and performance management, or sourcing (El Baz et al., 2018). Studies often focus on a particular industry, e.g., textile and apparel (Brandenburg et al., 2022) or agriculture and food (Aworh, 2021), or they analyze information technology (IT) as enabler of SCM (Schilling & Seuring, 2021).

Studying topics as green logistics, sustainable operations, SC ethics, and social responsibility in African supply networks with a focused lens from a single perspective necessarily limit the scope of analysis. Instead, interdisciplinary and intercultural investigations are recommended. These types of investigations are needed to leverage the full research potential, reveal new insights, and deliver strong research contributions. However, only 15 percent of all studies on logistics operations and SCM in Africa reflect theories related to micro- and macroeconomics (El Baz et al., 2018). The management research perspective on African supply networks could and need to be complemented by the view on global value chains in Africa from an economics and governance perspective (see, e.g., (Whitfield et al., 2020).

In 2003 Hamel and Välikangas noted that the world is changing more turbulently than companies are becoming resilient and that success has never been so fragile. Technological advances, fast-paced globalization processes, regulatory upheavals, geopolitical shocks, industry deverticalization and disintermediation, as well as sudden changes in consumer wishes underline the importance for risk reduction mechanisms (Hamel & Valikangas, 2003). In addition, many companies have taken SC adjustment measures, like Just-in-Time or lean manufacturing, to increase sales or reduce costs in a stable business environment. This research stream may also be promising for studying SCM in Africa.

The focus of this chapter is set on the African continent. The study takes a closer look at the different phases of resilience and identifies areas that are crucial for overcoming disruption in a particular phase. Two empirical studies elaborate two very different perspectives on SCM in Africa. First, a Delphi study presents the views of African experts on SC risk and resilience concerning the continent during the COVID-19 pandemic. Second, German businesses with SC ties to Africa are the basis of a study on the expected impacts, risks, and opportunities of the German Act on Corporate Due Diligence in Supply Chains.

The next section will give an overview of frame conditions of supply chains in Africa and outline definitions respectively used in this chapter. This will provide a base for the further study and helps to delimit the input of this chapter. Based on this background, existing concepts of SC risk and SC resilience in research and practice are outlined. The third section consists of two empirical studies giving insight into (1) SC risk and resilience during the COVID-19 pandemic and (2) the impact and perceived risks and opportunities of government regulation toward sustainability. The managerial implications section provide a strengths, weaknesses, opportunities, and threats (SWOT) analysis summarizing the internal and external environment of SCM in Africa. The conclusion and an outlook outlining ideas for future research are provided in the final section.

# 2 Background

## 2.1 Frame Conditions of Supply Chains in Africa

### Emerging Economies in Africa

The World Bank clusters EEs as all economies ranked with low income (< 1035 USD) and lower middle income (1036–4045 USD), defined by the thresholds developed for the per capita gross domestic income (GDI) (The World Bank, 2020a). By using only one key performance indicator (KPI) determined by the Atlas method, to classify economies, the World Bank provides a simple framework while knowing that the per capita gross national income (GNI) cannot summarize the complex levels of development and welfare. Still, according to the World Bank, the indicator can evidently be correlated with “other, nonmonetary measures of the quality of life, such as life expectancy at birth, mortality rates of children, and enrolment rates in school” (The World Bank, 2020a). African countries make 58 percent of the total EEs, and 46 African countries are defined as EEs (Fig. 1). For simplicity reasons, this study includes the remaining nine countries into the previous definition for the cause of this study.

In order to prepare for unforeseen events, it is necessary to be aware of possible weaknesses and their consequences. Especially in EEs with “limited health-care capacity, deeply integrated global value chains, heavy dependence on foreign financing and extensive reliance on international trade” are likely to experience significant decrease in commodity exports and tourism (Martin, 2020). According to the thresholds for EEs defined by the World Bank, African countries make 79 percent of the world’s lower-income countries and 46 percent of lower middle-income countries (The World Bank, 2020b).

## 2.2 Macroeconomic Factors, Infrastructure and Material Flows

In their annual report released in 2021, the African Development Bank projects the average African gross domestic product (GDP) to grow by 3.4 percent after a 2.1

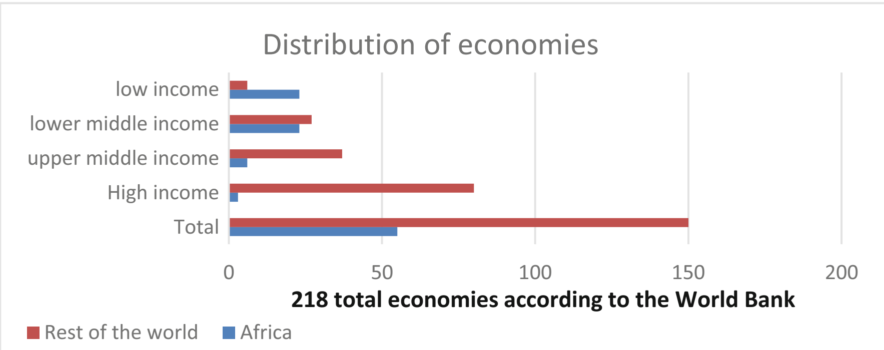


**Fig. 1** Own Illustration based on the distribution of global income groups (World Bank, 2020a, b)

percent decline in 2020. In line with developments globally, the current macroeconomic environment, performance, and prospect of the African continent is strongly influenced by the effects of the ongoing COVID-19 pandemic. While the number of COVID-19-related deaths in 2020 is lower compared to other continents, the negative development of the GDP growth rate was in line with the rest of the world (African Development Bank, 2021).

The impact of the pandemic was and still is as individual as the 55 economies of the continent. Exemplary for these differences is the pandemic-related GDP decline of 11.5 percent in tourism-dependent economies compared to a comparably low decline of 1.5 percent in Africa's oil-exporting economies. The report concludes that due to the pandemic, increased fiscal deficits, higher debt burdens, fluctuations in exchange rates, and disrupted financial inflows weakened the macroeconomic fundamentals of the continent (African Development Bank, 2021).

Infrastructure development facilitates economic growth and strengthens equity and thus reduces poverty. Of all EEs, countries in sub-Saharan Africa rank at the bottom of all dimensions of infrastructure performance – transportation, energy, and digital (Calderón, 2021). In their framework, El Baz et al. (2018) consider infrastructure to be one of the six challenges influencing African-based SCM practices and logistics, the other five being (1) geography/natural disasters, (2) technology shortage, (3) political risks, (4) inefficient networks, and (5) regulations and institutional aspects. A means to meet this need for infrastructure development is funding through foreign direct investments, which increased by 11 percent right before the pandemic (UN, 2019).

The limited access of rural areas to roads and geographical disadvantages as remoteness of most of the region's economies from global market centers increase transportation costs. The cost of moving imported goods to customers inland is 50 percent higher than in other regions and obstructs accessibility to consumers and interregional trade (El Baz et al., 2018; Calderón, 2021). There are geographical disadvantages of landlocked countries in the region – for example, Ethiopian textile and apparel producers that need to wait up to 21 days for goods to arrive through the port of Djibouti. Adding to this geographical disadvantage are political conflicts, which is the reason goods have to be moved through the port of Djibouti despite Eritrean ports being closer to some industrial sites (Warasthe et al., 2020; El Baz et al., 2018).

## 2.3 Risk and Resilience of Supply Chains

Every company decision and activity is accompanied with uncertainty, since wrong decisions might result in unforeseen impacts. In order to avoid these consequences, potential risks must be constantly factored in and controlled (Heckmann et al., 2015). Due to increasing complexity in intertwined modern supply networks and increased concerns about the rise of SC risks, the significance of risk management has increased (Hohenstein et al., 2015). Whole SCs are put in jeopardy if not managed accordingly. Therefore, after the establishment of SCM as an academic field, SC risks and their management received great consideration through a change in business practices starting at the beginning of the twenty-first century (Zsidisin & Henke, 2019).

Increased SC complexity makes them more prone to disruptions (Fiksel, 2015). External factors such as natural disasters, global outsourcing (Bakshi & Kleindorfer, 2009), and shorter product life cycles (Sodhi et al., 2012) further increases SC risk. A global pandemic such as COVID-19, which is still a global disruption, leads to unpredictable changes. COVID-19 exposes entire SCs to major social, economic, and ecological risks, influencing the development of the whole economic market (Alicke et al., 2020).

In April 2020, the department "Statistics South Africa" released its report on "Behavioral and health impacts of the COVID-19 pandemic in South Africa." Being one of the economically strongest countries in Africa, the participants of the survey rank economic collapse, the health of vulnerable persons and the overload of the health system as the most critical impacts resulting from the COVID-19 pandemic (Statistics South Africa, 2020). SC resilience needs to be strengthened to decrease the probability of disruption as well as impact of damages resulting from disruptive events (Seuring & Freise, 2011). Research combining a global pandemic, SC risk management, and SC resilience in EEs is scarce and requires investigation.

Current literature defines SC risk in a rather generalized, ambiguous, and unquantifiable manner. The understanding of SC risk and the attendant views on the design of risk management vary widely since researchers have tackled the topic from different perspectives (Sodhi et al., 2012). Therefore, their definitions often focus on specific functions of the SC and do not consider the whole chain (Ho et al., 2015). Heckmann et al. (2015) define SC risk as follows: "Supply chain risk is the potential loss for a supply chain in terms of its target values of efficiency and effectiveness evoked by uncertain developments of supply chain characteristics whose changes were caused by the occurrence of triggering-events" (Heckmann et al., 2015, p. 130).

SC risk management occurs at the interface of risk management and SCM (Fig. 2). As part of the planning and controlling of SC processes, it follows a collaborative and structured approach in order to minimize risks that jeopardize the company's target achievement (Tang, 2006).

In a more comprehensive approach, Ho et al. (2015) define SC risk management as "an inter-organizational collaborative endeavour utilizing quantitative and qualitative risk management methodologies to identify, evaluate, mitigate, and monitor unexpected macro and micro level events or conditions, which might adversely impact any part of a supply chain" (Ho et al., 2015, p. 5036). According to the literature review of Pournader et al. (2020), literature on SC risk management can be summarized into two main categories. One part aims to develop a framework to identify, categorize, evaluate, and handle SC risk, while the other part focuses on a specific type of risk, such as climate change (Ghadge et al., 2020) or the COVID-19 pandemic.

While SC risk management focuses on the identification of risks SCs can be confronted with and the management of such risks, SC resilience deals with developing frameworks and tools to prepare for such unforeseen events in order to recover

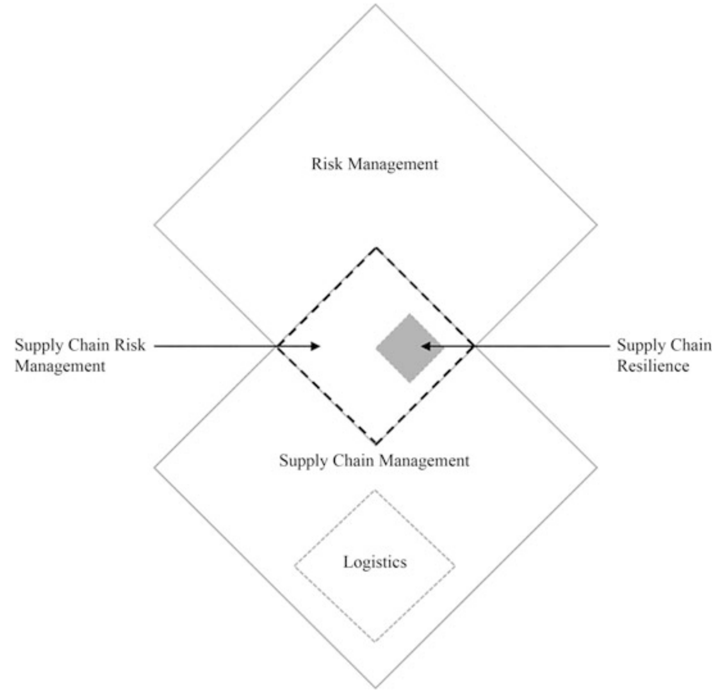


**Fig. 2** Schematic representation of the classification of SCM, SC risk, SC risk management, and SC Resilience (Biederman, 2018)

from them swiftly. The continuous adaptation and development of these capabilities needed in order to make SCs more resilient can create a sustainable competitive advantage (Hamel & Valikangas, 2003).

SC resilience has become increasingly visible in literature, yet the term and concept for creating SC resilience are still vague and still under development. There is no generally accepted definition for resilience (Hohenstein et al., 2015). In economic terms, resilience means "the capacity for an enterprise to survive, adapt and grow in the face of turbulent change" (Fiksel, 2006). But the term can also be found in areas unrelated to business. For instance, ecological science standardized resilience as "the ability for an ecosystem to rebound from a disturbance while maintaining diversity, integrity, and ecological processes" (Folke et al., 2004). This definition is also applicable to SCs, as they can be understood as a network of "living" systems. Christopher and Peck (2004) therefore also linked their definition of SCs with the definition from ecology: "The ability of the system to return to its original state or move to a new more desirable state after being disturbed." For the cause of this chapter the latter is used.

Studies distinguish different approaches to build resilience. According to Pettit et al. (2010), SC resilience can be developed by focusing on company's SC vulnerabilities and SC capabilities. SC resilience increases with increasing capabilities and decreasing vulnerabilities. Pettit et al. (2010) define capabilities as "attributes that enable an enterprise to anticipate and overcome disruptions" and vulnerabilities as "fundamental factors that make an enterprise susceptible to disruptions."

As Kochan and Nowicki (2018) point out in their literature review, the terms vulnerability, vulnerability drivers and factors, resiliency reducers, risks, risk sources and factors, and risk drivers are used interchangeably. In this chapter the terms risk and vulnerability will be used interchangeably. A similar variety of terms exists for capabilities. The term "elements" by Christopher and Peck (2004) or "antecedents" by Ponomarov and Holcomb (2009) as well as the terms "resilient enhancers," "attributes," and "competencies" are used in the literature (Hohenstein et al., 2015).

An organization with high vulnerability that does not have sufficient capabilities is at risk. In response, it should improve the necessary capability. Conversely, an organization that faces fewer vulnerabilities but has strong resilience capabilities might unnecessarily undermine its profits. Therefore, it is beneficial for firms to try to balance both sides. Within this "balanced zone of SC resilience" profits are neither undermined nor excessive risks are taken. To enhance its performance and achieve a sustainable competitive advantage, companies need to analyze their SC vulnerabilities and build up appropriate and matching SC capabilities (Pettit et al., 2019).

Hohenstein et al. (2015) identified in their literature analysis 36 different capabilities of SC resilience necessary to build a resilient SC. The major capabilities detected are flexibility, collaboration, visibility, agility, and multiple sourcing. This is broadly in line with the results of Jüttner and Maklan (2011) and Sá et al. (2020). These capabilities should be established prior to a disruption in order to build resilience (pre-disruption). In addition, other researchers focus on resilience capabilities that are necessary after a disruption (post disruption). These are capabilities such as recovery time, cost, and response effort (Sheffi & Rice, 2005). Some support the consideration of three phases of resilience, including (1) a required level of readiness during the pre-disruption phase, as well as (2) response and (3) recovery in the post-disruption phase (Chowdhury & Quaddus, 2016; Hohenstein et al., 2015). Chowdhury and Quaddus (2016) also point out the interdependency of the phases, since, e.g., higher readiness enables quicker response and recovery from the disruption.

Readiness describes a SC's ability for dynamic control and adaptive management in the time of disruptive events. It includes having the ability "to recognize, anticipate and defend the SC against risks before consequences occur" (Chowdhury & Quaddus, 2016, p. 712) as well as to "forecast, identify risk, asses risk and monitor deviation to prepare for mitigating disruptions" (Chowdhury & Quaddus, 2016, p. 712). By having these capabilities, precautions against disruptions can be taken. Therefore, readiness includes processes to proactively scan the environment, but also includes improved preparing processes linked to previous disruptive events. Besides readiness, current academic research focuses on response and recovery capability to build SC resilience. The ability to react and recover effectively from and quickly toward challenging situations is an important determinant for SC resilience, because a late response can be costly (Chowdhury & Quaddus, 2016). Therefore, it can be argued that those two post disruptive phases are necessary to build resilience.

Risk management and SC resilience are especially important for African countries, which represent the majority of EEs and therefore face specific vulnerabilities. The starting point of facing internal challenges such as weak infrastructure, geographical disadvantages, and dependencies from foreign investment exacerbates the effects of unforeseen external disruptions like the COVID-19 pandemic.

## 3 Emergent Supply Chain Risk and Regulatory Issues in the Africa Context

The following research studies on risk and resilience of SCs in Africa and the German Act on Corporate Due Diligence in Supply Chains have been published in conferences and summarized for this section.

### 3.1 Risk and Resilience of Supply Chains in Africa: Insights from a Delphi Study

We provide insights in risk and resilience of African SC from a three-round qualitative Delphi study. The study determined the risks and vulnerabilities caused by COVID19 in Africa as well as the measures to restore operations and build resilience. The majority of African countries were at the beginning of the pandemic; hence long-term consequences were not yet sufficiently apparent given the early study period (mid-2020), but general insights are still valuable from this time period.

*Vulnerabilities* within the COVID-19 pandemic are considered to be mainly caused by financial and logistical challenges, SC disruptions, and SC disturbances. Africa's dependence on China is an additional factor though seldomly mentioned by the respondents. Due to China's significance as a center of global economic activity, the outbreak in China led to international spill overs, particularly in international trade, mobility, finance, and commodity markets (Ni & Betti, 2020).

Countries with challenging political structures and health infrastructures as well as already existing vulnerabilities in the financial sector are particularly exposed to movements in the global markets (Utz et al., 2020). Due to the characteristics of EEs, among others, institutional constraints within the welfare system, labor market, and political leverage contribute to being exposed to global risks (Keen & Wu, 2011). Ernst and Young discuss a changed customer behavior and brand protection as an additional vulnerability (Dekker et al., 2020). They warn of non-reversible changes in values, habits, and consumption patterns. Consumer loyalty is inter alia built by communication, loyalty programs, and customer segmentation. Approaches to build long-term value range from "building trust in capital markets, having a positive social and environmental impact, or creating an inclusive culture of personal development and purpose" (Dekker et al., 2020).

Within the *response* phase, the reaction to the vulnerabilities is an improvement in financing and in addition the strengthening of the supply network, the digitalization of processes, and increasing SC agility. The identified problems of logistics can be solved by a high degree of agility within the response phase. Chowdhury and Quaddus (2016) combine several studies and support the study's findings. Without the ability to respond to and quickly recover from a changing environment, potential costs of several hundreds of million dollars may occur for companies and SC partners.

It is interesting to note that a strong supply network and the digitalization of the SC are essential in all phases for overcoming the disruption, as well as for building SC resilience. This importance is confirmed, for example, by Alicke et al. (2020), which draws a connection between close corporation among the supplier ecosystem and the resulting increase of SC resilience. COVID-19 has laid bare the negative aspects of globalized SCs to firms, and voices calling for localization are raised. Ivanov and Das (2020) identified in interviews with SC managers that localism is a key concern when redesigning SCs. The Boston Consulting Group also supports diversification and localization of manufacturing and supply networks as a method to mitigate risk (Aylor et al., 2020). As the experts have already pointed out, the supply network has undergone localization and will probably continue to do so to a greater extent in the future.

While the digitalization of SCs is also met with challenges such as the lack of spatially comprehensive digital infrastructure in some African countries, it should have a strong impact on the supply network. A digitalized SC strengthens the ability to anticipate risks, generate transparency and coordination between actors, and manage problems together, thereby reducing the risk for each individual (Alicke et al., 2020) and improving the response quality to disruptions (Queiroz et al., 2020). The resulting data is in turn of importance for the SC risk management, as it enables predictions of potential disturbances and reactions to disturbances to be derived (Ivanov & Dolgui, 2021). Yet, some scholars emphasize the complexity of forecasting and detecting disturbances (Ambulkar et al., 2015; Pettit et al., 2010).

The Delphi study shows that contingency planning is particularly important in the phase of recovery as well as for the construction of resilience, during the phase of readiness. Such plans are nevertheless mostly not implemented for reasons of cost and inertia (Ivanov & Das, 2020). In the context of malaria – a major disease affecting the African continent – Parvin et al. (2018) have shown that effective transport planning might contribute to a significant reduction of costs and shortages. However, the implementation is determined, independent of the disruption, by challenges such as lack of communication, weak governmental commitment, and poor logistical infrastructure (Parvin et al., 2018). In the readiness phase, contingency planning receives little acknowledgment in our study. According to Dekker et al., increasing the communication and assessing support programs is essential for businesses to understand the public policy landscape and to shorten the response time.

During the recovery and readiness phase, the importance of the supply network, digitalization, and contingency planning remains and is supported by a strong human resources management. Deloitte (2020) emphasizes and thus supports the findings that educating employees to prevent COVID-19 and introducing control mechanisms and promoting flexible working arrangements are means to handle the crisis.

In general, the recovery phase is one of the key phases within SC resilience. However, there is little research on this subject (Ivanov & Rozhkov, 2020).

However, the following limitations need to be noticed. As mentioned, the time frame in which the study is carried out has a decisive influence on the result. In the early stages of the epidemic, it was difficult to predict how the situation will further develop, which other long-term consequences will occur and how companies will react to survive the disruption and build resilient SCs. The generalization of received answers is limited by the demographic information provided by the experts in conjunction with the number of contacted countries. Kenya, Ghana, Namibia, and South Africa are the only confirmed countries participating in the study. Nevertheless, the results provide profound insights and in-depth information, as well as prospects are provided by the expert panel.

### 3.2 Impacts of the German Act on Corporate Due Diligence in Supply Chains: An African Perspective

It can be difficult to allocate products and resources to specific production sites which do not comply with human rights. Therefore, transparency along the global supply chain is considered an important mean to assure that human rights are mandatory for all participants of a supply chain. This can be achieved by governmental legislation or by self-regulation of companies (New, 2020). The lack of control in several countries, especially in developing and emerging countries in the global south, amplifies the need for home state regulation to enforce human rights along supply chains (LeBaron & Rühmkorf, 2017).

To meet its perceived universal responsibility of promoting human rights, the German government proclaimed in July 2021 the German Act on Corporate Due Diligence in Supply Chains ("Lieferkettensorgfaltspflichtengesetz") which aims to improve social and to a limited extent also environmental sustainability along the global supply chains of Germany-based enterprises (Bundesregierung, 2021). Effective by 2023 the act will commit Germany-based firms with a headcount of minimum 3.000 full-time equivalent employees (1.000 effective 2024) to fulfill certain due diligence obligations regarding a responsible management of their supply chains.

The act adopts a risk-based approach, as proposed by the UN Guiding Principles on Business and Human Rights (UN, 2011), obliging firms to implement a risk management system with measures to detect, prevent, end, or minimize the violation of social sustainability or environmental obligations caused by the firm, within its supply chain or to which the firm contributed. Most obligations are limited to direct (Tier-1) suppliers. Documentation and reporting duties enable the responsible federal office for economy and export control to examine the fulfillment of the obligations by companies. It is also able to impose fines on non-compliant companies.

Shortly before the German parliament has passed the Act on Corporate Due Diligence in Supply Chains in July 2021, research to study the resulting implications of this act for German firms with SC ties to Africa was conducted. In particular, the

**Table 1** List of interview partners

| Interview | Position | Industry |
|---|---|---|
| AA | Managing director Africa division | Construction |
| AB | Chairman of the managing board/business unit Africa | Automotive supplier and industrial technology |
| AC | Head of human rights | Consumer goods and retail |
| AD | Sustainability manager | Pharmaceuticals |
| AE | Senior vice president procurement and supply management | Automotive supplier |
| AF | CEO | Automotive supplier and industrial supplier |
| AG | Director governmental and external affairs | Hydroelectric power, energy production |
| AH | Supply chain management | Conglomerate |
| AI | Head of ethics and social impact | Chemistry and pharmaceuticals |

perception of risks and opportunities, measures to put the requirements into practice, and the expected impacts on sustainability performance were analyzed using empirical-qualitative case study research. Between Q2/2021 and Q3/2021, nine semi-structured interviews were conducted with managers of German firms with a head count higher than 1000 from different industry sectors with SC ties to Africa. Managers were chosen as interview partners based on their specialized knowledge and occupation of key positions concerning sustainability issues in the considered firms. The interviewees are employed at a cross-sectional variety of companies that are amenable to the due diligence act (Table 1).

### 3.3 Perceived Risks and Opportunities of the Act on Due Diligence

The data shows that the perceived risks outweigh the perceived opportunities of the act since interviewees discuss risk during the interviews three times more often than opportunities. Among the perceived risks of the act, uncertainty due to the broad scope of interpretation for the requirements was mentioned most frequently. Interviewees feel that the burden of defining and interpreting the relatively unspecified due diligence obligations is left to the affected firms since the act causes a high degree of insecurity. To firms it seems still unclear which measures will be considered appropriate under the law. This could also lead to the implementation at the lowest, least strict and least costly level. While one interviewee considered this to be a poor legal construct, another judged this as the inevitable downside of necessary flexibility.

Excessive bureaucracy is another frequently mentioned risk. It is based in the expectation that the implementation of the act's obligations regarding documentation and reporting will result in an immense administrative effort that could distract efforts for true sustainability improvements by setting a wrong focus on detailed administrative tasks. Consequential to the increased administrative effort, firms are worried about additional costs which will also affect them indirectly through their suppliers. Three interviewees see the withdrawal of their firms from markets associated with higher risks for human rights violations as one extreme potential consequence of a competitive disadvantage against international competitors, especially such from Asian countries who are not underlying a legal standard like the German Act on Due Diligence. If in turn these competitors increase their market share in African economies, it might lead to a subsidence of the overall sustainability level in global supply chains and also profit loss of German firms as a result of their withdrawal. The act is perceived as a potential barrier for German companies to operate in those markets.

Two firms believe that some German firms might individually be unable to accomplish the act's objective to safeguard human rights in international supply chains. They see possible conflicts with local regulations and consider the German government or the European Commission responsible for bilaterally negotiating better working conditions. Further risks mentioned are the market exclusion from public procurement due to mistakes made by the firm in high-risk markets and competitive disadvantages for medium-sized companies due to their limited bargaining power. It can be concluded that financial risks regarding the cost of complying to the law are of higher concern than such regarding overall instability or political environment of the supplier or buyer markets.

Despite not being discussed as often as risks in the interviews, the perceived opportunities of the act point to an increased awareness of the interviewees concerning social sustainability. With the exception of one interviewee, every firm mentioned at least one opportunity concerning the implementation of the act though remaining rather vague. Some of the opportunities are interlinked or can be considered a consequence of another.

The most frequently mentioned opportunity is a potentially improved standing of sustainability by putting the act's specifications into action. Thus, the significance of sustainability considerations increases in a firm's decision-making and business practices as stated by several interviewees. Interviewees are in favor of an expected formation of a level playing field which implies that the law creates equal requirements and conditions at least for German firms as all are required to comply with the act. Hence, keeping up with competition is considered less of an obstacle to sustainable business practices. The act can be considered as a form of quality assurance if a firm's supply chain complies with the act which can be attained by, e.g., improved sustainability monitoring safeguards.

### 3.4 Measures to Put the Requirements into Practice

Regarding the expected adjustments required to comply with the law, the responses are balanced as to whether firms will require measures or none at all. One adjustment mentioned is the need to define policies, i.e., implementing new policies or remodeling existing policies to oblige with the law. This might affect internal policies or policies concerning supplier relationships like a (supplier) code of conduct. Another adjustment considered is the mere fact of writing an additional report as the firms consider themselves prepared regarding the risk and sustainability management measures but expect an additional bureaucratic burden by reporting annually. The respondents that consider their respective firms prepared and with no need of adjustments have implemented more comprehensive sustainability measures in the past. There are also responses that imply an uncertainty about the need to adjust, particularly since the interviews were conducted before the final draft of the act was passed.

### 3.5 Expected Impacts on Sustainability Performance

Every interviewee without exception qualified the act on due diligence's impact on their own company's sustainability performance as neutral. Hence, this can be considered as the clear prevailing perception within the context of the study. Five of the nine firms argue that their current sustainable supply chain measures already comply with the act's regulations to a large extent and therefore perceive no need for major adjustments. Others doubt the act's capability to contribute to real improvements. At the same time, three respondents expect of a positive impact that the act might have by giving increased value and focus to sustainability and human rights in supply chains. Negative impact due to practical difficulties is mentioned as well and thus considering the act as an undesirable development.

To sum up, it can be said that SC due diligence acts represent important frame conditions and constraints for SCM in Africa which practitioners must adhere to in daily business. From a research perspective, the efficacy and impacts of such laws need to be explored and evaluated.

## 4 Sustainability of Supply Chains in Africa: Prerequisites, Practices, and Sustainable Development Goals

In addition to risk and resilience and to the due diligence act, sustainability issues are important concerns of SCM in Africa. These perspectives are briefly outlined in this section.

Prevailing working conditions especially in developing and emerging economies that produce for global markets are prone to most basic human rights violations. An example showing the dimension and significance of this challenge is the so-called Marikana massacre which took place in South Africa in 2012. During this incident, miners were shot by police after protesting for better working conditions and higher wages (Marinovich, 2016). While this case of human rights oppression is a widely known example, it is to assume that a many other violations remain unnoticed. According to the United Nations (UN) Guiding Principles on Business and Human Rights, businesses are responsible for respecting human rights and required to avoid contributions to adverse human right impacts and to mitigate those impacts that are directly linked to their operations (UN, 2011, pp. 13–26).

In sustainable SCM, the traditional focus of SCM is extended from economic criteria to socio-ecologic factors (Brandenburg et al., 2014). Growth in studies on green and social SCM has accompanied this development (Fahimnia et al., 2015). Although the African continent is most vulnerable to social and environmental sustainability and most strongly limited in capacity to manage these issues, fewer than 10 percent of all studies on logistics and SCM in Africa include aspects of sustainability (El Baz et al., 2018). Thus, the limited general SCM research in Africa is even scarcer for SSCM.

This large research gap shows the strong need for research on topics such as green logistics, sustainable operations, SC ethics, and social responsibility in African supply networks. Further research perspectives include cultural aspects and their importance for and influence on SCM (El Baz et al., 2018) analyses of developing country suppliers.

Societal effects of green and SSCM, namely, food security and environmental impacts, are topics of recent studies also in context of the COVID-19 pandemic. The resulting impact on vulnerable African societies and their food production and consumption varies depending on the proximity to rather rural or urban areas. Short food supply chains and urban gardening increase resilience and sustainability, while the reliance on global imports for food security proved to be particularly challenging the food security during the pandemic (Nchanji & Lutomia, 2021). Small- and medium-scale enterprises (SMEs) play a significant role in African agri-food chains. SMEs start to transform their practices toward social sustainability by implementing social compliance measures or collaborations, yet are aware of the challenges of their efforts. Customers' sustainability requirements such as food safety, labor condition, and traceability prove to be strong drivers also in the agri-food context (Agyemang et al., 2022).

The emphasis on the role of digitalization as enabler of sustainable practices in SCs is increasing globally across all industries. While SCs with ties to African countries are part of this development, they are met with challenges such as inter alia the local digital infrastructure and connectivity. The need for transparency along supply chains is driving the implementation of block chain technologies, yet the application along with artificial intelligence, Big Data, and Internet of Things in African countries is still scarce (Abban & Abebe, 2022; Bai et al., 2022).

## 5 A SWOT Analysis and Managerial Implications

In order to summarize and categorize the particularities of SCM in Africa derived from secondary data, research papers as well as own empirical research a SWOT analysis is conducted (see Fig. 3). It allows the exploration of internal and external environments based on strengths, weaknesses, opportunities, and threats (Ghazinoory et al., 2011).

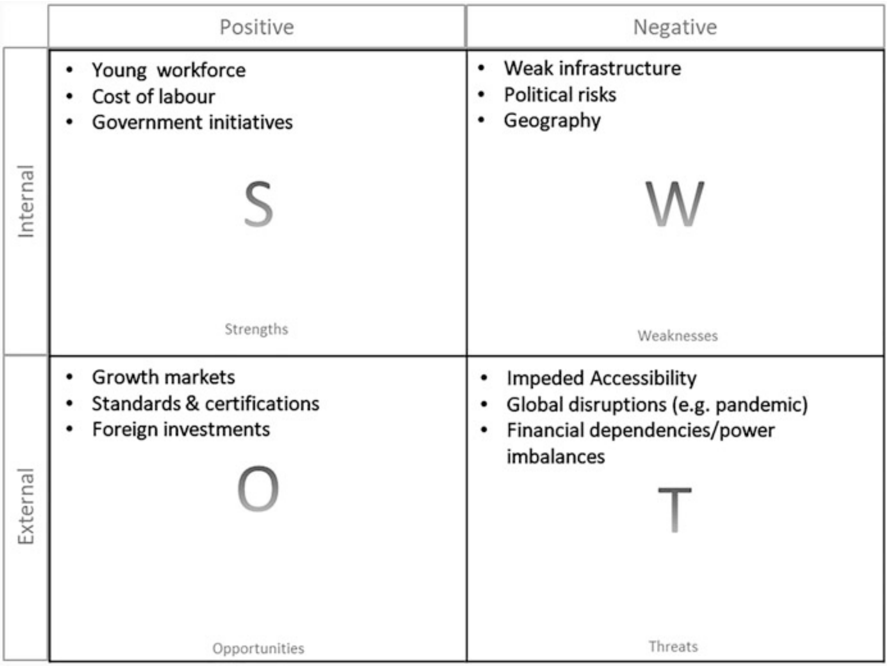


**Fig. 3** Supply chain management in Africa – a SWOT analysis

One of the strengths of African economies is the young workforce combined with the low cost of labor. The development away from agricultural to industrialized economies is enabled by this potential. This can be observed in Ethiopia, where the government launched initiatives to push industrialization through initiatives attractive for foreign investors, e.g., tax exemptions (Warasthe et al., 2020; Adikorley et al., 2017). Another strength is the multitude of government initiatives to tackle the weaknesses in African supply chains. Several African countries launched infrastructure projects expecting to improve the quality of their SCM practices and thus reduce freight costs and time delays (El Baz et al., 2018; African Development Bank, 2021).

The African continent's infrastructure can generally be considered one of its weaknesses. As described in previous paragraphs, countries in sub-Saharan Africa rank at the bottom of all dimensions of infrastructure performance (Calderón, 2021), and infrastructure is considered to be one of the core challenges influencing African-based SCM practices and logistics (El Baz et al., 2018). The limited access of rural areas to roads obstructs accessibility to consumers and hinders trade. The results from the empirical study on the German Act on Corporate Due Diligence in Supply Chains show that political instability and corruption are perceived risks when operating and sourcing from African countries. This further validates the findings of El Baz et al. (2018), who find political risks to be an obstacle to SCM. The geographical disadvantage of landlocked countries is more severe due to the lack of direct access to ports in order to import and export goods at low cost.

The opportunity of being considered one of the last growth markets and frontiers in trade encourages foreign investors to look at potential business ventures in African countries. While the COVID pandemic curbs the growth expectations, several African economies, such as those focusing on tourism and mineral oil, are expected to bounce back swiftly (African Development Bank, 2021). The presence of foreign firms is considered as a potential to positively influence SCM practices by attracting other businesses to supply to, manufacture in, and or source from African countries (El Baz et al., 2018). In order to ensure quality standards but also socially and environmentally sustainable operations, foreign investors rely on standards and certificates. A supplier with globally approved certifications and quality standards is considered trustworthy and a preferred business partner (Warasthe et al., 2020).

The impeded access of African businesses to foreign markets poses a threat to their economies. The remoteness of most of Africa's economies from global market centers leads to 50 percent higher cost of moving imported goods to customers inland and thus hampers accessibility to consumers and interregional trade (El Baz et al., 2018; Calderón, 2021). The Delphi study shows that global disruptions, such as the ongoing COVID-19 pandemic, invert the evolved competitiveness and economic growth of the pre-pandemic years. The financial dependencies of African economies lead to power imbalances, often with regard to China (Deloitte, 2020; Ni & Betti, 2020). Countries suffering from existing vulnerabilities in the financial sector are particularly exposed to and threatened by movements in the global markets.

## 6 Summary and Conclusion

While still underrepresented in research, SCM in the African context is defined by its vulnerabilities. This chapter has shown that intensifying structural transformation through government initiatives and foreign investments may lead to resilience. This chapter has also illustrated that Africa's transformation to a more resilient and sustainable post-pandemic recovery is still at the beginning and is dependent on foreign investment. (German) firms with SC ties to Africa will have to consider regulations to tighten further and their own responsibilities to maintain and further sustainability practices in those chains. Researchers may understand the two different empirically studied perspectives on SCM in Africa as opportunities to conduct broader empirical research.

The pandemic laid bare and acted as an incubator for vulnerabilities of supply chains in African countries, but also for response measures, restoring operations, and resilience building. As individual as the 55 African countries are, so are the effects of COVID-19 on these countries and how they deal with them. This chapter may be helpful to get a broad insight into the challenges and opportunities of SCM in African countries. It may increase the understanding of the particularities and future developments of the African countries tied to global markets.

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# Supply Chain Management in Latin America

Charbel José Chiappetta Jabbour and Adriano Alves Teixeira

## Contents



**Abstract**

This chapter aims to present issues on supply chain management in Latin America. To do so, we evaluate the body of literature and we identified 34 studies from which we collected information about: country in which the research was carried out, cooperation (Universities and authors), methodology used, and sector in which the research was performed. Finally, the main focus, results, challenges, and concerns about SCM are presented, along with a suggestion of future research, so that the theme supply chain management in Latin America can develop.

**Keywords**

Supply chain · Supply chain challenges · Latin America · Research agenda · New skills of SC professionals

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## 1 Introduction

Since the 1980s, globalization and the demands of stakeholders allied to various environmental and social challenges have expanded the scope of logistics operations from companies. These challenges caused a shift of the competitive focus of organizations evolving to considering competition among networks of companies. This new design's – supply chain management (SCM) – main purpose is to improve the costs of operations and deliver to customers a better service (Zhu et al., 2008).

SCM has served to describe the networking management relationships within a company among organizations and business units. These units encompass material suppliers, purchasing, production facilities, logistics, and marketing functions. SCM is also focused on upstream and downstream flow systems that include reverse logistics, materials, services, finance, and information from the original producer to the final customer. The ultimate purpose is to add value to customers while maximizing profitability through efficiency gains (Stock & Boyer, 2009).

The SCM focus can be characterized in four ways (Ahi & Searcy, 2013): (i) focus on the flow of materials, services, and information throughout the supply chain; (ii) focus on coordination consisting of the coordination activities within and among organizations, especially regarding the product life cycle or activities in all channels in the supply chain; (iii) focus on stakeholders by making explicit reference to stakeholders in the chain's business as customers, consumers, and suppliers; and (iv) focus on the relationship between the organizations and their business processes.

SCM philosophy is based on the tenet that organizations, in isolation, cannot meet all the demands of the market, so they need to partner to create competitive advantages through a close and lasting relationship. This partnering requires SCM supply chain management to be strategically important to organizations (Andersen & Skjoett-Larsen, 2009) contributing to organizational competitive advantages (Tarofder et al., 2017).

Despite SCM's importance in Latin America, there are institutional conditions which do not seem to favor the participation of its researchers in a global dialogue on SCM. Few studies address SCM with a particular emphasis on Latin America. A similar situation has already been detected in the research by Teixeira et al. (2020) on the state of the art of Green Supply Chain Management in Latin America – a major subtopic in SCM.

This chapter aims to integrate and systematize the current knowledge about SCM in Latin America demonstrating the main research, challenges, and concerns. The chapter also proposes a future research agenda to guide and encourage the development of SCM research and understanding in Latin America.

## 2 Supply Chain Management: An Overview

Numerous SCM definitions exist. The Council of Supply Chain Management Professionals (CSCMP 2023) defined the SCM as [. . .] "encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all Logistics Management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, Supply Chain Management integrates supply and demand management within and across companies." SCM has also been defined as "the coordination of activities, within and between vertically linked firms, for the purpose of serving end customers at a profit" (Larson & Rogers, 1998, p. 2).

A third definition of SCM is "the management of a network of relationships within a firm and between interdependent organizations and business units consisting of material suppliers, purchasing, production facilities, logistics, marketing, and related to systems that facilitate the forward and reverse flow of materials, services, finances and information from the original producer to final customer with the benefits of adding value, maximizing profitability through efficiencies, and achieving customer satisfaction" (Stock & Boyer, 2009).

SCM'S overall purpose is to create customer value. Customers demand improvements in products and services with low prices (Min et al., 2019). This multiplicity of goals has caused organizations to invest in older and emergent technologies such as the Internet of Things (IoT), Big Data, Artificial Intelligence (AI), and blockchain so that they can improve the management of their supply chains.

The Covid-19 disruption of global supply chains has caused greater investigation into crises such as natural disasters, wars, and how they can affect supply chain resilience and viability (El Baz & Ruel, 2021; Ruel & El Baz, 2021; Ivanov, 2021). Companies looking for establishing lean supply chains (using single sources and suppliers, for example) are rethinking SC design. SCM continues evolving from needs and changes in markets and technological changes.

Supply chains need to be efficient, responsive, agile, resilient, responsible, innovative, and adaptable, and that digital transformation will require integrated supply chains through new technologies and digital platforms (Min et al., 2019). Meeting these goals is not easy and will only be possible from partnerships and collaboration between supply chain members.

As supply chains constantly change and evolve because of technological advances, customers and markets require major organizational evolution as well. Personnel working across supply chain functions will need to acquire new and improved skills, as their assignments and challenges in managing supply chains change and grow. Despite the robust and diverse body of research, and knowledge about SCM competencies, they are still fragmented and inconclusive, as research and definitions on the subject vary in scope and meaning (Derwik & Hellström, 2017).

Shifting the focus, we recognize that supply chains in emerging markets are more vulnerable and prone to problems. They lack advanced technology, financial stability, adequate strategies, transport infrastructure problems, and poorer efficiency of rail and port services – see Global Competitiveness Report 2019 – (World Economic Forum, 2022) – to name a few pernicious difficulties they face. Understanding the current state of the literature of SCM in Latin America can help understand the issues and propose future directions or developments for Latin American practice and research in SCM.

## 3 Supply Chain Management in Latin America

To analyze the state of the art of SCM practice and research in Latin America, we turn to the research literature. Specifically, we looked into the broad-based Scopus database using the keywords of "supply chain management" and "Latin America," "supply chain management" and "South America," and "supply chain management" and Latin American Country Name (the country names were keywords – see Table 1).

We found 34 published studies. Their contents were evaluated, and we now report some of the findings.

### 3.1 Description of Latin America Supply Chain Management Studies

We first overview the various countries of the Latin American SCM studies, cooperation (Universities and authors), methodologies used, and the industrial sectors of the studies (see Sect. 3.1). Mainly, study results and challenges of these studies are then analyzed (see Sect. 3.2).

**Table 1** Search terms and keywords used

| String | Field | Type document | Language | Time |
|---|---|---|---|---|
| "Supply chain" and "Latin America" | Title, abstract keywords | Article, review and article in press | All | All |
| "Supply chain" and "South America" | | | | |
| "Supply chain" and Argentina | | | | |
| "Supply chain" and Bolivia | | | | |
| "Supply chain" and Brazil | | | | |
| . . .and so on | | | | |
| SCM and "Latin America" | | | | |
| SCM and "South America" | | | | |
| SCM and Argentina | | | | |
| SCM and Bolivia | | | | |
| SCM and Brazil | | | | |
| . . .and so on | | | | |

## Country

This category identifies the Latin American countries in which the SCM studies have been conducted. According to Fig. 1, 70.59% of the surveys were conducted in Brazil (24), 8.82% in Mexico (3), and 25.88% in Colombia, and other country studies with one study each includes the following: Ecuador, Cuba, Haiti, and Argentina (2.94%). Clearly, Brazil dominates and this makes sense since it is the largest country in Latin America (Fig. 1).

## Cooperation

We now consider author and university participation and cooperation. Only eight (25%) studies had international partnerships. Brazil was again the most represented cooperating country. São Paulo State University (Brazil) is the university investigating this area the most with six (18.75%) publications. Professor Ana Beatriz Lopes de Sousa Jabbour is the author or coauthor of the articles, therefore the most prominent author in Latin America.

## Research Type

The articles were also classified according to the research type (Fig. 2). The intention was to identify which methods are being used the most in Latin America: quantitative, qualitative, quantitative, qualitative (mixed), or others. It was found that

**Fig. 1** Latin American countries in which the SCM studies have been conducted

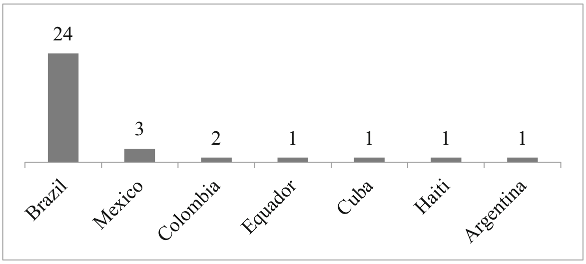
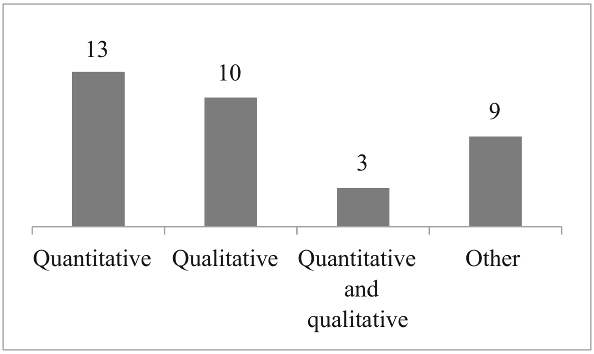


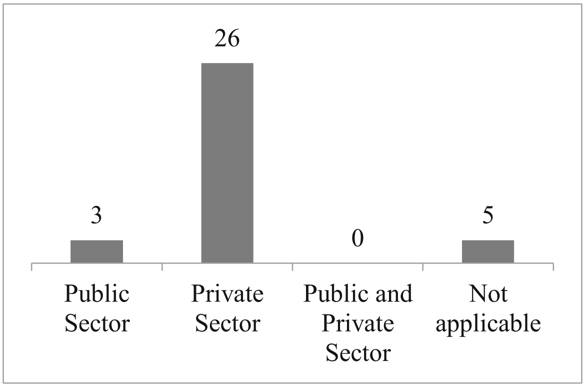

**Fig. 2** Research type



38.23% of these studies used quantitative research, 29.41% employed qualitative research, and only 8.82% used mixed methodologies (quantitative and qualitative).

**Sector**

The 34 articles can be separated into public, private, public, and private (altogether) sectors. They were not applicable when the study was not conducted in a specific sector, e.g., a literature review is also a category. The results indicated that more than half of the studies, 76.47%, were conducted in the private sector, 8.82% public sector, and 14.70% not applicable.




## 3.2 Focus and Main Results of Research

Based on the research methodology adopted, the first article involving SCM in Latin America was published in 1997 by the authors Chiappe and Herrero (1997), and addressed SCM in Argentina's food industry. The main objective of the article was to analyze the drives and trends emerging at the time.

The second study, published in 2011, appeared 14 years later and highlights and reaffirms the importance of supply chain management in the public sector to control current spending. The authors Tridapolli, Fernandes, and Machado (2011) develop a theoretical operational model of supply chain management for the government with an emphasis on government procurement using information technology techniques, process management, and e-commerce and affirm that the management of public spending in Brazil should be addressed to all stages of the supply chain of goods and services, from the survey of needs to the final use. Also in 2011, Machline (2011) developed a conceptual article demonstrating the evolution of concepts from the era of transportation to the era of supply networks, through the era of business logistics and the era of the supply chain.

de Sousa Jabbour et al. (2012) analyzes the level of adoption of SCM practices in the electronics sector in Brazil and identifies the management and information technology actions that have been implemented to support the adoption of these practices. The authors conclude that Enterprise Resources Planning (ERP), workshop with customers, Electronic Data Interchange (EDI), workshop with customers, and the use of electronic kanban are practices commonly used to support SCM practices.

The article is entitled Factors affecting the adoption of green supply chain management practices in Brazil: Empirical evidence by the authors de Sousa Jabbour et al. (2013) identifies and analyzes the factors that affect the adoption of green supply chain management (GSCM) practices in the Brazilian electronics sector. Among their findings, the authors mentioned that the size of the company, its previous experience with environmental management systems, and the use of dangerous inputs are correlated with the adoption of GSCM practices. In addition to this chapter, the article by Jabbour et al. (2013) entitled green supply chain management in local and multinational high-tech companies located in Brazil sought to analyze how GSCM practices are being adopted by high-tech companies in Brazil and identified that the most adopted practices are internal environmental management, investment recovery, and reverse logistics. Additionally, they report that Brazilian environmental legislation and international policies are driving the adoption of GSCM practices.

Studies involving the theme GSCM were further developed in seven more works:

- Da Rosa et al. (2017) conduct a theoretical survey on GSCM in the manufacturing and agriculture sector and affirm that there is a timid advance in the adoption of GSCM practices in the SCM of Brazilian companies.
- Lopes and Pires (2020), based on the most adopted practices of GSCM around the world, conduct a Delphi study and quantitative research with researchers and professionals from the automotive industry in Brazil to evaluate how these practices are understood. In addition, they identify and evaluate which practices are most adopted (e.g., internal environmental management) and least adopted (collaboration, green purchasing, and life cycle analysis), which most influence the environmental performance of companies (collaboration with suppliers).
- Teixeira et al. (2020) conducted a systematic review of the literature on GSCM in Latin America identifying gaps and suggesting future research agenda.
- Govindan et al. (2013) sought to identify the dependency relationship between GSCM practices in the electronics industry sector from Brazil. The findings conclude that the practice of cooperation with customers for the practice of eco-design is driving other GSCM practices in the sector; in addition, they found that the commitment as GSCM of senior managers and cooperation with customers for cleaner production occupy the highest level.
- Jabbour et al. (2014) conducted a study to verify the relationship between the maturity levels of environmental management (EM) and the adoption of GSCM practices in companies in the electronics sector in Brazil. They report that, in fact, the level of maturity of EM influences the adoption of GSCM practices and that there is coevolution between these variables, that is, the further the EM is

developed in the companies, much more complex are the GSCM practices adopted.

- Stefanelli, Jabbour, and Sousa Jabbour (2014) tested the research hypothesis: "can the adoption of GSCM practices improve the environmental performance of companies (micro, small and medium-sized Brazilian companies supplying inputs for the production of sugarcane and ethanol)"? Its results confirm that the proposed relationship is relevant in the companies studied and that GSCM practices are also being adopted to improve operational issues and the security of operations.
- Finally, de Sousa Jabbour and Souza's article (2015) presented the main barriers to the adoption of GSCM practices in companies in the automotive batteries sector installed in Brazil and discussed how these companies are dealing with these barriers. Its main results indicate that internal barriers "organizational values and factors," "human resources," external barriers, and "suppliers and consumers" are the main barriers to the adoption of GSCM.

Sanches and Lima Jr (2014) conducted a study to investigate the hockey stick phenomenon at the end of the sales period at Brazilian branch of a large multinational in the nondurable consumer goods sector. The results showed that the phenomenon impacted negatively to the long-term financial performance, and that there are policies capable to improving financial performance and proposed ideas to carry out the process of change.

Tesfay, Sakita, and Mawrides (2014) use simulated data (lead time, accidents, number of products shipped, and number of defective products after shipment) of a paint company in Brazil in order to discuss the various ways in which it can approach new markets for its products from the point of view of the supply chain, pointing out criteria and factors that should be considered to select a certain type of carrier, discuss key performance indicators (KPIs) when deciding to hire a logistics provider, and point out criteria to be prioritized in the screening of potential suppliers and critical success factors for the company's paint market in Brazil. For this, some dimensions are taken into account: actual size and market potential, growth and profitability of the market. In addition, the authors use indicators of the Panama Channel expansion, growth of the shipbuilding industry, logistics services, and infrastructure.

The next three articles deal with the theme sustainable supply chain management (SSCM). Van Hoof and Thiell (2014) studied 14 focal companies and 177 small- and medium-sized enterprises belonging to the Mexican Sustainable Supply Program (MSSP) with the objective to highlighting the collaboration capacity as a multidimensional organizational construction in cleaner production (CP) initiatives and propose a framework for the operationalization of this collaboration capacity in SSCM. Thus, the study identified that different levels of supplier collaboration capacity are explained by the organizational characteristics and profiles of their managers, that the collaboration capacity contributes to the implementation of cleaner production, and that few suppliers demonstrate coordination routines to involve external stakeholders.

Silva, Fritz, and Nunes' article (2015) brings a literature review on publications of the theme SSCM in Brazil and also applied a questionnaire to experts into the subject. The main objective of the article was to analyze how publications in Brazil are considering the relationship between sustainability and supply chain management. The results indicated that publications have been increasing, that social issues are not the focus of most articles, that the environmental dimension is leading the research on SSCM, and that the focus of publications in Brazil is economic.

The last article published on the theme SSCM deals with solid waste management in the largest Brazilian slum "Rocinha." The authors Azevedo, Scavarda, and Caiado (2019) proposed a framework for solid waste management on the perspective of SSCM in slum areas demonstrating actions supported by SSCM enablers in a real-world, complex, and chaotic scenario.

To develop a simple electronic system capable of managing a pharmacy's supply chain in a hospital in Haiti, Holm, Rudis, and Wilson (2015) propose a collaborative project to build a computerized software system to track the acquisition, storage, distribution, and use of medicines in order to optimize the availability of medicines and reduce their shortage.

Based on the research criteria adopted, Pires (2015) presents the first article that deals with the state of the art of the SCM theme in Brazil. The goal was to present to the public a broad overview of the situation of the SCM disseminating knowledge about fundamental aspects that characterize and influence it. Briefly, the article points out several positive aspects that Brazil has for the success of the SCM, while citing negative aspects that should receive attention that most often are the responsibility of the Brazilian government.

Ruiz-Torres, Mahmoodi, and Ayala-Cruz (2012) present a literature review on SCM in Latin America. Among their main findings, they show that the supply chains of many companies in Latin America have numerous internal vulnerabilities that can make it difficult for them to participate in global markets. Among the main factors, scholars point to economic integration, political risks, social concerns, geographic obstacles, inadequate infrastructure, inefficient logistics networks, and poor relations with suppliers as the region's main challenges.

López-Milán and Pià-Aragonés' academic work (2015) discussed the problem of planning the harvest, transport, and delivery for the management of the sugarcane supply chain in Cuba and proposed a model for optimization incorporated into a decision support system. The idea is to minimize transport costs and ensure the supply of sugarcane.

De Mattos and Laurindo (2016) conducted a study (literature review and cluster analysis) with companies in Brazil to analyze the application of collaborative tools in the supply chain and verify whether managers identified performance improvements in the group of companies that apply them. In fact, the authors conclude that managers of companies with more significant collaborative profile have different perceptions about performance and demonstrate the impact of collaboration technologies on the integration of SCM, and the importance of working on internal and external integration based on information and electronic connectivity for better coordination of processes and activities within and between organizations.

Colin et al. (2016) conducted a survey with managers of 288 Manufacturing SMEs in Mexico to analyze the relationship between information technologies (ITC), strategies, and SCM. The results of this research indicate the following: (i) Strategies and ITCs have an impact on the performance of SCM; (ii) more than one-third of companies (36%) have defensive strategies; (iii) the ITCs impact on the quality control of supplier products and services and on the quality of customer service; and (iv) companies that focus on the development of strategies have important intentions in favor of new developments of opportunities and know how to face important challenges to stay in the market.

Viana and Sousa-Filho (2017) investigated, through multiple case studies in the textile, footwear, and food industries in Brazil, the SCM role in relational competitive advantage. Among the contributions of the article, the authors highlight the application of RBT theory to understand how relationships and CMS may contribute to the relational competitive advantage, and the need to develop relational resources and capacities that are aligned to the competitive positioning of companies and allow the exploration of competitive advantages.

Tanco et al. (2018) carry out a bibliometric analysis with the aim of discussing the contribution of Latin American researchers in the area of SCM. Furthermore, the authors raise, together with Latin American researchers and consultants, what would be the main difficulties that cause the greatest negative impacts in the field of SCM in Latin America. They conclude that there are five main areas that should be the subject of further investigation: SCM for small firms, use of data-driven and emerging technologies to reduce bureaucracy and customs paperwork, establishment of priorities for investment in logistics infrastructure, implementation of innovative solutions for urban logistics and last mile operations, and finally strengthening human capital and needed skills over SC in Latin America.

Roque Júnior, Frederic, and Costa (2019) developed a case study in a Brazilian biotechnology company (molecular biology) with the main purpose of showing the level of maturity and complexity of the SCM and the relationship between them. In addition to establishing the dimensions of the company's SCM maturity, they conclude that there is a clear relationship between the maturity levels of the SCM and its complexity.

Aldana-Bernal and Bernal-Torres' academic work (2019) involved a study from 232 companies of the several sizes, and economic sectors in Colombia with the objective of analyzing the relationship between social capital (SC) and the integration of supply chain management (SCI) processes. The results indicate a significant relationship between CS and SCI, which indicates that soft elements (behavioral factors), and specifically those of social capital, are key factors for the development of organizational functions and for the strengthening of interorganizational integration.

The article by Campos et al. (2019) aims to analyze the competencies of professionals in SCM in the medium supermarket sector in Brazil with the idea of broadening the understanding about the importance and use of skills in business development. For so much, the authors collected data from 60 managers and 34 supermarkets and identified that the ethical and moral posture followed, respectively, by leadership, relationship management, creative problem solving, communication, budget and cost control, and information technology which are considered the most important. In addition, they point out that there is a low use of specific SCM competencies in the sample studied and these companies do not focus on external relations, internally. However, these companies do not put logistics as a business strategy. The authors also suggest that a focus on external relations would require a stronger approach to developing competencies related to ECR (Engineering Change Request), and skills to maintain relationships with suppliers aiming at good demand, inventory, and purchasing management in order to put customer needs ahead of operational concerns.

Peña, Livisaca, and Siguenza-Gusman (2020) lead a systematic review of blockchain literature on food supply chain management in Ecuador demonstrating its main contributions and potential benefits. In their results, they point out that only two works on blockchain were developed in Ecuador, and there is no study (in Ecuador) on the joint use of IoT (Internet of Things) and blockchain technologies, which can harm SCM.

Reis, Minerbo, and Miguel (2021) developed a survey with 239 logistics/SCM professionals to raise the skills required for SCM professionals in Brazil. The authors found eight main competencies in this order: logistics and distribution skills, knowledge in negotiations and purchases, technical and specific expertise, analytical skills, behavioral skills, awareness of business dynamics, expertise in systems and processes, and knowledge about other areas.

Lejarza, Pistikopoulos, and Baldea (2021), in their academic work, based on information on storage and transportation conditions, presented a decision-making framework that mitigates losses in the food chain-balancing stock deterioration, and the energy use to refrigerate all the food which come out from Mexico and are transported to the United States.

Patrucco et al. (2022) analyze how the skills and competencies of SC employees, their external network of relationships, their job satisfaction, and the company's investments in training are related to the results of SC growth. The results indicate that a broad professional network of relationships contributes to increasing the skills and competencies of SC professionals, which, in turn, impact job satisfaction and SC performance, reinforcing the importance of investing in employee training to obtain better competitiveness in SC.

Finally, the last study analyzed, Ferreira and Marques (2022), demonstrates that cultural and infrastructure peculiarities in Brazil create barriers to the collaboration and integration of supply chains, which may be hindering the country's insertion in global supply chains, and require attention of the researchers.

## 4 Discussions About the State of Art Concerning the SCM Subject in Latin America and Recommendations for Further Future Research

Overall, it is clear that few studies exist on SCM in Latin America. This is surprising given that Latin America is composed of 20 countries. Even much more concerning is that from the 34 studies, 24 studies (70.58%) were developed in a single country, Brazil, demonstrating that, in fact, Latin America is outside the global discussion on SCM. Few researchers in Latin America have been interested in the subject which is very harmful to the region – especially given globalization of the supply chain is more critical now.

A large number of publications have occurred between Brazilian authors and universities, including with regard to international partnerships. However, there are still few international partnerships involving authors from Latin American countries and even fewer partnerships when considering authors from Latin America and other parts of the world.

Most studies addressed either quantitative (38.23%) or qualitative (29.41%) research, separately. Few studies have used mixed methodologies, e.g., qualitative and quantitative at the same time. Research using mixed methodologies are important because they can be complementary and important to filling gaps about SCM in Latin America.

Another very interesting point of the research on SCM in Latin America is that only 8.82% of the research was developed in the public sector, that is, the vast majority of studies were developed in the private sector (76.47%). In this context, we recommend more studies are needed in the public sector. Given that only 34 papers on SCM in Latin America were found in one of the most reputable databases worldwide, researchers from Latin America need to devote themselves much more to developing cutting-edge research on SCM (e.g., through partnerships). Some of this can include special issues in flagship supply chain journals on the topic SCM. Special issues/call for papers contemplating SCM in Latin America can greatly increase the number of articles, but understanding the need for these types of studies is critical.

Therefore, according to our results, the research on SCM in Latin America lacks studies, especially with regard to its dissemination in journals indexed to important international databases. This further damages the development of the subject, therefore a great challenge for researchers in the area to change these statistics.

Continuing, Table 2 summarizes the 34 studies (see Sect. 3.2) found in the literature and presents the main challenges highlighted by the authors. In Table 1, we tried to create group studies that had similar subjects to facilitate reading and understanding.

From Table 2, it is observed that there is much to advance. First, almost 40% of the studies deal with the themes GSCM (nine papers) and SSCM (three papers) and only 22 studies address some subject related to SCM. Considering the several decades of development of the SCM theme around the world, it is clear that Latin America is out of the world discussion, and even on more recent topics related to the supply chain (e.g., GSCM and SSCM mentioned above) there is still little research

**Table 2** Brief summary of the 34 articles on SCM in Latin America

| Authors | Title | Summary | Challenges reported in these studies analyzed and/or pointed out by the authors of this chapter |
|---|---|---|---|
| Sánchez Chiappe and Angel Herrero (1997) | The status of supply chain management in Argentina's food industry | The authors analyzed the drives and emerging trends on SCM in Argentina's food industry | – |
| Tridapalli, Fernandes, and Machado (2011) | Supply chain management for the public sector: an alternative for the expenditure control in Brazil | The authors do a link between SCM and current spending in the public sector | Lack of studies on SCM in the public sector in Latin America |
| Machline (2011) | Five decades of business logistics and supply chain management in Brazil | Develops a conceptual article on the evolution of terms until it reaches supply chain management | – |
| De Sousa Jabbour, Alves Filho, Noronha Viana, and Chiappetta Jabbour (2012) | Supply chain management practices in the electro-electronics sector in Brazil: evolutionary approach, information technology adoption, and management actions | They identify the management and information technology actions that have supported the adoption of SCM practices in the Brazilian electronics sector, as well as the level of adoption of these practices | Identify and analyze all the technologies (blockchain, IoT, etc.) which have been adopted by companies in Latin America, and how they have contributed to sustainable, resilient, and innovative supply chains |
| de Sousa Jabbour, Jabbour, Govindan, Kannan, Salgado, and Zanon (2013) | Factors affecting the adoption of green supply chain management practices in Brazil: empirical evidence | Identify the factors that affect the adoption of GSCM practices in the Brazilian electronics sector | Identify the main players who may be pushing the adoption of GSCM/SSCM practices in companies located in Brazil, and understand the role of the focal company (or leading companies) as encouraging/facilitating the adoption of GSCM/SSCM practices |
| de Sousa Jabbour, De Souza | Green supply chain management in local and multinational high-tech companies located in Brazil | They analyzed how GSCM practices have been adopted and which are the most | Conducting studies that try to relate the adoption of SSCM and GSCM practices with better risk management in supply |

(continued)

**Table 2** (continued)

| Authors | Title | Summary | Challenges reported in these studies analyzed and/or pointed out by the authors of this chapter |
|---|---|---|---|
| Azevedo, Arantes, and Jabbour (2013) | | adopted in multinational high-tech companies located in Brazil | chains, aiming to make them more robust and resilient |
| da Rosa, Onófrio, Nicola, and Noranha (2017) | Green supply chain management: analysis of scientific production on the green manufacturing and agriculture in Brazil | The authors make a theoretical survey to understand the progress of GSCM practices in the Brazilian manufacture and agriculture sector | Identify the low level of adoption of GSCM practices in Latin America countries |
| Lopes and Pires (2020) | Green supply chain management in the automotive industry: a study in Brazil | The authors led three surveys: The first is to understand the knowledge of professionals and researchers about GSCM in the Brazilian automotive sector; second, they identify which practices are more and less adopted; and third, point out which GSCM practices most influence the environmental performance of these companies | Understand why certain practices, for example, product lifecycle analysis, are generally the least adopted in localized Latin American companies |
| Teixeira, Moraes, Stefanelli, de Oliveira, Teixeira, and de Souza Freitas (2020) | Green supply chain management in Latin America: systematic literature review and future directions | The study surveys the state-of-the-art GSCM subject in Latin America to later discuss a research agenda for further future studies | Integrate research agendas (Circular Economy, GSCM, SSCM, Green Human Resource Management (GHRM, etc.) with SCM<br>Need to develop articles on the following: relevance and benefits, motivations and pressures to implement SCM/SSCM/GSCM, barriers to implement SCM/SSCM/GSCM, and competitive advantage, SCM/SSCM/GSCM dynamic implementation, and SCM/SSCM/GSCM KPIs |

| | | | |
|---|---|---|---|
| Govindan, Kannan, Mathiyazhagan, Jabbour, and Jabbour (2013) | Analyzing green supply chain management practices in Brazil's electrical/electronics industry using interpretive structural modeling | This paper identifies the dependency relationship between GSCM practices in the electrical/electronics industry in Brazil | Identifying and analyzing which GSCM practices can most influence other GSCM practices and how this relationship occurs |
| Jabbour, Jabbour, Govindan, Kannan, and Arantes (2014) | Mixed methodology to analyze the relationship between maturity of environmental management and the adoption of green supply chain management in Brazil | The aim of this study was to identify the relationship between maturity of environmental management and GSCM practices in the Brazilian electronic sector | Identify which environmental management practices most influence the GSCM practices, and how this relationship occurs |
| Stefanelli, Jabbour, and de Sousa Jabbour (2014) | Green supply chain management and environmental performance of firms in the bioenergy sector in Brazil: an exploratory survey | Empirical study that sought to identify whether GSCM practices are influencing the environmental performance of micro and small companies supplying productive inputs for the sugarcane and ethanol sector in Brazil | – |
| De Sousa Jabbour and De Souza (2015) | Opportunities and challenges for dealing with barriers to the adoption of green supply chain management practices: guidelines based on multiple-case studies in Brazil | The authors present the most prominent barriers to the adoption of GSCM practices in the automotive battery companies sector in Brazil | Better understanding the barriers to the implementation of GSCM practices in micro-, small-, and medium-sized enterprises in various industrial sectors |
| Sanches and Lima (2014) | Hockey stick phenomenon: supply chain management challenge in Brazil | The study investigates the hockey stick phenomenon that occurs at the end of the sales period of a Brazilian subsidiary of a multinational in the durable consumer goods sector in order to understand and eliminate/reduce the impact, as well as its causes | Perform comparative studies between companies and similar sectors for better understanding about the Hockey stick phenomenon in Latin America |
| Tesfay, Sakita, and Mawrides (2014) | Developing a new market strategy from supply chain management perspective: a case of Jotun in Brazil | This academic paper aimed to discuss and present the ways in which a paint manufacturing company in Brazil can use to achieve new markets demonstrating the | – |

(continued)

**Table 2** (continued)

| Authors | Title | Summary | Challenges reported in these studies analyzed and/or pointed out by the authors of this chapter |
|---|---|---|---|
| | | criteria and factors to be considered in the choice of the carrier and presenting indicators capable to guide the company in hiring a logistics provider | |
| Van Hoof and Thiell (2014) | Collaboration capacity for sustainable supply chain management: small- and medium-sized enterprises in Mexico | The authors evaluate the capacity for collaboration between companies belonging to the Mexican sustainable supply program and highlight that capacity is a multidimensional organizational construction capable of collaborating with the implementation of cleaner production initiatives | Study needs to analyze organizations' ability to collaborate in supply chains, and the results achieved or that can be achieved |
| Silva, Fritz, and Nunes (2015) | Sustainability and supply chain management: publications in Brazil | This study led a survey of the literature about SSCM and performs the application of a questionnaire with specialists to understand the relationship between sustainability and supply chain management in Brazil | SSCM research needs to be developed in Brazil, as it is still in the beginning<br>More emphasis on studies involving the social dimension |
| Azevedo, Scavarda, and Caiado (2019) | Urban solid waste management in developing countries from the sustainable supply chain management perspective: a case study of Brazil's largest slum | The authors propose a framework for the management of solid waste in slum areas | Needs of global industries in partnership with the community and governments to assume their responsibilities and work in the form of partnerships for better urban waste management |
| Holm, Rudis, and Wilson (2015) | Medication supply chain management through implementation of a hospital pharmacy-computerized inventory program in Haiti | The construction of a system (software) is proposed for the management of pharmacy supplies in a hospital in Haiti | – |

| | | | |
|---|---|---|---|
| Pires (2015) | The current state of supply chain management in Brazil | It is presenting the state of the art of the theme SCM in Brazil, and the positive and negative aspects are pointed out | Infrastructure problems (telecommunications and transport),<br>fiscal system,<br>geographic localization,<br>lack of skilled labor, and environmental sustainability |
| Ruiz-Torres, Mahmoodi, and Ayaka-Cruz (2012) | Supply chain management research in Latin America: a review | The authors present a literature review on SCM research in Latin America and point out the main factors that hinder its development | Economic integration, political risks, social concerns, geographic obstacles,<br>inadequate infrastructure,<br>inefficient logistics networks, and<br>poor relations with suppliers |
| López-Milán and Plà-Aragonés (2015) | Optimization of the supply chain management of sugarcane in Cuba | The authors propose a model for optimizing the harvest, transport, and delivery of sugarcane in Cuba | Develop further studies with the objective of optimizing the harvesting and transport of sugarcane, and/or other crops, for example, in Brazil<br>Need for further studies to identify and understand the sustainability practices adopted by sugarcane and ethanol companies in Latin America and how these practices can benefit the circular economy |
| de Mattos and Laurindo (2016) | Electronic collaboration in supply chain management: a study of manufacturing companies in Brazil | This study approaches to a literature review and cluster analysis in order to verify the use of collaborative tools and their role in the group of companies that apply them | Identify and understand communication, coordination, and collaboration practices, including the use of electronic technologies which are being put into practice by companies from various sectors in Latin America |
| Colin, Galindo, and Hernández (2016) | Information and communication technologies, strategy, and supply chain management in manufacturing SMEs of Aguascalientes, México | This research with managers of 288 manufacturing SMEs in Mexico analyzes the relationship between information technologies, strategies, and SCM | – |

(continued)

**Table 2** (continued)

| Authors | Title | Summary | Challenges reported in these studies analyzed and/or pointed out by the authors of this chapter |
|---|---|---|---|
| Viana and De Sousa-Filho (2017) | Supply chain management in traditional industries in Brazil: a relational view | Led a study of multiple cases with companies in the textile, footwear, and food sector in Brazil with the goal to investigating the role of SCM in relational competitive advantage | Develop relational resources and capabilities that are aligned with the competitive positioning of companies and that, in fact, provide competitive advantages |
| Tanco et al. (2018) | Supply chain management in Latin America: current research and future directions | The authors point out the five main areas that should be the subject of investigations | SCM for small firms, use of data-driven and emerging technologies to reduce bureaucracy and customs paperwork, establishment of priorities for investment in logistics infrastructure, implementation of innovative solutions for urban logistics and last mile operations, and strengthening human capital and needed skills over SC in Latin America |
| Roque Júnior, Frederico, and Costa (2019) | Supply chain management maturity and complexity: findings from a case study at a health biotechnology company in Brazil | The authors identified and analyzed the level of maturity and complexity of the SCM in a Brazilian biotechnology company and the relationship between them | Which are the practices that make it the maturity-level progress of SCM in Latin America |
| Aldana-Bernal and Bernal-Torres (2019) | Social capital and the integration of processes in the supply chain management in the real sector in Colombia | This study analyzes the relationship between share capital and the integration of processes in the SCM from 232 companies of various sizes and sectors in Colombia | Which are the key factors (behavioral, social capital) that can most contribute to the planning, coordination, and integration of SCM in Latin American countries |
| Campos, Lima, Silva, and Fernandes (2019) | Professional competencies in supply chain management in the midsized supermarket sector in Brazil | The authors analyze the competencies from the SCM professionals for the medium supermarket sector in Brazil | Need to know the main competencies of SCM professionals aligning to these skills with the customer needs |

| | | | |
|---|---|---|---|
| Peña, Llivisaca, and Siguenza-Guzman (2020) | Blockchain and its potential applications in food supply chain management in Ecuador | This paper approaches the literature review on blockchain in the food SCM in Ecuador | Need for more research using blockchain and Iot in food SCM in Ecuador technologies |
| Reis, Minerbo, and Miguel (2021) | SCM professionals' competencies in Brazil | This study raises (with 239 professionals in the logistics/SCM area) what are the main competencies required for SCM professionals in Brazil | Provide specific skills and knowledge, according to their area of expertise, professionals in the area of SCM; inefficient use of time (professionals), bureaucratic demands, and complex tax legislation |
| Lejarza, Pistikopoulos, and Baldea (2021) | A scalable real-time solution strategy for supply chain management of fresh produce: a Mexico-to-United States cross-border study | The authors present a framework for decision-making to reduce losses and deterioration of inventory and energy use for the cooling of food that depart from Mexico to the United States | Inefficiencies of CMS (storage and transport – temperature, humidity issues, etc.) that lead to food deterioration |
| Ferreira and Marques (2022) | Cultural traits, infrastructure, and feedback mechanisms as barriers to supply chain management in Brazil | This study demonstrates that peculiar aspects of culture and infrastructure in Brazil emerge as barriers to collaboration and integration between companies, harming the insertion of the country in global supply chains | Infrastructure that is not modernized (dependence on roads)<br>Shortage of qualified professionals<br>Excessive bureaucracy<br>Regulatory complexity |
| Patrucco et al. (2022) | Can you grow your supply chain without skills? The role of human resource management for better supply chain management in Latin America | The authors analyze how the skills and competencies of SC employees, their external network of relationships, their job satisfaction, and the company's investments in training are related to the results of SC growth | – |

and most of them have been developed in organizations located in Brazil. We have not found any work that addresses to circular supply chains.

Regarding the challenges for SCM in Latin America, there is a large avenue with numerous intersections to be explored (see some tips in the last column to the right of Table 1), and taking into account the current issues already discussed in the first sections of this chapter, research that explores the following topics in the context of Latin America is mainly suggested:

- Social and environmental demands and their implications for SCM
- Technological changes (e.g., Internet of Things (IoT), Big Data, Artificial Intelligence (AI), and blockchain) and its implications for SCM
- Infrastructure issues and fiscal complexity
- Bureaucracy
- Viability and resilience of SC
- Provide SC professionals with competencies and skills that follow the social, environmental, and technological changes mentioned above
- And, not at least, studies on behavioral skills needed aiming at good relationships to enable better planning, integration, and coordination of SC

## 5 Final Considerations

The main objective of this chapter was to integrate and systematize the literature on SCM in the Latin American context presenting the main research, challenges, and concerns. Furthermore, we propose a future research agenda to guide and encourage cutting-edge research on SCM in Latin America. Studies of this nature categorize what has already been published on the subject and suggest future research agendas capable of guiding academics and professionals interested in work in this field of research (Teixeira et al., 2020). Therefore, the main role of this chapter is to demonstrate the existing research gaps on SCM in Latin America and the main challenges faced for its development, while directing academics, professionals, organizations, and governments to develop work/actions that can prioritize and lap Latin America in the global discussion on SCM.

We hope that this chapter will be able to empower readers with important information about the research gaps in Latin America and the need for further studies on infrastructure issues, market changes, technological changes, and the new skills of SC professionals in the search for better control, integration, planning, and coordination of SCs in order to provide greater value to customers, and competitive advantages for organizations and their supply chains.

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# Entrepreneurship in Supply Chain Management

Yiming Zhuang

## Contents



**Abstract**

Research at the interface of supply chain management and entrepreneurship is relatively new and scattered in its focus. However, researchers and practitioners have increasingly been directing their attention to this area. With the aim of capturing these emerging developments, this book chapter focuses on the articles exploring the interface of supply chain management and entrepreneurship. We first present an overview of the current developments in this stream of research to offer a better understanding of the field. Based on the review, we consider multiple directions for future development.

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**Keywords**

Entrepreneurship · Supply chain · Interface study · Logistics

## 1 Introduction

Supply chain management (SCM), as defined by Mentzer et al. (2001), involves multiple functions of a firm. Due to the cross-functional nature of SCM, studies on the interface of SCM and other fields have been quite common in the literature (Ketchen & Giunipero, 2004). For instance, marketing is a domain that is frequently linked to SCM, and the term "demand chain management" has been proposed based on the integration of marketing and SCM (Jüttner et al., 2007). The interface of supply chain issues and finance has recently been studied under the umbrella of supply chain finance (Gelsomino et al., 2016). Firms also commonly adopt information systems to better support their supply chain activities. For example, Jayaram et al. (2000), studies have been conducted on the effects of information system infrastructure on supply chain time performance. The intersection of strategic management and SCM has been explored in the extant literature through the application of strategic management theories, such as the resource-based view, knowledge-based view, and institutional theory (Ketchen & Giunipero, 2004). Consistent with the previous efforts conducted in other fields, we in this chapter take a look at the interface between SCM and entrepreneurship.

Entrepreneurship, in general, is defined as "the process whereby an individual or a group of individuals use organized efforts and means to pursue opportunities to create value and grow by fulfilling wants and needs through innovation and uniqueness, no matter what resources are currently controlled" (Coulter, 2001). The extensive benefits of entrepreneurship create problems that are of interest to researchers from various academic disciplines and fields. Like SCM, the cross-disciplinary nature of entrepreneurship also offers great opportunities to study entrepreneurial phenomena through different lenses. For instance, strategic entrepreneurship brings together unique perspectives from strategic management and entrepreneurship (Ketchen & Craighead, 2020). In addition, the integration of marketing and entrepreneurship has been widely explored in the extant literature (Edwards et al., 2020). Phan and Chambers (2013) have even called for theoretical advancement in entrepreneurship research from the perspective of operations management. Therefore, reviewing the efforts to examine the interface of SCM and entrepreneurship benefits not only the SCM field but also other entrepreneurship fields. Both SCM and entrepreneurship problems are cross-disciplinary in nature and need to be taken into consideration simultaneously in decision-making.

This chapter looks at the interface of entrepreneurship and SCM research in the literature. Scholars have outlined a number of research opportunities at the interface of SCM and entrepreneurship (Ketchen & Craighead, 2020). Specifically, Cortes et al. (2021) recently conducted a review of the usage of entrepreneurial orientation in SCM. Our chapter extends their review by covering additional aspects of entrepreneurship, instead of only focusing on entrepreneurial orientation. In another review on entrepreneurship research, Ireland and Webb (2007) conducted a review including accounting, anthropology, economics, finance, management, marketing, operations management, political science, psychology, and sociology in relation to SCM. This chapter offers a more recent overview of the research on the interface between SCM and entrepreneurship.

After synthesizing the existing research on entrepreneurship in SCM, we propose multiple directions for future research. We believe integrating entrepreneurship-related concepts into SCM can bring novel perspectives to both scholars and practitioners. Both entrepreneurship and SCM are essential components of the economy and have a huge effect on society. This chapter also identifies some managerial implications for managers and policymakers.

Accordingly, the rest of this chapter is structured as follows. We begin with a brief description of SCM and entrepreneurship, followed by a presentation of various areas of SCM related to entrepreneurship. We conclude the paper with a discussion and suggestions for future research.

## 2 Areas of SCM Related to Entrepreneurship

The studies with interface of SCM and entrepreneurship cover the various topics from the upstream to the downstream of the supply chain. To better organize these topics, we cluster reviewed papers into five categories depending on the main focus: strategic issues, upstream management, operational issues, and logistics and transportation. Note that the scope of our chapter considers SCM activities in small and medium enterprises (SMEs) for multiple reasons. First, as stated by Olusegun (2012, p. 487), they argue that "entrepreneurship is a process leading to the creation of SMEs." SMEs are commonly entrepreneurial in nature. Second, this review especially followed the protocol of the study by Olanrewaju et al. (2020), who conducted an extensive review of studies on the interface of social media and entrepreneurship. SME-related terms are included in their review. Third, a substantive proportion of SMEs is start-up companies, which are founded by entrepreneurs to grow into scalable businesses (Katila et al., 2012). Fourth, the research regarding the intersection of entrepreneurship and SCM is at a very early stage. Including SME can expand the scope of this review and cover more relevant studies.

### 2.1 Strategic Issues

This stream of research includes strategic issues regarding the intersection between SCM and entrepreneurship. Strategic issues focus on the supply-chain-related decisions that are strategically important to firms. Multiple strategic issues are discussed below.

## Sustainability in Supply Chains

As suggested by Elkington (1998), organizational sustainability includes three elements: the natural environment, society, and economic performance. Due to the importance of sustainability, it has become a strategic issue in many firms. There are multiple studies included in this stream of research. Studies cover either only one element of sustainability or all three elements. There are studies that focus on environmental sustainability by examining the antecedents of environmental practices (Centobelli et al., 2021) or supply chain ecosystem in startups (Wagner, 2021). In addition, a study has examined the influence of entrepreneurial orientation on firms' adoption of social sustainability supply chain practices (Marshall et al., 2015). Studies further address sustainability as a unified construct. Topics vary from voluntary sustainability initiatives (Peters et al., 2011) to sustainable performance and development (Ndubisi et al., 2021). Relevant studies are summarized in Table 1.

## Supply Chain Finance

Supply chain finance refers to "an approach for two or more organisations in a supply chain, including external service providers, to jointly create value through means of planning, steering, and controlling the flow of financial resources on an inter-organisational level" (Hofmann, 2005, p. 3). Adopting financing options such as supply chain finance becomes a strategic issue to firms (Li et al., 2020). Multiple studies fall into this category by studying the implementations of supply chain finance practices such as reverse factoring (Lekkakos & Serrano, 2016) and buyer-backed purchase order financing (Huang et al., 2018). Work has also been extended to explore the role of financial service providers and banks in helping Chinese SMEs to access finance (Song et al., 2018). Relevant studies are summarized in Table 2.

## Supply Chain Capabilities

Supply chain capabilities are defined as "the ability of an organization to use internal and external resources to facilitate supply chain performance" (Rajaguru & Matanda, 2019, p. 304). Various supply chain capabilities, which are strategically important to firms, are also a topic at the nexus of entrepreneurship and SCM discussed in the reviewed papers. Supply chain capabilities can be intra-organizational and inter-organizational. Multiple studies focus on intra-organizational capabilities such as new product development capability (Bolumole et al., 2015) and SCM implantation (Schulze-Ehlers et al., 2014).

Multiple studies examine inter-organizational capabilities. For instance, Hsu et al. (2011) proposed a new concept of entrepreneurial SCM competence, which refers to an SCM capability of discovering entrepreneurial opportunities to promote firm growth. Entrepreneurial SCM competence encompasses multiple dimensions such as Innovation orientation and relational capital skill. Coopetition and knowledge acquisition have been studied to develop capabilities with distributor firms with entrepreneurial orientation in supply chains (Li et al., 2011). In addition, a new concept of supply chain entrepreneurial embeddedness is proposed, which refers to

**Table 1** Relevant studies on sustainability in supply chains with respect to entrepreneurship

| Authors | Title | Theory | Data | Method | Topic |
|---|---|---|---|---|---|
| Peters et al. (2011) | Institutional entrepreneurship capabilities for interorganizational sustainable supply chain strategies | Institutional entrepreneurship theory, resource-based view | Five voluntary sustainability initiatives | Case study | Voluntary sustainability initiatives |
| Marshall et al. (2015) | Going above and beyond: How sustainability culture and entrepreneurial orientation drive social sustainability supply chain practice adoption | Strategic choice theory | 156 firms in Ireland | Survey | Social sustainability supply chain practice |
| Centobelli et al. (2021) | Determinants of the transition towards circular economy in SMEs: A sustainable supply chain management perspective | Planned behavior | 212 SMEs in Europe | Survey | Circular economy |
| Wagner (2021) | Startups in the supply chain ecosystem: An organizing framework and research opportunities | | | Theoretical | Supply chain ecosystem |
| Ndubisi et al. (2021) | Small and medium manufacturing enterprises and Asia's sustainable economic development | | | Theoretical | Sustainable economic development |

large firms' decisions to integrate entrepreneurial business capabilities into supply chains (Ketchen & Craighead, 2021). Relevant studies have been summarized in Table 3.

## Performance Measurement and Management

Multiple studies focus on various types of performance in the supply chain and its measurement. Performance measurement systems play a crucial role in business

**Table 2** Relevant studies on supply chain finance with respect to entrepreneurship

| Authors | Title | Theory | Data | Method | Topic |
|---|---|---|---|---|---|
| Lekkakos and Serrano (2016) | Supply chain finance for small and medium sized enterprises: The case of reverse factoring | | | Math modeling | Reverse factoring |
| Huang et al. (2018) | Supporting small suppliers through buyer-backed purchase order financing | | | Math modeling | Buyer-backed purchase order financing |
| Song et al. (2018) | Financial service providers and banks' role in helping SMEs to access finance | | Three SMEs in China | Case study | Financing |

operations by providing information to make business decisions (Gunasekaran & Kobu, 2007). Performance measurement systems have been linked to different aspects of entrepreneurship such as in various international contexts (Dung et al., 2020; Pešalj et al., 2018). Terjesen et al. (2016) explored the supply chain actions to increase the new ventures' survival chances in Portugal. Relevant studies have been summarized in Table 4.

#### Partnership Development

Building partnerships is an important and strategic component of SCM. Carnovale and Yeniyurt (2014), Carnovale et al. (2016), and Carnovale et al. (2017) explore the role of various types of network structures in the formation of joint ventures in the supply chain. Relevant studies have been summarized in Table 5.

## 2.2 Upstream Management

There is a stream of studies that focus on firm upstream activities in supply chain management. Multiple topics are included in this category. Three studies focus on the upstream supply chain performance and quality. For instance, Ren et al. (2010) investigated the factors in determining the quality of outsourcing partnerships in China. The antecedent of supplier performance in India is investigated by Mani et al. (2020). Essuman et al. (2021) examined the influence of purchasing recognition on purchasing quality performance. Studies under this category focus on public procurement. Specifically, Loader (2015) analyzed the challenges faced by SME suppliers in public procurement in the UK. Glas and Eßig (2018) examined the determinants of SME supplier success in public procurement in Germany. There are studies that evaluate knowledge acquisition and innovation in upstream of the supply chain. Specifically, studies have focused on the SMEs' collaborative

**Table 3** Relevant studies on supply chain capabilities with respect to entrepreneurship

| Authors | Title | Theory | Data | Method | Topic |
|---|---|---|---|---|---|
| Hsu et al. (2011) | Entrepreneurial SCM competence and performance of manufacturing SMEs | | 165 suppliers in five ASEAN countries | Survey | Entrepreneurial SCM competence |
| Li et al. (2011) | Co-opetition, distributor's entrepreneurial orientation and manufacturer's knowledge acquisition: Evidence from China | | 225 dyad manufacturer–distributor relationship in China | Survey | Knowledge acquisition |
| Schulze-Ehlers et al. (2014) | Supply chain orientation in SMEs as an attitudinal construct: Conceptual considerations and empirical application to the dairy sector | | 279 SMEs in Germany | Survey | Supply chain orientation |
| Bolumole et al. (2015) | New product development in new ventures: The quest for resources | Signaling theory | 745 NPD projects in the United States | Survey | New product development |
| Ketchen and Craighead (2021) | Toward a theory of supply chain entrepreneurial embeddedness in disrupted and normal states | | | Theoretical | Supply chain entrepreneurial embeddedness |

innovation with suppliers (Benitez et al., 2021). In addition, a study found that external supply knowledge acquisition promotes SME's supply performance in Finland (Kilpi et al., 2018). Additionally, studies have focused on outsourcing in the supply chain. Ren et al. (2011) studied software outsourcing in Chinese SMEs. Bjørgum et al. (2021) examined the sourcing decisions in new ventures in Norway. There are studies that are focused on the new venture suppliers. Zaremba et al. (2016) studied the determinants of new venture suppliers selection. Zaremba et al. (2017) looked at the new venture partnering capability with suppliers in Europe.

**Table 4** Relevant studies on supply chain performance with respect to entrepreneurship

| Authors | Title | Theory | Data | Method | Topic |
|---|---|---|---|---|---|
| Terjesen et al. (2016) | Founded in adversity: Operations-based survival strategies of ventures founded during a recession | | 404 ventures in Portugal | Survey | New ventures survival |
| Pešalj et al. (2018) | The use of management control and performance measurement systems in SMEs: A levers of control perspective | | A small-sized company in the Netherlands | Case study | Performance management |
| Dung et al. (2020) | Entrepreneurial orientation, knowledge acquisition and collaborative performance in Agri-food value-chains in emerging markets | | 233 actors, including farmers, intermediaries, and retailers in Vietnam | Survey | Collaborative performance in supply chain |

**Table 5** Relevant studies on supply chain partnership development with respect to entrepreneurship

| Authors | Title | Theory | Data | Method | Topic |
|---|---|---|---|---|---|
| Carnovale and Yeniyurt (2014) | The role of ego networks in manufacturing joint venture formations | Network theory | 589 joint ventures | Archival | Joint venture formations in supply chain |
| Carnovale et al. (2016) | Bridging structural holes in global manufacturing equity based partnerships: A network analysis of domestic vs. international joint venture formations | Network theory | 1203 joint ventures | Archival | Joint venture formations in supply chain |
| Carnovale et al. (2017) | Network connectedness in vertical and horizontal manufacturing joint venture formations: A power perspective | Network theory | 1203 joint ventures | Archival | Joint venture formations in supply chain |

Kurpjuweit et al. (2021) investigated how to select startup firms as suppliers in Germany. All relevant studies are summarized in Table 6.

**Table 6** Relevant studies on upstream management

| Authors | Title | Theory | Data | Method | Topic |
|---|---|---|---|---|---|
| Ren et al. (2010) | Examining the determinants of outsourcing partnership quality in Chinese small- and medium-sized enterprises | | 126 SMEs in China | Survey | Outsourcing partnership quality |
| Ren et al. (2011) | Managing software outsourcing relationships in emerging economies: An empirical study of the Chinese small- and medium-sized enterprises | Transaction cost, theory of institutional framework, and reciprocal action theory | 83 software outsourcing projects of SMEs in China | Survey | Software outsourcing |
| Loader (2015) | SME suppliers and the challenge of public procurement: Evidence revealed by a UK government online feedback facility | | Comments from 252 SME respondents in the UK | Content analysis | Public procurement |
| Zaremba et al. (2016) | Strategic and operational determinants of relationship outcomes with new venture suppliers | | 136 buying firms in Europe | Survey | New venture suppliers selection |
| Zaremba et al. (2017) | New venture partnering capability: An empirical investigation into how buying firms effectively leverage the potential of innovative new ventures | | 14 buyer-supplier dyads in Europe | Case study | New venture partnering capability with suppliers |

(continued)

**Table 6** (continued)

| Authors | Title | Theory | Data | Method | Topic |
|---|---|---|---|---|---|
| Kilpi et al. (2018) | The effect of external supply knowledge acquisition, development activities and organizational status on the supply performance of SMEs | Knowledge-based view | 143 SMEs in Finland | Survey | Supply knowledge acquisition and performance |
| Glas and Eßig (2018) | Factors that influence the success of small and medium-sized suppliers in public procurement: Evidence from a centralized agency in Germany | | 380 contract award files in Germany | Archival | Public procurement |
| Mani et al. (2020) | Supply chain social sustainability in small and medium manufacturing enterprises and firms' performance: Empirical evidence from an emerging Asian economy | | 327 SMEs in India | Survey | Supply chain social sustainability; supplier performance; supply chain performance |
| Essuman et al. (2021) | Does purchasing recognition help or hinder purchasing quality performance in developing market SMEs? Effects of resource conditions | Upper echelons theory | 138 SMEs in Ghana | Survey | Purchasing recognition; purchasing quality performance |

(continued)

**Table 6** (continued)

| Authors | Title | Theory | Data | Method | Topic |
|---|---|---|---|---|---|
| Kurpjuweit et al. (2021) | Selecting Startups as suppliers: A typology of supplier selection archetypes | | 20 buying firms in Germany | Case study | Start-up suppliers selection |
| Benitez et al. (2021) | Industry 4.0 technology provision: The moderating role of supply chain partners to support technology providers | | 77 SMEs in Brazil | Survey | Innovation collaboration with suppliers |
| Bjørgum et al. (2021) | Low power, high ambitions: New ventures developing their first supply chains | | Six hardware start-ups in Norway | Case study | Sourcing decisions |

## 2.3 Operational Issues

Studies also had a major focus on organizational operational issues. Multiple topics are included in this stream of research. These multiple operational issues include:

### Operational Performance

The topics regarding various types of operational performance have been discussed in the extant literature. For instance, Martínez-Caro and Cegarra-Navarro (2010) and Brazhkin (2018) have studies productivity-based performance. Martínez-Caro and Cegarra-Navarro (2010) found postive impact of e-business on SME's capital productivity in the UK. Brazhkin (2018) assessed the labor productivity in a small warehouse. Other studies examine the various antecedents of operational performance such as operational supply chain risk (Chowdhury et al., 2019), innovation quality (Guo et al., 2020), and entrepreneurship orientation (Dubey et al., 2020). All relevant studies are summarized in Table 7.

### Operational Capabilities

Meanwhile, the literature also focuses on the different types of operational capabilities, which refer to "firm-specific sets of skills, processes, and routines, developed within the operations management system, that are regularly used in solving its problems through configuring its operational resources" (Wu et al., 2010).

**Table 7** Relevant studies on operational performance and linkage to entrepreneurship

| Authors | Title | Theory | Data | Method | Topic |
|---|---|---|---|---|---|
| Martínez-Caro and Cegarra-Navarro (2010) | The impact of e-business on capital productivity: An analysis of the UK telecommunications sector | | 132 SMEs in the UK | Survey | Capital productivity |
| Brazhkin (2018) | Outside the box warehousing: When thinking of inputs as outputs makes sense | | 257 days with picking activity in a small warehouse | Archival | Labor productivity |
| Chowdhury et al. (2019) | Operational supply risk mitigation of SME and its impact on operational performance: A social capital perspective | Social capital theory | 485 SMEs in Bangladesh | Survey | Operational supply risk, operational performance |
| Guo et al. (2020) | A paradoxical view of speed and quality on operational outcome: An empirical investigation of innovation in high-tech small and medium-sized enterprises | | 247 SMEs in China | Archival | Operational performance |
| Dubey et al. (2020) | Big data analytics and artificial intelligence pathway to operational performance under the effects of entrepreneurial orientation and environmental dynamism: A study of manufacturing organisations | Dynamic capabilities view; contingency theory | 256 firms in India | Survey | Operational performance |

Specifically, studies investigate the various antecedents and consequences of different operational capabilities. Studies have a focus on the driving factors such as corporate entrepreneurship (Hsu et al., 2014), entrepreneurial orientation (Sahi et al., 2019), and in promoting different operational capabilities, including operations core competency, operational responsiveness, and operational ambidexterity respectively. Other studies explored the performance-related outcomes of different operational capabilities such as manufacturing agility (Ismail et al., 2011), operational responsiveness (Shin et al., 2015), and manufacturing capability (Linder, 2019). In addition, Goodale et al. (2011) explored the moderating effect of operational control in the relationship between corporate entrepreneurial activity and innovation performance. Mittal et al. (2020) proposed a framework for smart manufacturing in SMEs. All relevant studies are summarized in Table 8.

#### Quality Management

Quality management is an important operations topic. Quality management includes practices such as total quality management, Six Sigma, lean production, and ISO 9001. Studies under this category have examined the various practices, antecedents, and consequences of quality management.

The implementation of quality management practices and frameworks has been investigated or proposed in various contexts (Knol et al., 2018, 2019). Studies have also linked quality management to various performances such as firm performance (Kitchot et al., 2021), financial performance (Shashi et al., 2019), and strategic alignment (McAdam et al., 2019).

Meanwhile, three studies take a look at the factors that determine quality management. Agarwal et al. (2013) explored the factors in determining the quality management practices in SMEs in New Zealand. The relationship between ERP systems and lean production has been studied by Powell et al. (2013). All relevant studies are summarized in Table 9.

#### Miscellaneous Topics

Finally, there are two studies focusing on miscellaneous topics related to operational issues. Phan and Chambers (2013) discussed how operations management could advance theory in entrepreneurship. Similarly, Shepherd and Patzelt (2013) proposed a concept of operational entrepreneurship, which aims to advance entrepreneurship from the perspective of operations management. Darby et al. (2021) have focused on production planning and decisions in family business. All relevant studies are summarized in Table 10.

### 2.4 Logistics and Transportation

This stream of research focuses on the downstream supply chain issues related to logistics and transportation. This stream also includes the relevant issues regarding customer relationship management. As compared to another stream of research, there are fewer studies under this category.

Studies have focused on the customer management in downstream of the supply chains in SMEs (Kitchot et al., 2021). Mitręga and Choi (2021) explored how SME transportation firms in Poland manage asymmetric customer relationships when facing the COVID-19 pandemic. Customer involvement, as a type of SCM practice, has been studied for its influence on firm performance among SMEs in Thailand (Kitchot et al., 2021).

**Table 8** Relevant studies on operational capabilities with respect to entrepreneurship

| Authors | Title | Theory | Data | Method | Topic |
|---|---|---|---|---|---|
| Ismail et al. (2011) | The role of agile strategic capabilities in achieving resilience in manufacturing-based small companies | | Two SMEs | Action research | Manufacturing agility |
| Goodale et al. (2011) | Operations management and corporate entrepreneurship: The moderating effect of operations control on the antecedents of corporate entrepreneurial activity in relation to innovation performance | Agency theory | 177 firms in the United States | Survey | Operations control |
| Hsu et al. (2014) | Corporate entrepreneurship, operations core competency and innovation in emerging economies | | 165 SMEs in ASEAN countries | Survey | Operations core competency |
| Shin et al. (2015) | Strategic agility of Korean small and medium enterprises and its influence on operational and firm performance | | 244 SMEs in Korea | Survey | Operational responsiveness |
| Linder (2019) | Customer orientation and operations: The role of manufacturing capabilities in small- and medium-sized enterprises | | 1663 SMEs in Europe | Survey | Manufacturing capabilities |
| Sahi et al. (2019) | Relating entrepreneurial orientation with operational responsiveness: Roles of competitive intensity and technological turbulence | Dynamic capability theory, contingency theory | 164 SMEs in the United States | Survey | Operational responsiveness |
| Mittal et al. (2020) | A smart manufacturing adoption framework for SMEs | | Two SMEs in India | Case study | Smart manufacturing |

**Table 9** Relevant studies on quality management and leanness with respect to entrepreneurship

| Authors | Title | Theory | Data | Method | Topic |
|---|---|---|---|---|---|
| Agarwal et al. (2013) | Determinants of quality management practices: An empirical study of New Zealand manufacturing firms | Contingency theory | 152 SMEs in New Zealand | Survey | Quality management |
| Powell et al. (2013) | Lean production and ERP systems in small- and medium-sized enterprises: ERP support for pull production | | Four SMEs | Case study | Lean production, ERP |
| Knol et al. (2018) | Implementing lean practices in manufacturing SMEs: Testing "critical success factors" using necessary condition analysis | | 33 SMEs in the Netherlands | Survey | Lean practices |
| Shashi et al. (2019) | The impact of leanness and innovativeness on environmental and financial performance: Insights from Indian SMEs | | 374 Indian SMEs in India | Survey | Leanness |
| Knol et al. (2019) | The relative importance of improvement routines for implementing lean practices | | 38 SMEs in the Netherlands | Survey | Lean practices |
| McAdam et al. (2019) | Towards a contingency theory perspective of quality management in enabling strategic alignment | Contingency theory | Five SMEs | Case study | Quality management |
| Kitchot et al. (2021) | The mediating effects of HRM practices on the relationship between SCM and SMEs firm performance in Thailand | | 152 SMEs in Thailand | Case study | SCM implementation (i.e., information sharing, lean practices, management leadership, customer involvement, and supplier involvement) |

**Table 10** Relevant studies on miscellaneous topics

| Authors | Title | Theory | Data | Method | Topic |
|---|---|---|---|---|---|
| Phan and Chambers (2013) | Advancing theory in entrepreneurship from the lens of operations management | | | Theoretical | Interface between entrepreneurship and operations management |
| Shepherd and Patzelt (2013) | Operational entrepreneurship: How operations management research can advance entrepreneurship | | | Theoretical | Operational entrepreneurship |
| Darby et al. (2021) | The role of small and medium enterprise and family business distinctions in decision-making: Insights from the farm echelon | | 18 farmers from SMEs and family businesses in the United States | Interpretive approach | Production and storage decisions |

Logistics-related partnerships are another topic that has been studied in the literature. It includes different forms of partnership in logistics activities such as joint routing and truck deployment (Zhen et al., 2020) and horizontal logistics alliances (Gao et al., 2017). Multiple types of logistics capability and performance have been addressed, including distribution capabilities (Eng, 2016), logistic responsiveness (Belvedere et al., 2010), and logistics performance (Tuan, 2017). All relevant studies have been summarized in Table 11.

A diagram to summarize the results is presented (Fig. 1).

## 3 Future Directions and Managerial Implications

In the following sections, we outline a few suggestions for future research regarding the interface of SCM and entrepreneurship. These suggestions are based on the above review results and include theoretical and methodological issues. Meanwhile, implications for managers have been discussed.

### 3.1 Relying on and Developing Theories

Based on the review results, it is clear that most studies consistently lack a theory. Theory is used to systematically describe the knowledge in a particular area and to explain the mechanism by which it works. A good theory is able to offer a coherent

**Table 11** Relevant studies on logistics and transportation with respect to entrepreneurship

| Authors | Title | Theory | Data | Method | Topic |
|---|---|---|---|---|---|
| Belvedere et al. (2010) | The responsiveness of Italian small-to-medium sized plants: Dimensions and determinants | | 200 SMEs in Italy | Survey | Logistic responsiveness |
| Eng (2016) | An empirical study of Chinese SME grocery retailers' distribution capabilities | Resource-based view | 247 SMEs in China | Survey | Distribution capabilities |
| Gao et al. (2017) | The impact of partner similarity on alliance management capability, stability and performance: Empirical evidence of horizontal logistics alliance in China | | 262 small and medium logistics enterprises in China | Survey | Horizontal alliances |
| Tuan (2017) | Under entrepreneurial orientation, how does logistics performance activate customer value co-creation behavior? | Dynamic capabilities theory | 328 dyads of logistics managers in Vietnam | Survey | Logistics performance |
| Zhen et al. (2020) | Bus tour-based routing and truck deployment for small-package shipping companies | | A logistics company in China | Math modeling | Joint routing and truck deployment |
| Mitręga and Choi (2021) | How small-and-medium transportation companies handle asymmetric customer relationships under COVID-19 pandemic: A multi-method study | Dynamic capabilities view | 8 polish road transportation SMEs | Interview; archival study | Customer relationship management |
| Kitchot et al. (2021) | The mediating effects of HRM practices on the relationship between SCM and SMEs firm performance in Thailand | | 152 SMEs in Thailand | Case study | SCM implementation (i.e., information sharing, lean practices, management leadership, customer involvement, and supplier involvement) |

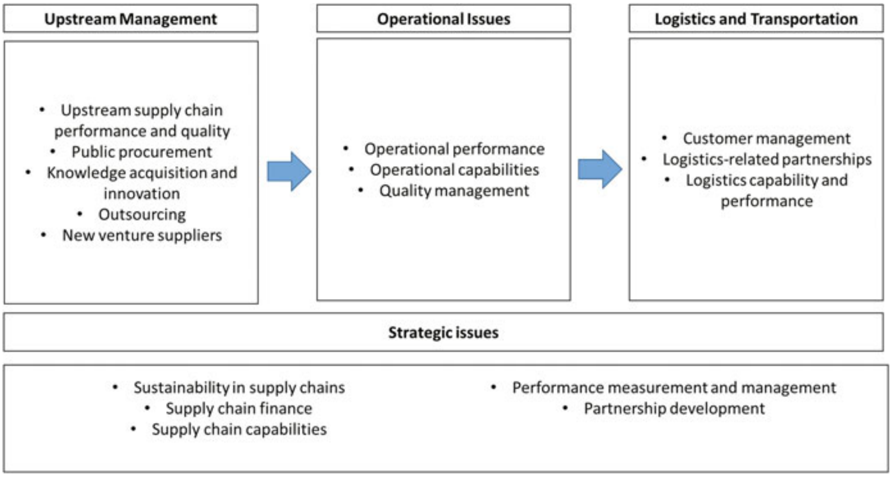


**Fig. 1** Overview of topics at the interface of supply chain management and entrepreneurship

explanation for findings derived from empirical analysis while excluding the seemingly plausible relationships that are derived from the data (Flynn et al., 2020). Thus, we encourage scholars to incorporate more theories into their SCM and entrepreneurship interface research.

In addition, both SCM and entrepreneurship have called for the development of domain-specific theories (Flynn et al., 2020; Wiklund et al., 2011). Scholars from these two areas borrow theories from other fields, and this borrowing is supported by the review results. The lack of domain-specific theory could be attributed to the fact that both SCM and entrepreneurship have only recently obtained their legitimacy as disciplines. While borrowing theories from other fields has several advantages, a number of problems may arise since they are not developed for the specific domain context (Flynn et al., 2020). These problems include both theoretical formulations and methodology-related issues. Consequently, future research could consider developing and testing theories tailored to the interface research between SCM and entrepreneurship.

## 3.2 Multilevel Modeling Studies

While most research in the areas of SCM and entrepreneurship use a firm as the unit of analysis, some studies from these two areas also employ an inter-organizational and individual level of analysis. In SCM research, scholars look at the dyadic relationship between buyers and suppliers (Clottey & Benton Jr., 2020) or explore issues such as supply chain integrations across the whole supply chain. Network analysis has been used in SCM research analysis for some time. Entrepreneurship research uses individual entrepreneurs or teams as its unit of analysis. For instance, entrepreneurial passion literature looks at “an entrepreneur’s intense affective state accompanied by cognitive and behavioral manifestations of high personal value" (Chen et al., 2009, p. 199).

Among our reviewed papers, there are multiple studies that introduced the concept of entrepreneurial orientation into SCM research. These studies mostly used the firm-level of entrepreneurial orientation. However, entrepreneurship literature also includes individual- and team-level entrepreneurial orientation (Covin et al., 2020). Research concerning the interface between SCM and entrepreneurship involves phenomena that are multilevel in nature. For example, its founders' entrepreneurial passion could influence a firm's overall supply chain and operational performance. Using a multilevel modeling approach could better explain the mechanism regarding the interactions between SCM and entrepreneurship.

From a manager's perspective, it is essential to look at the relationship between entrepreneurship and SCM at different levels (i.e., strategic, tactical, and operational levels). At the strategic level, managers can look at the role of firms' strategic mission and vision in the interactions between entrepreneurship and SCM. At the tactical level, managers can focus on how each business unit within the firm impacts entrepreneurship and SCM. At the operational level, managers can spotlight the role of individuals such as an employee in affecting entrepreneurship and SCM.

## 3.3 Novel Data Sources and Analysis Methods

Based on the review results, the survey method predominates in the extant literature. This could be due to several reasons. First, since most samples are SMEs, it isn't easy to find archival databases that include relevant information. Second, many constructs in SCM and entrepreneurship – such as SCM performance and entrepreneurial orientation – are more easily captured using surveys. However, survey studies have multiple limitations. For instance, the self-administered survey is subject to a low response rate, which makes it more difficult for the results to be generalized (Coughlan et al., 2009).

Appropriate sample selection could be another issue that needs to be seriously addressed. In addition, while single respondent bias and social desirability bias could be reduced using specific methods, they could not be eliminated entirely. Also, survey measures are based on the respondents' subjective perceptions, thus increasing the likelihood of bias. For instance, most studies reviewed in our sample used respondent survey answers to measure SCM performance, operational performance, and firm performance. This method may not reflect the actual performance of the firms.

Alternatively, future research could look for archival data sources related to entrepreneurship and SCM. For instance, immigrant entrepreneurship has gained more attention over the past decades (Dheer, 2018). Relating to SCM research, future studies could explore whether immigrant entrepreneurs are more likely to choose international sourcing. Similarly, because they are more aware of uncertainties in the global supply chain and have more international experience, firms with immigrant entrepreneurs are less likely to be subject to supply chain disruptions.

Researchers could obtain data from platforms like crunchbase.com concerning the backgrounds of entrepreneurs in start-up and young firms. In addition, future studies could use data crawling and scraping methods to retrieve unique data. Massimino (2016) discussed the techniques of web-crawling and information-scraping in SCM research, while Hain and Jurowetzki (2020) considered data crawling in entrepreneurship research. However, scholars should pay attention to the ethical and confidential issues involved in data crawling and scraping. Some journals require that a letter of data authorization be included with manuscript submissions.

Since most studies in the extant literature rely on surveys to collect data, the methods used for data analysis are limited to structural equation modeling and regression analysis. Multiple novel analysis methods are featured among the reviewed papers. For instance, Sabahi and Parast (2020) used multiple machine learning algorithms (i.e., lasso, ridge, support vector machines, neural networks, and random forest) to investigate the relationship between an individual's entrepreneurial orientation and project performance. These novel methods offer unique perspectives that have not been observed using conventional methods. Accordingly, there are several methods that could potentially be used in the interface research between SCM and entrepreneurship. For instance, future research could use facial recognition techniques (Choudhury et al., 2019) to analyze the CEO personality in SMEs, which in turn affects firm SCM activities.

## 3.4 The Impact of the Pandemic

The COVID-19 pandemic has created unprecedented effects on businesses (Sarkar & Clegg, 2021). Supply chain crises have demonstrated firms' lack of resiliency in their supply chains (Ivanov & Dolgui, 2020). The impact of the pandemic has caused even more difficulties for SMEs. For instance, based on the large-scale survey collected by the National Defense Industry Association, Melnyk et al. (2021) found that the weakest suppliers in the early stages of the pandemic were the very small SMEs. Moreover, the authors found that most government measures and initiatives are not effective in helping these suppliers. Future research could investigate how firms responded to the outbreak of the pandemic regarding their supply chain functions.

An interesting industry to explore is the farm industry, which is an important economic sector the world over (Timmer, 1992). Among the reviewed papers, a few address the SCM issues in the SEMs and family businesses of the farm industry (Darby et al., 2021). Most firms in the farm industry are either SEMs or family businesses. Due to limited resources and technology, these farms are struggling to survive, a situation worsened by the COVID-19 pandemic. Future research should focus more on identifying SCM solutions for these farms during the pandemic.

From the perspective of managers, firms have faced unprecedented challenges during the pandemic. The disruption of the supply chain due to the pandemic led to a huge impact on firms' operations. Therefore, managers need to proactively approach to designing a robust supply chain network to mitigate the risk of unexpected events like the pandemic. In addition, managers need to also pay attention to the effects of post-pandemic challenges. Some firms have re-design the supply chain network due to the pandemic, and therefore it is important to closely monitor the influence due to these changes.

### 3.5 Cross-Disciplinary Perspectives

While the interface research between SCM and entrepreneurship is cross-disciplinary in nature, scholars could take an even broader view by also looking at the problems that interact with other disciplines. For instance, future studies could explore the influence of the characteristics and personalities of CEOs and top management on SCM-related outcomes in SMEs. Although CEO characteristics and personalities are common topics of studies in the field of strategic management, SCM areas have been neglected. The roles of CEOs and top management are even more important in SMEs than in larger firms because they have more power and control over the firms.

The research connecting marketing concepts to SCM and entrepreneurship is well-established in the extant literature. However, few studies integrate the concepts from these three fields simultaneously. In small firms, SCM and the marketing department always work closely. In some cases, the marketing department takes charge of SCM activities. Thus, it is particularly important to determine how to achieve a cohesive relationship between SCM and the marketing function.

In the area of information systems, researchers could look at the role of social media (e.g., Facebook, Instagram, Twitter, and TikTok) in the interface between SCM and entrepreneurship. Some studies have looked at the interface between social media and SCM (Huang et al., 2020). Some exemplary topics demand forecasting and new product development based on social media mining, supplier management with the help social media, and customer communication in product return and recall on social media (Huang et al., 2020). Similarly, there are studies examining the interaction between social media and entrepreneurship (Olanrewaju et al., 2020). The openness and connectivity of social media overcome entrepreneurs' incompetence or difficulty in identifying and seeking expert opinions and guidance (Kuhn et al., 2016). For example, young firms could advertise their products and brands on social media platforms at a lower cost (Brink, 2017). However, research concerning the interface of entrepreneurship, SCM, and social media is rare in the literature. Future studies could take a look at how SMEs or young firms can use social media to better manage their supply chain activities.

From a practical point of view, managing social media in order to build a positive firm image is crucial for firms. Firms share information regarding how they take the responsibility of protecting the environment by reducing carbon emissions in supply chains on social media platforms such as Twitter. For instance, Walmart has regularly addressed its solutions to climate change on its Twitter account.

### 3.6 Interface of Global SCM and International Entrepreneurship

A firm's supply chain commonly involves international activities, such as global sourcing and purchasing, and the customers of the firm may be dispersed all over the world. A firm's manufacturing plants could be built overseas to leverage local resources. Tesla is a typical example. Tesla has suppliers and customers from different countries and has manufacturing plants all over the world, in places such as Germany and Shanghai. A firm's SCM, in the global context, faces a greater variety of uncertainties. Similarly, international entrepreneurship, defined as "the discovery, enactment, evaluation, and exploitation of opportunities—across national borders—to create future goods and services" (Oviatt & McDougall, 2005, p. 540), also positions entrepreneurship in a global context. Both global SCM and international entrepreneurship focus on the firm's activities in the global context. Future research could focus on the problems that are related to the interface. For instance, scholars could explore how young firms build their local supply chain networks when they penetrate into new foreign markets. NIO, a young Chinese automobile manufacturer, entered its first overseas auto market – Norway – in 2021 and plans to deliver 20 battery swap stations by the end of 2022. Future research could investigate how these young firms manage their supply chains when entering new overseas markets.

From a practical point of view, globalization in the past few decades has created numerous opportunities for supply chain practitioners and entrepreneurs. Firms rely on global sourcing to reduce costs and search for components and materials of the best quality. It increases the demand for people who have international backgrounds. Entrepreneurs in the start-ups can also seize the opportunities to expand their international business. Platforms such as AliExpress help these start-ups reach out to the international markets and provide support for logistics activities.

### 3.7 Government, Policy, and Regulation

The government plays an important role in both SCM and entrepreneurship by implementing policies and enforcing regulations due to their important position in the economy. However, studies that have examined the role of government are fragmented when it comes to addressing both SCM and entrepreneurship research. Government forms the institutional environment in which business is conducted. Both a firm's supply chain and entrepreneurship activities are profoundly influenced by the institutional environment, as well as policies and regulations. SCM scholars have called for research at the intersection of SCM and government regulation and public policy (Fugate et al., 2019). Consequently, future studies could explore how SCM and entrepreneurship have been influenced by the government. For instance, President Biden's bipartisan infrastructure law, with its focus on investment in the nation's infrastructure and competitiveness, has had a huge impact on logistics and entrepreneurship. Future studies could specifically examine government influence in the long run.

## 4 Summary and Conclusion

Our review synthesizes existing research on entrepreneurship in SCM based on selected papers. Specifically, we summarized the topics into four categories: strategic issues, upstream management, operational issues, and logistics and transportation. This review serves as a foundation for researchers and practitioners to explore more opportunities in the study of the role of entrepreneurship in SCM research. We argue that there exist various research and practical opportunities for integrating entrepreneurship concepts into SCM. We have also outlined various directions for future researchers to explore and multiple implications for practitioners.

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# Gender Diversity for Supply Chain Sustainability

## Challenges and Opportunities

Salomée Ruel, Minelle Silva, Morgane Fritz, and Anicia Jaegler

## Contents



**Abstract**

The study of gender diversity in supply chain management (SCM) has been overlooked in the literature and still remains a marginal subject for most companies even though it is part of the Sustainable Development Goals from the United Nations. Nevertheless, this chapter provides an overview of the scientific literature on the subject within three frames: from the careers of women in SCM, analyzing the expected benefits of true diversity management in SCM, and to the issue of women and transgender "victims" approach linked to supply chain

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activities. This overview leads us to ratify the importance of debating gender diversity as a vital issue towards sustainability. Examples of companies' initiatives and other representative organizations are presented as illustrations of these frames. All the elements presented allow us to draw up managerial implications on the benefits companies could gain from an increased gender diversity and how to get there. Finally, avenues for future research are presented to foster the subject.

**Keywords**

Gender diversity · Social sustainability · Women · Change-makers · Supply chain sustainability

## 1 Introduction

In 2015, the United Nations created the 2030 Agenda for Sustainable Development, represented by the 17 Sustainable Development Goals (SDG). The fifth SDG refers to achieving gender equality and empowering all women and girls. According to the World Health Organization,[1] *"The word gender is used to describe the characteristics, roles and responsibilities of women and men, boys and girls, which are socially constructed. Gender is related to how we are perceived and expected to think and act as women and men because of the way society is organized, not because of our biological differences."* Thus, this chapter aims at showing how gender diversity has been discussed and practiced in supply chain management (SCM).

Gender diversity is about the fair representation of different genders within a particular context and is often measured through ratios of men and women, for instance, within a company. However, gender diversity includes many other nuances that need to start being recognized in the SCM field (Ozar, 2006). For example, Paiva et al. (2020) highlight the inclusion of self-identified transgender people as a relevant group often marginalized in society, which is addressed in this chapter. In this chapter, we refer only to women and men expressions since they cover both cisgenders and transgenders; however, we understand the existence of nonbinary people who are not part of our current debate due to its exploratory phase. Therefore, we acknowledge that greater woman representation in a male-dominated context such as supply chains (Zinn et al., 2018) alone cannot impact gendered organizational practices (Grosser & Moon, 2019). Further factors are to be taken into account such as institutions, culture, and socioeconomic context for sustainability, which we will touch upon through specific examples of gender diversity in supply chains.

This chapter is structured in four main parts: (1) a background of research on gender diversity and supply chain management. We present here general information on what has been published on the subject; (2) the current concerns such as the victimization approach (Jeffrey, 2005) related to gender diversity. By presenting both the deliberated and the taken-for-granted perspective of victimization, we argue

[1] https://www.who.int/westernpacific/health-topics/gender-equity-and-human-rights, accessed 3 November 2021.

how challenging it is to stop thinking as solving current problems and instead to start looking for new solutions; (3) the emergent concerns as how to analyze women as change-makers overcoming the victimization approach; and (4) we explore conclusions by providing a research agenda for future research on the topic and implications for managers. More than focusing on what has been done, this chapter goes a step forward to demonstrate that supply chain sustainability is only possible when gender challenges are addressed and opportunities taken as part of SCM and procurement departments' daily operations.

## 2 Background

Historically, SCM is a function where men as professionals are in a majority, since the logistics professions – transport and storage – are male-dominated. Although the trend for more women working in the field is increasing (from 37% women employees in 2018 to 41% in 2021), few women have top management positions (between 11% and 17%) (Gartner, 2021). So, it is important to understand the *ins* and *outs* of this situation to help companies solve this imbalanced situation.

However, the literature on gender in supply chains is scarce. Some research on different academic databases (i.e., Ebsco, Emerald, and Science direct) with the string "gender" AND "supply chain" returns very few relevant articles. The first studies were published in transport-oriented journals, then in management-oriented or business ethics-oriented journals. Recently, Zinn et al. (2018) confirm and call for research in this area as they notice that the topic is under-researched, while Yawar and Seuring (2017) show that gender is one of the main social issues in supply chains. Figure 1 provides a snapshot of research trends over the years (1995–nowadays).

**1995–2001** – The first studies date from the 1990s. They focused on transportation and career. André (1995) compared career status among genders. She found that women within the SCM function are younger than men and that women held less top management positions than men. Lynagh et al. (1996) and Knemeyer et al. (1999) concluded identically and added that their average salary is lower. Lynagh et al. (1999) offered an explanation for this result. They explained that women have reservations about careers in SCM and that education is one of the keys to make a difference.

**2002–2008** – Ten years later, researchers focused on the practices in the purchasing and transportation sectors to better understand these phenomena. Prieto Carron (2008) highlighted that no gender discrimination means equal pay and fair treatment. So it is crucial to identify what are the contributors to equity.

1. Larson and Morris (2008) confirmed the previous research on the impact of education. Education is the first lever for equity. In the supply chain, women are often at the lowest position. To access higher positions, women need to access higher education. At the same time, managers with a C.P.P earn over 13 k$ more

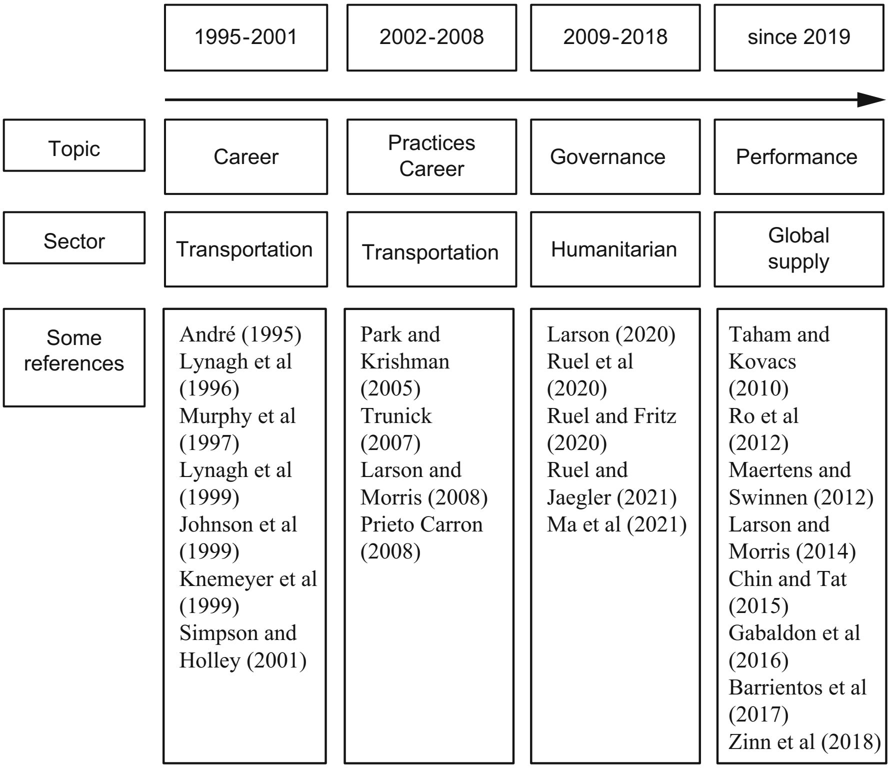


**Fig. 1** Research trends on gender in SCM. (Source: the authors)

than managers without. Educated women will gain twice: higher positions and higher salaries.

2. A second lever is to consider the division of labor at home as Trunick (2007) explained the gender differences by the work-family conflicts. Women are *de facto* out of the network, because they are more often in charge of the family and therefore do not have time for after work drinks. Moreover, for the same reason, they often travel less, and refuse or are refused jobs that require them to travel.
3. A third one is the image of the profession (Trunick, 2007). SCM is seen as a difficult function, with long working hours, travel, and high pressure, which women identify as incompatible with their personal life and feel that it is not a good fit for them. A glaring example is in the textile supply chains. In this sector, Burchielli et al. (2009) indicated that homeworkers are mainly women. Homeworkers are in precarious situations with weaker social protections. Thus, when women work in the supply chain, they not only do not reach top management but they are also the most numerous in precarious positions.

To increase equity, these contributors have to be activated as numerous research studies show the positive impact of women at different levels. Women can be part of the SCM and procurement departments and thus take part in the decisions. Nevertheless, some of them are already "at the helm" of international supply chains, and the share of women managers/directors is gradually (though slowly) increasing. Yet, the impacts of gender diversity on boards of directors can be spotted in the literature: on climate change (Galbreath, 2010; Ben-Amar et al., 2017) and on moral duties of boards (Flynn & Adams, 2004). Moreover, with regards to supplier selection, it appears that there are significant differences in the way women and men select suppliers and evaluate them afterwards. Park and Krishnan (2005) show that women supply chain managers have a greater focus on the long-term future of their suppliers and on workplace safety issues at suppliers, while men supply chain managers are more likely to look primarily at the economic performance of suppliers.

This research is indicative of a more sustainable, time-based view of women as decision makers in the supply chain. While this result may seem surprising at first, it is easily explained by women's ability to collect and process information while using their emotional intelligence to interpret it (Thayer & Johnsen, 2000). Second, these findings confirm the preliminary results from Park and Krishnan (2005) about supplier selection practices by pointing out that women will better look at and include social aspects in the selection process. Overall, this research retains the determining impact of gender diversity in the SCM function on the social pillar of sustainability that is usually understudied (Seuring & Müller, 2008; Ruel & Fritz, 2021). Thus, the presence of women acts on sustainability: they are change-makers.

**2009–2018** – Tallontire et al. (2005) confirmed the previous research and that most marginalized supply chain workers are women. Taham and Kovacs (2010) showed that the humanitarian logistic exacerbates these phenomena. The research also highlighted the fact that women face a glass ceiling – it is more difficult for them to access managerial and executive positions (Lawrence et al., 2018).

However, research goes even further by looking at governance, performance, and compliance in more diverse sectors than before. In the field of corporate governance, the research of Dawar and Singh (2016) has pointed out that when women are part of the board of directors, they influence decision-making for sustainability as it appears that gender diversity at the supply chain managerial level would bring more empathy and listening skills which are necessary to improve the social sustainability in the supply chain, which has long been undermined (Yawar & Seuring, 2017; Ashby et al., 2012; Benoît et al., 2010). More women on board has a positive impact on the environmental and sustainability management of the company (Post et al., 2011; Bernardi & Treadgill, 2011; Harjoto et al., 2015). In the same line, a gender diverse board composition is positively influencing the sustainability ratings of the company (Bear et al., 2010). Other positive impacts of board gender diversity can be spotted in the literature: on climate change (Galbreath, 2010; Ben-Amar et al., 2017), on the quality of sustainability reporting (Al-Shaer & Zaman, 2016), or on environmental sustainability (Kassinis et al., 2016) and workplace, social, and economic sustainability (Zahid et al., 2020).

Focusing on specific sectors, some research highlights other positive impacts. With regards to violations reporting in the supply chain, Short et al. (2016) highlight that in the field of supply chain auditing, having more women is crucial. Indeed, the audit team's gender composition impacts the capacity of the team to detect and report violations. They show that the most efficient teams are the ones based only on women or which are mixed-gendered.

Gender bias in the buyer-supplier relationship has also been found to exist (Ro et al., 2012), which argues for diversity as women are more collaborative in both ways – as suppliers or buyers. Finally, research has shown that women are more likely to adhere to and follow rules than men (Portillo & DeHart-Davis, 2009). Additionally, in line with Short et al. (2016), women in the supply chain pay more attention to rules, especially quality, health, safety, and environment (QHSE) rules, which is an essential aspect of supply chain sustainability (Ruel & Fritz, 2021).

In entrepreneurship, women-owned family businesses show both more innovation and sustainability (Gundry et al., 2014). One should note that the contribution of gender diversity to supply chain sustainability is indeed not limited to multinational company actions but also to micro, small, and medium enterprises (MSMEs). The UN (2020) report shows multiple ways of contribution from MSMEs to the SDG number 5 – gender equality – which is aligned with the change-maker perspective. For example, this report mentions that a significant proportion of MSMEs are owned by women and that MSMEs employ many women. With this finding in mind, it is understood that a gender balance is possible within supply chains when thinking of the power to promote sustainability (UN, 2020). Women employees and leaders are key to reaching supply chain sustainability.

**2019–2021** – Some recent research reinforces previous works or introduces new perspectives. One study shows fewer women are in SCM master degree programs (Ruel & Jaegler, 2021) and with women still experiencing slower career progression, which is problematic since gender inequality generates lower performance (see Larson, 2020; Ma et al., 2021).

In SCM, as shown, the issue is therefore very recent and totally emerging. Since research about the impact of women on sustainable decision-making in supply chains is in its infancy (Ruel et al., 2020; Ruel & Fritz, 2021), it seems necessary to look in other areas at how they appear to contribute to sustainability. In R&D, including more women, also leads to more innovations that are effective in the fight against global warming (Le Loarne-Lemaire et al., 2021). In the end, if in other functions of the company a better gender distribution leads to an improvement in decision-making in favor of sustainability, it seems relevant to question whether such an analogy is possible in SCM.

Very little work in SCM exists indicating how more gender diversity improves decision-making for sustainability, or even sustainable performance (Ruel et al., 2020; Ruel & Fritz, 2021). Ruel and Fritz (2021) further highlight such conclusions based on qualitative research with supply chain consultants and managers. They show that women in the supply chain bring soft skills that support more social sustainability in management (empathy) and operations (responsible supplier selection, procurement practices). Ruel and Fritz (2021) also show that women in SCM are more rules-compliant which makes it possible to advance on sustainability issues at the workplace, especially for the most operational tasks within the warehouses.

In the supplier selection process, women pay more attention to social considerations, e.g., well-being at work, equal treatment of employees, workplace atmosphere. Thus, gender diversity supports higher sustainability performance in terms of health and safety, the respect of rules and social relations (Amorelli & García-Sánchez, 2021). Ma et al. (2021) find that both men and women are more collaborative when paired with women and that the supply chain is more efficient when there are female buyer-supplier pairings.

The research over the past couple decades has seen a number of concerns and issues related to gender specific supply chain management concerns. Yet, much of this research and these findings cannot fill the many gaps that remain. Some of these current gaps and requirements are now identified.

## 3 Current Concerns

Despite the previously presented growth, the literature on gender diversity in SCM is more focused on reporting a few existing initiatives than developing insights on how to move forward. For instance, why are women, in most research studies, considered victims? In this section, it is argued that this situation occurs because of deliberated or taken-for-granted reasons.

First, there is a movement to deliberately put genders that are not cisgender-male as victims (HRC, 2021; UN, 2021). This happens because of the existence of a male hierarchy or homophily, especially in SCM. Second, there are local cultural elements that take-for-granted such victimization. This is related to a historical sequence of events in which the society already accepts that only purely male genders are stronger and powerful enough to develop some actions and take decisions in many areas, including in SCM. We explore these elements along this section.

## 4 Deliberate Victimization

One of the main issues related to social sustainability addresses the need for social justice and equal treatment in society with changes in behaviors (Vallance et al., 2011). However, there are multiple contrary actions to reach this perspective, which directly covers gender diversity. For example, Paiva et al. (2020) highlight the existence of gender inequality in SCM based on three main issues: (1) low participation of women-owned business in supply; (2) wage inequality along the supply chain; and (3) gender-related modern slavery or forced labor throughout multiple tiers. These issues seem to demonstrate that in one way or another gender diversity is deliberately avoided based on few beliefs and decisions. In this context, there is a trend to understand women as victims of the system, which needs to be challenged (Ruel et al. 2020). Based on this reflection, studies need to increase interest on gender diversity in SCM; however, at the same time, they also need to question and overcome this victim approach. More than studying and defining gender diversity through victimization, it is necessary to understand the existing potential within diversity.

The deliberate approach assumes that gender diversity should be something not expected or necessary since the industry is centrally dominated by males (Zinn et al., 2018), which makes it difficult to overcome the victim approach. For example, Lawrence et al. (2018) claimed that women procurement professionals suffer with underrepresentation because of the existence of homophily, which is the tendency to have a bias against those that do not belong to your group when recruiting and promoting (Smith et al., 2012). Homophily also refers to the tendency to engage more with those who share a mindset, which is easier inside the male-dominated perspective (Smith et al., 2012).

Homophily in SCM exists at a significant level. For example, Johnson et al. (1999) expressed the necessity for many companies to insist that existing managers (mainly men) recruit more women; otherwise, they did not pay attention to recruiting women. Despite this recognition, often it is through the recognition of victim conditions that bring new reflections on the subject. It is not an easy task to overcome this approach because there are some embedded issues that make no male identification being affected by behavioral and cultural issues.

## 5 Taken-for-Granted Victimization

The existing victimization approach refers to a constant identification and reporting of issues and examples that make gender diversity more related to a challenge than an opportunity in supporting SCM and supply chain sustainability. Most studies assume that gender diversity should be analyzed with the same lens for different countries and industries, which is not possible. For example, when focusing on corporate governance (Ruel et al., 2020), many studies have shown that the number of women in the board of directors is positive in Europe or in the USA; however, the opposite occurs when it refers to Latin American countries (Husted & Sousa-Filho, 2019). Two main reasons exist for this difference: (1) because the small number of women (i.e., maximum three per company), a lack of critical mass exists since they usually are unable to join deliberations effectively and (2) the cultural setting of Latin America does not work in favor of supporting women as part of a board of directors (Husted & Sousa-Filho, 2019).

These issues represent the taken-for-granted victimization since they are institutionalized and are usually accepted without further questions. This is an example of the need to understand gender diversity based on singular characteristics of each SCM context, whether it is industry based, product based, or regionally based contingencies.

When considering specific industrial sectors, a victim-approach is also taken in some specific areas such as the informal mining sector, as studied by Fritz (2017). In this research, it is highlighted that informal mining is taking place for a variety of minerals in developing countries, mainly on the African, Latin American, or Asian continents. It is taking place in countries where other activities do not allow to earn such a good living as with mining, often referred to as the "vicious circle of poverty" (Fritz, 2017). Informal mining, contrary to large-scale mining, consists of activities led by small groups of miners and their community, often including women and children. Women often work in mining to support the schooling of their children (when possible) and provide their families with basic needs (Fritz, 2017). They participate mostly in cleaning and crushing minerals extracted by men, or in cooking and selling food on mining sites, and in some cases, they also prostitute themselves. Women thus appear as victims of men-led activities. But, it is not so simple. Culture plays an important role and women as miners are sometimes not accepted due to cultural beliefs (Fritz, 2017).

Nongovernmental organizational (NGO) programs used to exclude women from training on mining because of the taken-for-granted victimization, thus perpetuating this exclusion of women from the more lucrative mining activity. This situation is one example among many others that reinforces the need to consider country, culture, and sector specificities when addressing gender diversity in SCM.

Amidst the existent examples globally, we found two very representative company initiatives – L'Oreal and Schneider Electric – demonstrating the uniqueness of a region, even though it is still based on a taken-for-granted victims approach. As previously mentioned, we are still experiencing the need to rise above this issue in research and understanding, thus the more examples highlighted, the more we advance to see gender diversity as an opportunity for supply chain sustainability.

First, consider the sourcing program of L'Oreal – a multinational cosmetics company – which is interested in contributing to social inclusion worldwide. Among their multiple projects, various regions can address a different marginalized group. An important and key project exists in Mexico to ensure gender diversity to overcome their victim situation. The program consists in stimulating suppliers in Mexico to hire single mothers, who are marginalized in this marketplace. Second is the example of Schneider Electric, a multinational electric company, which develops engaging actions toward gender diversity in Brazil. They developed a program to ensure equal opportunities to include transgender individuals as employees, but also with some partners locally. This issue is key, because Brazil is the country with the largest number of deaths of transgender people in the world because of prejudice. Both examples support gender diversity, while seeking to reduce this victimization approach. It is necessary that further actions are taken beyond the need to solve a problem, such as considering these people as change-makers in SCM, that deserve further attention and opportunities.

## 6 Emergent Concerns, Outstanding Research, and Future Directions

The research and current knowledge in this area offers an initial stepping-stone to avenues for improving diversity within the supply chain. Gender diversity in SCM has often been observed in research under the prism of victims. This perspective is especially true in emerging countries, where large companies exploiting – sometimes in a very inequitable way – both natural and human resources. Research needs to move away from a victimization emphasis to reinforce the potential of diversity as an agent of change.

In previous subsections, we have seen facts, figures, and hints that highlight that more gender diversity in SCM could make supply chains more sustainable. Increasing such opportunities can take two forms: either gender diversity in supply chains is supported by some external stakeholders and organizations through initiatives that can be considered as positive discrimination, or gender diversity is put in place by women themselves which we refer to as "change-makers" with a proactive approach.

## 7 Positive Discrimination and Representative Organizations

As shown several years ago, one of the key factors to increase sustainability in supply chains is the legal framework (Seuring & Müller, 2008). By acting on laws, governments can force companies to increase gender diversity with a binding quota on women. So far, such laws have not focused on SCM, but on boards of directors in general. Several countries have opted for this solution to increase gender diversity among top management (e.g., France, Italy, Germany) but limited research has investigated the impact of such quotas on the short and long term, except in Norway (Smith, 2018). Studies on the Norwegian case are not very conclusive so far as there is a need for "diffusion" of gender diversity impacts in companies, which takes time (Smith, 2018).

It is believed that quotas set by politicians may not be the most effective way to increase gender diversity: *"politicians might have to change the focus from quotas at the top of the organization to the much broader task of getting a more equal gender division of careers within the family. This might be achieved through gender-neutral family policies and quotas for fathers in parental leave schemes"* (Smith, 2018, p.9).

Indeed, bringing more gender diversity through binding quotas accompanied by sanctions or fines in case of noncompliance allows reaching a higher number of women in top positions. But, these changes should not be only a question of numbers, instead impacts on firm and supply chain performance should be assessed and the wider socioeconomic environment should be studied. Voluntary and bottom-up initiatives have also been successful in some cases (ILO, 2021). However, what is highlighted in the "quota debate" is the essential need for managers and politicians to engage in a dialogue in order to ensure a sufficient number of women are trained and qualified to access top management positions, according to company needs (ILO, 2021). Furthermore, companies need to create the right conditions to attract more women in the workplace in sectors and firms where they are underrepresented compared to their male counterparts (ILO, 2021). Again, in such sources, it is a question of men versus women, which would benefit from being extended to other genders as well.

Other approaches exist to increase gender diversity such as women training and empowerment. For instance, in the mining sector, a male-dominated sector, the International Women in Mining organization works on the topic and highlights that more women in the sector will *"improve diversity, governance and sustainability"* (WIM, 2021). Through their work, they underline four key lessons as put by Gillian Davidson, Chair of the Board of Directors of International Women in Mining

(IWiM) and leading sustainability, corporate social responsibility, and responsible supply chains specialist.

First, "*Women in Mining (WIM) organisations have an important role to play. Women get support through the WIM organisation to have their voices heard at a national or regional level to obtain the support they need.*" Second, *"The gender agenda needs global alliances,"* which WIM works on by representing women in mining and developing partnerships at a global level to enhance gender equality. Third, *"Data is a challenge."* There is a lack of experience-sharing among women and a lack of data from companies, governments, and associations to better understand the challenges around gender diversity in the sector and to develop better practices. Such data is necessary to reinforce WIM activities and develop more factual arguments in favor of gender diversity.

Fourth, *"We all have a role to play,"* which enhances all men and women's efforts to increase gender diversity and equality have their importance, whether men or women, employer/employee, colleague, individual or else. Actions such as mentoring women, debates on policy improvements in companies, participation or development of surveys can support the creation of knowledge and awareness raising on the topic, that are the baseline for necessary changes (IWIM, 2021). Such key lessons are worth being emphasized in this chapter since the recommendations made for this sector also apply to a variety of other sectors and to the wider supply chain field, especially regarding the lack of data and research on gender diversity, echoing Zinn et al. (2018).

Some organizations specifically focus on empowering women leadership in supply chains such as the "Achieving Women's Excellence in Supply Chain Operations, Management & Education" (AWESOME).[2] This organization created in 2013 groups about 1500 women in senior SCM positions to share their knowledge and expertise, as well as conduct several actions for encouraging women in following higher education programs in SCM. However, there is limited information provided on the benefits of such activities within supply chains and for supply chain sustainability. Such observation highlights the need for more industry organizations to become involved in these activities. Professional SC associations such as the Association for Supply Chain Management (ASCM)[3] and industrial associations could take a proactive stance and may want to focus their efforts on promoting gender diversity. Their engagement in this direction may change institutions and norms to change the common view of women as victims or as unable to perform a SC-related management job. By communicating on such engagement and the related benefits, industries as a whole may adopt mimetic approaches that will set new norms and facilitate an increased gender diversity in SC management functions.

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[2] https://www.awesomeleaders.org/about-awesome/

[3] https://www.ascm.org/

## 8 "Self-Made Women" as Change-Makers for Sustainability in Supply Chains

A recent study has shown that women leaders in the workplace tend to stimulate change and social inclusion, especially following the COVID-19 pandemic (McKinsey & Company, 2021). They promote well-being, diversity, equity, and inclusion more than men (see Fig. 2), but although 70% of the companies surveyed recognized these efforts as being crucial, less than 25% reward this investment (MacKinsey & Company, 2021).

Although this study is not focused on SCM, transferring these efforts women make to the supply chain context would imply that more gender diversity in SCM contributes to higher social performance (i.e., well-being, work-life balance) in the supply chain.

In the SCM field, several sources highlight women as successful supply chain leaders. For instance, Kroll (2019) portrays seven female leaders in supply chain and logistics management, chosen for *"strong work ethic, a passion for supply chain and logistics, and the ability to be comfortable as one of a few—sometimes the only—women in the room."* Awards and recognitions are being created to encourage more women participation in supply chain leadership positions, such as "The Women in Supply Chain" award from the Supply & Demand Chain Executive magazine (Moralez, 2020) or the Top 100 Women in Supply Chain from the BizClik Media

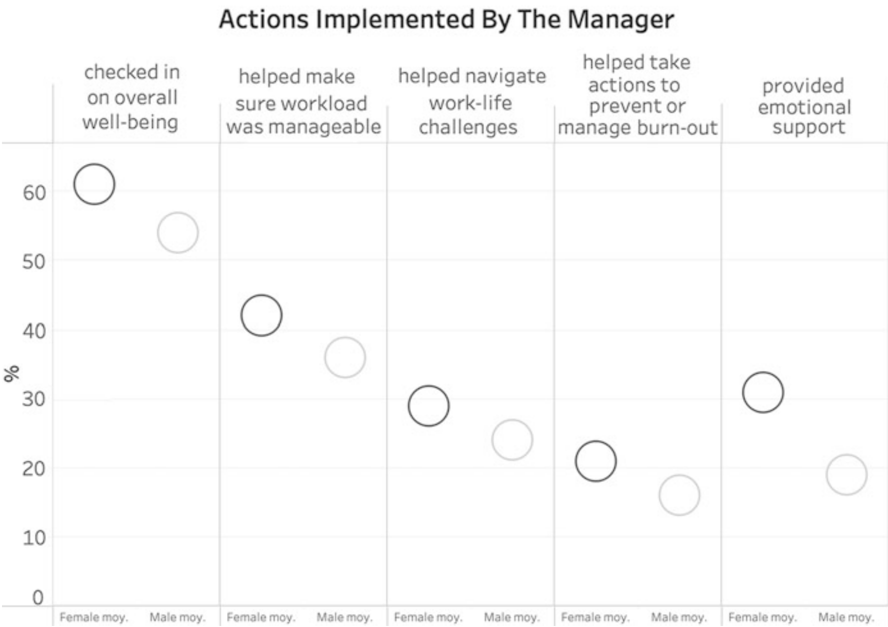


**Fig. 2** Social actions led by men and women managers during the COVID-19 pandemic. (Adapted from McKinsey, 2021)

Group (Freeman, 2020). According to BizClik Media Group's Chief Operating Officer, Stacy Norman, such recognitions are essential nowadays since *"women are playing crucial roles"* especially in supply chain, digital technology, and FinTech sectors which *"are undergoing a digital transformation and women are leading the way."*

Given the various barriers women may face in the SCM field, some women leaders take the opportunity to stimulate more diversity as pictured by Wilson (2020). For instance, Megan Smith, CEO of Symbia Logistics, revised her company's policy when reaching this position to put gender diversity at the core of its strategy. Ellen Voie, CEO of the Women in Trucking Association, gives talks worldwide to encourage more women to join the trucking sector. Still, many organizations promoting gender diversity in SCM state there is a need for more women in supply chain positions because of the great divide between the number of women compared to men (e.g., "Women in Supply Chain Initiative"[4]). However, few are able to explain further the added value of a higher share of women in top management positions, which highlights a gap to be addressed in research. Investigating with a scientific approach what gender diversity concretely brings to SCM would help develop strong arguments and make several industries invest time in attracting more women and other gender types. Furthermore, educational institutions have an increasing role to play to set a favorable ground for more gender diversity in supply chains. SCM-related jobs are historically more targeting men, so to increase gender diversity, there is a need to train and encourage women to follow-up on supply chain education and prepare them for SCM-related jobs as well as to create and develop an attractive working environment and career perspectives for women to apply to such jobs.

## 9 Future Direction on Gender Diversity for Sustainability in SCM

Several theoretical approaches could be useful to study these new aspects related to the issue of gender diversity in SCM, with an emphasis on sustainability. For instance:

– Practice theories can support the understanding of gender diversity in SCM for sustainability mainly when they challenge a static understanding of specific practices and look for deeper understanding of what can happen in terms of supply chain sustainability (Silva & Figueiredo, 2020). Further studies could look at understanding what are the meanings in developing gender diversity for supply chain sustainability as well as what kind of competences are necessary for that.
– Social justice theory. This theory works well in this debate since it can help companies and their supply chain management to ensure social sustainability.

[4] See: https://wisci.mit.edu/

Young (2011) explores through the politics of the difference how social justice may be developed to reduce discrimination and create a more distributive paradigm in which oppression is overcome. Such a perspective is not well applied to SCM and may be used to ensure supply chain sustainability, not only looking for gender diversity but stimulating further social sustainability under multiple facets.

The study of Ruel et al. (2020) also identifies several relevant theoretical frameworks for studying the issue of gender diversity in SCM. Among these:

- Gender schema theory (Bem, 1981), which explains how characteristics related to sex and gender are integrated and persistent in a group of individuals. This could enable researchers to better embrace the role of gender stereotypes in women's careers and contributions in SCM.
- Social identity theory (Tajfel & Turner, 1986), which explains behavior between different groups of individuals depending on their perceived differences of status and legitimacy, could be of interest to understand career paths in SCM and the leaky pipeline.

Other theories called "feminist theories" can contribute to address gender diversity in SCM with a theoretical background (Touboulic & McCarthy, 2019). For instance, "feminist ethics" (Crane & Matten, 2016, pp. 115–116) recognizes the differences of attitude between men and women, such as in resolving ethical conflicts. Crane and Matten (2016) highlight that almost all ethical theories have been developed by men and focus on individual interests. On the contrary, feminist ethics focuses on interrelations between individuals that are embedded in a network (Crane & Matten, 2016, p.116) and thus may be more appropriate for SCM than other ethical approaches (e.g., utilitarian, ethics of rights). In the same line, Grosser and Tyler (2021) justify the appropriateness of mobilizing radical feminism (Hooks, 2000) as a theory because the labor conditions in supply chains show many gender discriminations, sexual violence, and harassment, and this theory offers a perspective that is not individualized but rather more class-based (based on sex-class) with a focus on structures of inequality. Finally, Loosemore et al. (2020) suggest that the intersectionality theory (Crenshaw, 1991) should be mobilized as novel lenses in future research to better explain how gender and race may intersect and create an accumulation of discriminations and violence in SCM. Overall, feminist theories may be mobilized as "emancipatory" theories to shift understanding and advancement of supply chains.

These theories can create new avenues for gender diversity in SCM for sustainability. However, we cannot forget that traditional organizational theories applied to SCM can also support such a debate. They include: institutional theory (Powell & DiMaggio, 1991), stakeholder theory (Freeman, 1994), agency theory (Jensen & Meckling, 1976), intercultural dimensions theory (Hofstede, 1980), and so on. We need to advance towards a research context in which gender diversity becomes mainstream in supply chain sustainability studies, instead of being considered a marginal subject of research. By following such a perspective, scholars can better support practitioners to understand their role in SCM.

## 10 Managerial Implications

There are several implications of gender research and observations for supply chain practitioners. With this study, we encourage companies to create self-reflection on how to reduce or to eliminate the victimization approach toward a true gender diversity for sustainability in SCM. This evolution can relate to how engaged they are with education, for instance. Thus, starting from education in supply chain programs, in which women are less numerous than men, the entire sector has to promote and encourage access to supply chain training for young girls. In this sense, such an action might require that some industries have to improve their image and make their sector more attractive to women, especially heavy industries such as automotive or aviation. Supply chain actors can get involved in higher education, and even in secondary education. For instance, women leaders can share their experience and give talks or guest lectures at high schools and universities. In parallel, higher education institutions need to amplify their actions for that, pushing managers and lecturers to engage more and more with the subject.

Furthermore, for buying companies that are already engaged in promoting gender diversity in SCM, it is needed to analyze and share their knowledge regarding the benefits of an increased gender diversity in SCM. Partnerships or cooperation with researchers could help elucidate this lack of knowledge to build further arguments to promote gender diversity rather than numbers "only." This can support the gender diversity practice to increase and become a mainstream theme. Companies engaged with gender diversity in SCM should ensure that this is not a subject centered in top management involvement of different supply chain members, but a real matter in gender diversity in multiple levels. One way for that is developing sourcing or purchasing programs that engage supply chain members on the subject. Another way is to revise human resources policies and practices (e.g., hiring criteria).

Indeed, the buyer-supplier relationship seems key to develop sustainable practices along the supply chain. Research shows that more women at the supplier's side support the social pillar and foster both interorganizational collaboration and innovation towards sustainability. This characteristic implies that procurement managers should consider improving the diversity of their teams. Then, some MNEs, such as L'Oréal, are already reflecting on how to cascade their sustainable practices to their suppliers (Wilhelm & Villena, 2021) which are globally located. As part of those sustainable practices are social inclusion practices. We believe that MNEs have a big role to play in setting up cascading mechanisms that will empower their suppliers and lead them to have sustainable practices, such as including more women in their operations. In turn, these women working at suppliers can foster the emergence of new responsible practices, sometimes in connection with their own suppliers (tier 2). However, it is important to highlight again the need to align such practices with the socioeconomic and cultural contexts of suppliers.

Finally, this chapter provides practitioners with a reflection on the practices of human resources management applied to SCM regarding gender diversity. First, the SCM function is recognized as being male-dominated. Increasing the number of women would have important consequences for sustainability decisions along the supply chain, as depicted in the chapter. Also, in a world disrupted by the COVID-19 pandemic, it appears that building more resilient supply chains is desired. However, supply chain resilience requires different capabilities (Pettit et al., 2013), including organizational capabilities that rely on human resources and skills. The skills of both women and men are needed to achieve this goal. In addition, this chapter could also support women with their career path and limit the glass-ceiling issue: the more women there are in the function, the more likely they are to be considered when it comes to moving up the hierarchy.

Furthermore, increasing the number of women in the SCM function could help the entire company to increase diversity and its related positive impacts on sustainability. Finally, this chapter also allows practitioners to realize that in order to end the "talent war," considering hiring women into the role would help limit the shortage of such talent. To do so, employers are recommended to set up support for women – e.g., mentorship from supply chain leaders; making mandatory to have women in short list for an internal promotion process; facilitate distance working and increase the use of videoconferencing to limit long business trips; better recognize soft skills in recruitment ads for SCM positions; and create favorable conditions for women to participate in professional networking activities.

## 11 Summary and Conclusion

In this chapter, gender diversity in SCM has been explored from multiple lenses: victim-approach, positive discrimination, and self-made women. This review of literature and current trends among businesses highlight that gender diversity is underexplored, although some contributions show the added value gender diversity can bring to sustainability in the supply chain. Due to limited research and knowledge sharing on the topic, no generalities can be made. However, this chapter provides some hints on what can be done or what is missing by putting forward several theoretical perspectives that could help to better embrace this vast subject. Moreover, the chapter highlights rich contributions for the managerial world.

Nevertheless, these could be strengthened if more empirical research with the great involvement of practitioners would be conducted. In the same line, the involvement of practitioners in education would be appreciated to support the feminization of SCM educational programs. Probably, including gender diversity more thoroughly in business education programs would also help train more "gender-aware" supply chain managers. Finally, this chapter is a contribution to the fifth SDG which refers to achieving gender equality and empowering all women and girls.

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# Integrated Thinking of the Construction Supply Chain and Project Management

## Performance Domains and Delivery Principles

Gamze Tatlici Kupeli and Begum Sertyesilisik

## Contents



**Abstract**

The construction industry contributes to social development and the economy. However, the industry encounters numerous challenges that pertain to construction supply chain management (CSCM) and construction project management (CPM). Multi-stakeholder structure-based construction projects can challenge construction project management processes making them difficult to handle. Significant effort has been made to enhance the performance of CSCM and CPM. Despite these efforts, the construction industry still experiences challenges and problems. This chapter examines project delivery and project performance relationships within the construction supply chain. The chapter evaluates the construction supply chain from a project management perspective. The chapter emphasizes the need for integrated thinking to achieve value-oriented goals.

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Fundamental principles of the CSCM are assessed on various project performance domains.

**Keywords**

Supply chain management · Project management · PMBOK · Project delivery principles · Project performance domains

## 1 Introduction

Construction is among the most comprehensive, and dynamic industries worldwide. The global construction market is anticipated to grow by approximately $4.5 trillion in the 2020–2030 period (Marsh, 2022). Construction activities are complex, involving many stakeholders. Construction contributes greatly to economic development. Despite construction's economic significance, many problems remain, including low employee satisfaction levels, construction delays, and quality deficiencies. There are many uncertainties that also exist – for example, supply of raw materials, market demand, finished products, price of raw materials, production processing time, transportation and delivery budget and time, challenges due to vertical and horizontal competition, and collaboration between various parties. These challenges increase complexity, making optimal decisions even more difficult (Zhuang et al., 2014).

As construction projects are problem-, claim-, and dispute-intensive, it is critical to establish and manage competent and competitive construction supply chains starting from the early stages of construction project management (CPM). Many studies (e.g., Dubois & Gadde, 2000; Riley & Clare-Brown, 2001) emphasize the importance of improved construction supply chain (CSC) performance for achieving business objectives and gaining competitive advantage (Eriksson, 2010). Industrial supply chains are critical to organizational success (Aloini et al., 2015). Strategic supply chain management helps to facilitate organizations in improving their key outcomes (Hult et al., 2004). Project management within the supply chain can help increase efficiency, minimize risks, and minimize disruptions – but it may also result in complex activities.

Supply chain and project management are related and can be integrated. There are a number of ways for integrating supply chain strategies and with project management principles. Production and supply chain-related processes can set the stage for this integration (Tatlici & Sertyesilisik, 2019). Supply chain and project management integration has been investigated for many years (e.g., Fewings & Henjewele, 2019; Wei et al., 2021).

Various supply chain and project management models have been developed to define, explain, and obtain solutions to practical issues the industry faces (Zhuang et al., 2014). Examples of these models include input-output models and closed-loop supply chain network equilibrium models. The construction literature has also emphasized the need for an integrated supply chain and project management (Hu, 2008; Wei et al., 2021).

In this chapter, we focus on integrating supply chain and project management using the Project Management Institute (PMI) (2021)'s delivery principles and performance domains for the construction industry. Specifically, we use the project management body of knowledge (PMBOK) with its latest structure based on 12 project delivery principles (PDPs) and 8 project performance domains (PPDs) (PMI, 2021).

The importance of project management (PM) and SCM integration with relation to value creation, enhancing CPM, and construction company competitiveness are emphasized. This chapter emphasizes the importance of performance- and principle-based project management (PMI, 2021) and supply chain integration. This chapter discusses how construction project value can have the potential to be supported through effective and strategic integration based on the PMI (2021)'s PDPs and PPDs. We also discuss how this integration can be further integrated with and supported by lean, sustainable, and agile approaches.

The remainder of the chapter includes background, current concerns in the construction supply chain, PPDs and PDPs. It also provides recommendations for supporting the integration of CPM and construction supply chain management (CSCM) section with a summary and conclusion.

## 2 Background

Construction competition requires construction projects to be efficient, effective, and smart. Construction's fragmented supply is a shortcoming (Department for Business and Innovation Skills (DBIS), 2013). Many studies (e.g., Egan, 1998; Latham, 1994; Wolstenholme, 2009), strategies, and policies (e.g., UK's Construction 2025: Strategy (HM Government, 2013)) have focused on and called for construction performance improvement. For example, Latham (1994) emphasized the construction industry's under-performance related concerns and the need for improving performance without losing time.

The reports emphasized common and similar concerns and targets, including reductions in cost (Latham, 1994; Egan, 1998; DBIS, 2013); quality improvement and defect reduction (Latham, 1994; Egan, 1998); value for customer (Latham, 1994; Egan, 1998; Wolstenholme, 2009); and the need for partnering in the supply chain (SC) (Egan, 1998) and integrated SCM (DBIS, 2013).

Egan (1998) identified key drivers for change in construction with a focus on customers, integrated processes, and teams. Wolstenholme (2009) focused on business and economics, capability, delivery, and industrial structure and emphasized leadership, holistic thinking, integration, and value. In support of these studies, the HM Government (2013) emphasized "people, smart, sustainable, growth and leadership" keywords as main constructs of the Construction 2025 Strategy. Furthermore, the European Union has established the Construction 2050 Alliance, focusing on the construction value chain.

DBIS (2013)'s report on SC in the construction industry, highlighted construction industry's delay in taking relevant steps. Even if the reports and strategies (e.g., Egan, 1998; Latham, 1994; Wolstenholme, 2009; UK's Construction 2025: Strategy (HM Government, 2013)) have been prepared in different dates, these reports and strategies have common focuses and concerns. The timeline of the reports reveals that there is still a need for enhancing CPM and the construction industry, and for dealing with the construction industry and SC-related concerns.

PM guides the project to attain the desired outcomes through the application of skills, techniques, knowledge, and tools to project activities so that project requirements can be achieved (PMI, 2021). The objectives of reducing the cost, increasing quality, and improving all processes have fostered the widespread of SCM in the construction industry (Akboga & Baradan, 2011). Furthermore, the intensive use of outsourcing in the construction industry supports the adoption and implementation of SCM (Akboga & Baradan, 2011). Effective SCM can provide advantages to companies. SCM, as a structure formulated around a customer-oriented corporate vision, has its objective to manage the internal and external relationships of an organization (Min and Zhou, 2002). Contractors can get benefits from SC collaboration through reduced bureaucracy and cost, and increased profitability and market competitiveness (Akintoye et al., 2000). When PM and SCM are integrated, the value added to the project and the improvement in performance have been noted in various studies (e.g., Fewings & Henjewele, 2019; Wei et al., 2021). Furthermore, effective SC can support resilience of the PM. For example, 57% of the companies consider that diversification in their SC can prevent future disruptions (Hubs, 2021).

Egan (1998) asserted that goals and effective measures of performance are critical to improvement. SC plays a vital role in innovation and sustained performance improvements (Egan, 1998). SCM incorporates ways of eradicating waste and adding value to the SC (Saad et al., 2002; Amade et al., 2016). Latham (1994) and Egan (1998) suggested that the construction industry should implement SCM techniques (Amade et al., 2016). The construction industry should seek to develop conditions that support SC growth and encourage investments in the latest technology and employees (HM Government, 2013).

## 3 The Construction Supply Chain, Project Performance Domains (PPD), and Project Delivery Principles (PDP)

PMI's 8 PPDs and 12 PDPs comply with SC objectives (see Table 1). Companies willing to retain their competitive advantage should consider CPM and CSCM in an integrated way, relying on PMI (2021)'s PDPs (Table 1). The relationship among and importance of the PPDs of the PMBOK7 and the PDPs of the PMBOK7 (PMI, 2021) are examined from the SC and SCM perspectives under the PPDs headings using various relationships identified in Table 1. This section summarizes each PPD category and some of the major relationships and contributions to SCM.

**The stakeholders PPD:** Various stakeholders are involved in different project phases. Stakeholder impact, authority, and values may change as the project

**Table 1** Relationships among project performance domains (PPDs) and project delivery principles (PDP) for enhancing SCM

| | | PDP* | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Stewardship | Team | Stakeholders | Value | Holistic thinking | Leadership | Tailoring | Quality | Complexity | Opportunities and threats | Adaptability and resilience | Change management |
| PPD | Stakeholders | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Team | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Life cycle | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Planning | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Project Work | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Delivery | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Measurement | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Uncertainty | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

* PMI (2021) indicated PPDs and PDPs

progresses (PMI, 2021). Integration of SC stakeholders into the process can affect SC success (PMI, 2021). Success in the SCM necessitates the integration of business processes into the SCM's main objective, which is to create value for the SC (Lambert & Cooper, 2000).

The relationship between the stakeholder PPD and the team PDP needs to be considered and well-managed in the CSCM and CPM. Even if stakeholders are prioritized by team members, it can become difficult for the project team to effectively and directly engage with all stakeholders (PMI, 2021).

Integrating the SC into the project implementation process can enable improvement in the project outcomes through clearer objectives, stakeholder involvement, and result-oriented efforts (Børve et al., 2017; Erkul et al., 2020). The relationship between stakeholder PPD and stakeholder PDP needs to be considered in CSCM and CPM. As stakeholders differ from each other with respect to their power, interest, and involvement in projects (Erkul et al., 2020), each stakeholder's position related to the project needs to be analyzed (PMI, 2021).

Various aspects are involved in assessing stakeholders – for example, project interest, project proximity, influence degree, expectations, beliefs, attitudes, impact, power, and other features associated with the stakeholder and project interaction (PMI, 2021). Stakeholder PDP has effects on the project, performance, and results (PMI, 2021). Stakeholder performance can be improved by SC transparency in construction projects.

The relationship between the stakeholders PPD and holistic thinking PDP needs to be managed in the CSCM. Soft skills – such as interpersonal skills, conflict management, listening, and leadership skills like critical thinking and creating a vision – are needed to ensure that stakeholders are and remain engaged (PMI, 2021). Moreover, it is important to understand how requirements can influence integrated projects where stakeholders and teams are expected to work together (Karim Jallow et al., 2014).

**The team PPD:** The entire CSC needs to support the team PPD. The "project team" PPD involves creating a culture and atmosphere to create and establish a high-performing project team (PMI, 2021). This PPD involves identifying the steps required to encourage project team development and to motivate all staff to serve as leaders (PMI, 2021).

To improve process performance, PM can be delivered through teams (Larsson et al., 2018). The establishment of an effective and competent SC in compliance with the team PPD is important for CPM success. Lack of sufficient, effective, and robust project team integration among clients, the SC, and the supplier team is among the common reasons for project failure (Office of Government Commerce, 2005; Karim Jallow et al., 2014).

The team PPD, the stewardship PDP, and the team PDP can be considered together to enhance CSCM. The stewardship PDP is an indispensable principle for the team PPD (PMI, 2021). The establishment of the SC consisting of accurate and competent teams based on the stewardship PDP can support the PM process.

Relationships between the team PPD and the team PDP can be managed to support CSC and CSCM. The construction project team is established through the establishment of the SC. It may be difficult to manage teams (Oppong et al., 2017). Furthermore, the teams to be integrated into the SC must be selected, appointed, and assigned carefully so that the project can be accomplished successfully (PMI, 2021).

Team harmony, capacity equivalence, and their communication tools need to be considered in establishing the teams in the SCM (PMI, 2021). Furthermore, the relationship between the team PPD and the holistic thinking PDP can enhance the effectiveness of the CSCM. Fragmentation in project teams needs to be substituted by integrated teams working in collaboration (Sinclair, 2012; Karim Jallow et al., 2014). This integrated work environment can enable companies in the CSM to work complying with the holistic thinking PDP.

CSC needs to be established based on the competencies of the CSC companies. This necessity is supported by *HM Government (2013)'s Construction 2025 Strategy*, which emphasizes that multidisciplinary competencies are required by the construction industry so that integration throughout the SC can be achieved. Furthermore, as project teams and their members should be able to analyze each action's impacts on the construction process objectively (PMI, 2021), the holistic thinking PDP is needed. Holistic thinking involves critical thinking, disciplined thinking, as well as the evidence-based thinking (PMI, 2021).

Chan et al. (2003) highlighted the importance of a comprehensive system-thinking perspective to support SC performance and comply with SCM.

CS and CSM can be enhanced by the team PPD and the leadership PDP. Effective leadership's objective is to establish project teams that perform efficiently (PMI, 2021). Through the "effective leadership" PDP, project teams can introduce an adaptable and ethical environment (PMI, 2021). PMI (2021) recommends shared leadership in the SC. Shared leadership based on the fields of interest and experience in SC can support success in the PM.

**The life cycle PPD:** CSM and CSC need to comply with and support the life cycle PPD. The life cycle PPD is about all phases through which the project passes (PMI, 2021). According to the performance measurement perspective, the notion of life cycle is multifaceted (Suomala, 2005).

Relationships between the life cycle PPD and the holistic thinking PDP need to be considered in the CS and CCSM. Many changes can arise when the project progresses throughout its life cycle (PMI, 2021). It is important to manage information on client requirements throughout different life cycle stages and among all stakeholders (including designers and clients) (Karim Jallow et al., 2014). There have been project failures because of the inability to meet stakeholder requirements throughout the project life cycle (Chan & Oppong, 2017). Therefore, stakeholders should be involved in project delivery so that their expectations are systematically incorporated into the project policies and plans (Li et al., 2013; Chan & Oppong, 2017).

**The planning PPD:** CSCM needs to support the planning PPD. Project deliverables, development approach, organizational requirements, legal or regulatory restrictions, and market conditions are among the essential factors that determine the manner of executing project planning (PMI, 2021).

Weak project planning due to insufficient planning and risk assessment can result in a weak business case where there is a lack of consistency between organizational objectives and the project (Suomala, 2005). SC actors are linked to each other throughout the construction network, and they are brought together in the CSC planning and operations phases (Luong Le et al., 2021).

Relationships between the planning PPD and the team PDP need to be managed in the CSCM. It is vital to recognize areas to be modified so that the teams can anticipate changes and proactively formulate their responses to these changes (Ibbs et al., 2001). Adaptive approaches to the changes often use timeboxes so that the work quantity managed within a specific time-box can be determined (PMI, 2021).

SC integration and compliance among SC participants can enhance Construction planning and development productivity (Bankvall et al., 2010; Luong Le et al., 2021). The planning PPD needs to be considered in an integrated way with the stakeholder's PDP. Effective management can support shared understanding and consistency, leading to the attainment of project outcomes (PMI, 2021), which can be supported by SCM.

Project managers should know stakeholder-related opportunities and threats, accomplish social responsibilities, formulate shared goals, design relevant strategies, and increase stakeholder satisfaction to ensure effective management (Chan & Oppong, 2017).

Relationships between the planning PPD and the holistic thinking PDP need to be considered within the scope of the CSCM. When planning physical resources, many aspects – such as storage, movement, and disposition of materials – each being SCM activities – need to be considered, and the project team needs to make plans regarding the timing of materials (PMI, 2021). Using a holistic technique, it can be possible to describe emergent properties, which could not be identified through analysis and planning (Kraft & Steenkamp, 2010).

Planning PPD and tailoring PDP relationships need to be managed in CSCM. Through planning and tailoring, projects can achieve benefits such as reduction in waste, increased productivity, and efficiency in the use of project resources (PMI, 2021).

The planning PPD and the adaptability and resilience PDP can jointly support CSCM. Few projects can be performed exactly as they have been planned due to changes in estimates, information, and conditions (PMI, 2021). Furthermore, natural and man-made disasters foster the need for and importance of SC's resilience. For this reason, foreseeing possible scenarios and being prepared for different circumstances with the help of planning skills may make the project and SC process successful (PMI, 2021). For example, the pre-disaster as well as the post-disaster stages of construction depend on the SC disaster resilience (Sertyesilisik, 2017).

The SC needs to be adaptable to the changes. Supply change is a significant component of PM, where the following factors have an impact on supplier resilience: variations in cost and supplies, supplier geographical location, unpredictable quality parameters, supplier technical expertise, supplier flexibility, and inconsistencies in lead time (Shishodia et al., 2019).

Relationships between the planning PPD and the change management PDP can affect CSCM. Modifications may have to be made throughout the PM phases for a variety of reasons, including customer requests, the occurrence of a risk event or a change in the project environment, or understanding the requirements extensively (PMI, 2021). Various processes like change control processes, backlog reprioritization (re-arranging the list of pending project processes), or project re-baselining (updating the project baseline with respect to changes in cost, time, or goals of the project) need to be considered in the development approach (PMI, 2021). As a result, project change management should not be considered separately from the CSCM, as each decision made in this process is related to the project teams in the CSC.

**The project work PPD:** CSCM needs to enable SC to support the project work PPD. Project work is related to the development of processes and the performance of tasks to ensure that the project team delivers the estimated deliverables and results (PMI, 2021).

Jabarzadeh et al. (2021)'s study revealed a positive impact of supplier integration and organizational internal integration on the performance of the project-based organization. Managers should pay attention to supplier integration and internal integration so that project-based organizations can be successful, and their organizational performance can be improved (Jabarzadeh et al., 2021).

The relationship between the project work PPD and the team PDP plays a role in CSCM. Balance within the project team needs to ensure that business and stakeholder value are attained (PMI, 2021). The project work PPD and complexity PDP need to be carefully managed within the scope of the CSCM. Extensive complexity may be involved in SC (HM Government, 2013). As materials and supplies from third parties are required in many projects and as the planning, transportation, ordering, storing, tracking, and managing these resources require time and effort (PMI, 2021), an integrated logistics system and a logistics plan are required (PMI, 2021).

The project work PPD and the adaptability and resilience PDP in CSCM mean regular inspection of project work to identify improvement opportunities that can support project adaptability and resilience (PMI, 2021). Uncertainty may increase from scope changes. Organizations and managers need to make an assessment of the new risks emerging from these changes in scope (PMI, 2021).

It is vital to integrate resilience to the policies, codes, culture, and work traditions in the SC (Sertyesilisik, 2017). A robust and resilient SC can help attain the vision of the industry, along with a reputation for efficiency (HM Government, 2013). Sustainability of construction industry can be enhanced by its efficient project delivery technique, supported by integrated and robust SCs and efficient long-term associations (HM Government, 2013). Furthermore, as SC resilience is vital to ensure smooth flow of operations, construction SC resilience can improve the construction industry resilience (Sertyesilisik, 2017).

**The Delivery PPD:** CSCM needs to support the delivery PPD. Quality expectations, requirements, and scope should be fulfilled to attain the required deliverables that can help achieve the desired delivery PPD outcomes (PMI, 2021).

The delivery PPD and the value PDP jointly are integral to CSCM. The value PDP focuses on the outcome of the deliverables, and the focus of project teams shifts from deliverables to the desired outcomes to support achieving value in the projects (PMI, 2021).

The delivery PPD and the quality PDP relationships also require CSCM consideration. SCM is a critical success factor to meet the expectations on quality and deliveries. Ensuring quality of project processes and project deliverables can support SC integration, enhanced cost control, and reduced scrap and rework (PMI, 2021). From the logistics perspective, for example, the idea of quality management and waste reduction was stressed by Solaimani and Sedighi (2020). Materials are frequently damaged in transportation and material handling, causing write-offs and waste (Solaimani & Sedighi, 2020).

The delivery PPD and the complexity PDP relationship are integral to CSCM. For example, requirements elicitation, evolving and discovering requirements, and managing requirements are important items to deal with project complexity (PMI, 2021). The relation between the delivery PPD and the change management PDP needs CSCM management. To deal with the scope change, project teams can use a change control mechanism to examine all changes and the value these changes can add to the project (PMI, 2021). This change control mechanism needs to be at the SC level.

**The measurement PPD:** CSCM needs to support the measurement PPD. The extent to which the work carried out in the delivery PPD fulfills the metrics recognized in the planning PPD is determined by the measurement PPD (PMI, 2021). Common categories of metrics include business value, resources, delivery, deliverable metrics, forecasts, baseline performance, and stakeholders (PMI, 2021).

The measurement PPD and the value PDP relationship are important for CSC and CSCM. Value management is a PM approach that offers a structured way of assessing and designing a project to fulfill or surpass stakeholder requirements and improve the possibility of meeting benefits (Kliniotou, 2004; Karim Jallow et al., 2014). Use of the business value measurements can support the project deliverables to stay consistent with the business case and the benefit realization plans (PMI, 2021).

The measurement PPD and the holistic thinking PDP relationships provide the CSC and CSCM with how the data are used to take accurate action and as system interactions can support positive results (PMI, 2021). This relationship can support accurate and timely action in the CSCM.

Relationships between the measurement PPD and the tailoring PDP can be managed for enhancing effectiveness of the measures in the CSC. Effective measures can help to track, assess, and report information on project status, enhance project performance, and decrease the risk of weak performance (PMI, 2021). As measurement requires time and effort, it is important for project teams to measure relevant things and use correct metrics (PMI, 2021). The use of performance measurement approaches can enable measurement of the performance's efficiency and effectiveness (Yang et al., 2010). Further advancements in technologies and commercial models can provide benefits through transparent data sharing abilities throughout the SC (Construction 2025, 2013).

The measurement of PPD and the opportunities and threats of the PDP relationship can support CSCM. Performance measurement can provide effective results in the SCM process. With the help of various (e.g., the SCOR Model) performance measurement systems (PMS) in SCM, project opportunities can be assessed, and project risks can be minimized.

Different objectives for the advancement of a PMS in SCs include, but are not limited to: recognizing enhancement prospects, challenges, waste, bottlenecks, and accomplishment; enabling clear coordination and interaction, monitoring, and enabling growth; offering decisions based on facts, comprehension of business operations, and recognizing satisfaction of client needs (Gunasekaran & Kobu, 2007). Furthermore, Gunasekaran and Kobu (2007) determined the primary performance measures of SC to select cost-effective and accurate performance parameters (Najmi et al., 2013).

A complete analysis of a construction SC's efficiency is required for accurate monitoring of enterprise and cost (Tatlici & Sertyesilisik, 2019). The Supply Chain Council (SCC) created SCOR in 1996 as one of the performance evaluation models to evaluate four main factors (i.e., committed capital turnover, SC cost, flexibility/responsiveness, and commercial performance dependability) to make strategic and functional decisions about a firm's strategy development (Estampe et al., 2013). SCOR can be employed to assess, enhance, and standardize SC (SCC, 2008).

**The uncertainty PPD:** CSCM needs to support the uncertainty PPD. Uncertainty is related to inadequate understanding and awareness of events, issues, methods to follow, or solutions to attain (PMI, 2021). The uncertainty that a project may have to experience may be ascertained by the SC (Schlittgen et al., 2016).

Information is important in dealing with uncertainty. For example, when there is a lack of accurate and real-time as-built information, the managers can be unable to keep track of schedule, cost, and other indicators of performance, and they can encounter difficulty in managing uncertainty and variability involved in project activities (Zhang et al., 2009).

Many causes of SC complexity can contribute to the uncertainties, which can lead to vulnerability factors (Simangunsong et al., 2012; Thomè et al., 2016; Wei et al.,


**Fig. 1** PMI (2021)'s PDPs 12 principles based SCM to achieve PMI (2021)'s 8 PPDs

2021). The relation between the uncertainty PPD and the opportunities and threats PDP needs careful consideration in CSCM. Risks are an aspect of uncertainty (PMI, 2021). As different projects involve different degrees of risks and uncertainties due to their unique nature, the emerging risks must be carefully detected by the project team to capitalize on the opportunities and prevent threats at the same time (PMI, 2021). Threats and opportunities are integral parts of project implementation, and they are presented by uncertainty examined and investigated by project teams, who then can determine solutions to address them (PMI, 2021). Project managers need to concentrate on managing the time-use of important sources, greater clarity of task-to-task interfaces, and eliminating unpredictability from every SC member and specific project activities to avoid those threats that imperil project efficiency (Wei et al., 2021).

The project team must have a proactive plan of response ready to deal with threats and opportunities in case of risk emergence (PMI, 2021). The relation between the uncertainty PPD and the adaptability and resilience PDP needs to be managed within the scope of the CS and CSCM. An organization can strategize its SC resilience by developing innovation, technological, and collaborative efficiency (Chatterjee & Chaudhuri, 2021). SC resilience can facilitate PM by handling unpredictable SC disruption, which can support competitiveness of the organization (Wei et al., 2021).

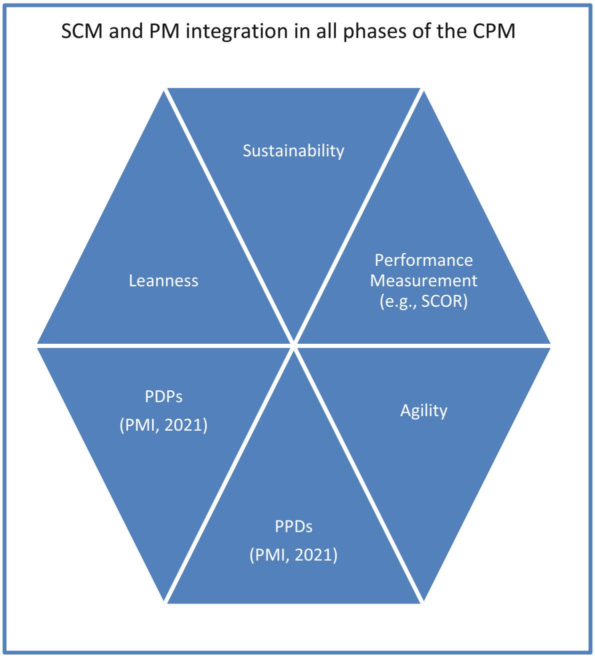
### 3.1 CSCM's Contribution to PM Principles and Performance Areas

SC and their SCM need to be based on all 12 PDPs of PMBOK7 (PMI, 2021) to achieve the 8 PPDs of the PMBOK7 (PMI, 2021) (Fig. 1). In other words, the 12 PDPs, which are indicated in the PMBOK7 (PMI, 2021), need to be considered as fundamental principles of the SCM. Furthermore, success and effectiveness of the SCM need to be considered in correlation with the achievement level of the 8 PPDs indicated in the PMBOK7.

## 4 Recommendations for Supporting the Construction Project Management (CPM) and the Construction Supply Chain Management (CSCM) Integration

The main constructs of integrated SCM and PM in all phases of the CPM in compliance with PMI (2021)'s PDPs and PPDs are highlighted in the Fig. 2. The PDPs and PPDs of the PMBOK7 are important and need to be considered for the

**Fig. 2** Main constructs of integrated SCM and PM in all phases of the CPM




establishment of effective, sustainable, agile SC in the construction industry. Waste in the processes can be removed by agile and lean (agilean) PM. Agilean PM has been described by Demir et al. (2013). Universal PM approaches, like those from the PMI, reinforce agilean PM at the strategic level (Demir et al., 2013). Sustainability, lean, and agile approaches can be used to enhance PM and SCM in compliance with PMI (2021)'s PPDs and PDPs. SCM performance measurement needs to be performed throughout the CPM phases. With the use of the SCOR paradigm in SCM, it may be possible to increase the efficiency of lean, agile, and sustainable systems as well as to reduce PM issues in the construction industry (Tatlici & Sertyesilisik, 2019).

The PPDs of the PMBOK7 (PMI, 2021) emphasize the importance of value creation (e.g., the delivery PPD), which complies with the lean management principles. Lean approaches can support the achievement of the PMI (2021)'s PPDs, as lean construction (LC) is mainly value-focused. LC takes lean production system's goals (i.e., maximization of value and minimization of waste) and implements them to procedures in project delivery approach (Marhani et al., 2013).

Fawcett et al. (2008) and Rausch-Phan and Siegfried (2022) have emphasized benefits – such as risk mitigation, better collaboration, reduced uncertainty and construction waste, enhanced communication, project flow and quality control, and project value creation – from integrating SCM to PM and SCM to obtain project value.

Lean establishes sustainable utilization of assets to enable the company to cut expenses, remove waste, and accomplish projects on time (Lim, 2008). Hence, LC is a significant milestone in the construction industry, ensuring value delivery to clients (Marhani et al., 2013). Advantages offered by LC to the construction industry have been identified by many researchers, including Lim (2008) and Koskela (1992), Abdullah et al. (2009), and Jørgensen and Emmitt (2008), who have emphasized that LC can support project planning and lead to enhanced project quality and sustainability (Marhani et al., 2013).

Lean principles and value-oriented work are in compliance with the goals of PM and SCM. Lean should be considered as an integral part of SC, especially due to the many benefits of lean approaches (e.g., resource management and waste reduction) (Suresh et al., 2011). Lean SCM can be effective for achieving PM performance and principles.

The PPDs of the PMBOK7 (PMI, 2021) emphasize the importance of agility (through the uncertainty PPD). All PMBOK editions had a narrative based on the predictive and waterfall methods, which is a traditional PM approach. Agile PM frameworks have emerged since the 2000s due to many reasons, including technological development, and increasing competition (Guvenatam, 2021). Agile concepts and methodologies offer the prospect for a better pre-design strategy (Owen et al., 2006). Application of agile PM (APM) concepts in the design phase is suited to the construction industry requirements (Owen et al., 2006).

To be agile, an organization or a project must be designed in such a way that it can accept the disruption effectively embracing possibilities to augment value outputs (Galankashi & Helmi, 2016). Most agile development methodologies divide work into little chunks to reduce cumulative threats and help the project to respond to modifications (Straçusser, 2015). Furthermore, agile allows users to provide prompt input to the team and to introduce or change functionalities (Straçusser, 2015).

Environmental, social, and economic sustainability are the three main pillars of sustainability (Purvis et al., 2019). These three pillars can support sustainability and serve as a guide for standards and certifications that assess the sustainability of businesses, goods, and services. Therefore, sustainability is among the main constructs of integrated CSCM and PM in all phases of the CPM in compliance with PMI (2021)'s PDPs and PPDs. Incorporation of sustainability considerations into fundamental business plans can support sustainability practices in companies (Elmualim et al., 2012). Adherence to sustainable practices necessitates the inclusion of sustainability into the corporate plan (Ikediashi et al., 2012).

## 5 Summary and Conclusion

This chapter examined PMI (2021)'s PDPs and PPDs from the CSC perspective, emphasizing the importance of integrated thinking of PM and CSCM and the relationship among PDPs, PPDs, and SC.

PMBOK v7 has evolved the PM approach into performance and principles and prioritized the competencies of each team involved in the project – including working with team, adaptability to changes, and quality of work (PMI, 2021). Furthermore, PMI (2021)'s PPDs and PDPs are value-focused, and their integrated thinking with CSCM can improve CSCM. Thus, it is important to integrate PM and CSCM for value- and success-oriented, sustainable, and agile projects.

This chapter, focusing on the PMI (2021)'s PPDs and PDPs, draws attention to the need for integrated thinking of CSCM and PM to achieve CPM's value-oriented goals supported by the main constructs – specifically sustainability, lean, agility, PMI (2021)'s PPDs, PMI (2021)'s PDPs, and performance measurement (see Fig. 2).

This chapter focused on project management and SCM integration based on PMI (2021)'s PPDs and PDPs. Furthermore, this chapter emphasized the necessity of understanding the importance and benefits of the widespread use of the PDPs based on sustainable, resilient, agile, and lean SC, which enabled agilean PM to achieve PMI (2021)'s value-based PM (Fig. 3). This use complies with and supports construction industry-related main reports (e.g., Latham, 1994; Egan, 1998) and their recommendations. CSCM is essential for enhancing PM's performance and PMI (2021)'s PPDs. Effective CSCM, in compliance with PMI (2021)'s PDPs, can support project performance and PPDs in compliance with the project's goals.

PMI (2021)'s PPDs are the basis of SCM to achieve value-based PM. The PPDs are the criteria surrounding the SC. Relations among PMI (2021)'s PDPs and PPDs need to be managed throughout the entire CPM processes to enhance the value creation capacity of the PM and CSCM (Fig. 3). For project success, the SC must become an intrinsic component of the project ecosystem.

Main constructs of integrated SCM and PM in all phases of the CPM (Fig. 2) can act as supporters of the CSCM and PM integration. Leanness, agility, and sustainability principles/tools/topics should be integrated with the consideration of the PPDs of PM to enhance the performance of the SC. Identifying the accurate performance tools to support the SC strategy is important for sustainable, lean, and agile approaches for the success in the CSC performance. The SCOR model can be used together with the other main constructs (Fig. 2) of integrated CSCM and PM in all phases of the CPM. PM's success can be enhanced by establishment of a successful and competitive SC.

This chapter's emphases are in compliance with the emphases in construction industry-related reports (e.g., Egan, 1998; Latham, 1994). Construction project value can be enhanced by effective and strategic PM and SCM integration based on the PMI (2021)'s PDPs and PPDs, which can be further integrated with and supported by the lean, sustainable, and agile approaches in the CPM to gain competitive advantage in the construction industry.

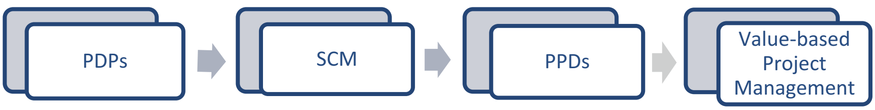



**Fig. 3** Relationship among SCM, PPD, and PDP

Researchers, academics, students, and professionals in the relevant field can benefit from this chapter. Future research is recommended to be performed on artificial intelligence's and industry 4.0 technologies' potential contributions to enhance CSCM and PM integration and performance.

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# Conceptualizing Circular Supply Chains: A Theory Building Approach

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## Contents



**Abstract**

Integrating circular economy (CE) principles into supply chains and operations is generating a lively debate among scholars and practitioners. However, while this literature stream is becoming abundant, there are still ambiguities in the adopted terminologies. While the established terms in the supply chain management domain, such as closed-loop and open-loop supply chains, are frequently used in the CE context, the term "circular supply chains (CSCs)" is gaining

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prominence on its own. Hence, the purpose of this study is to provide clarity on this terminology while conceptualizing CSCs through a theoretical approach. We conceptualized CSCs as complex adaptive systems, with supply chain actors in physical and support supply chains who ensure the flow of products, End-of-Life products and materials, and, at the same time, considering the critiques on CE. We introduce three different CSC archetypes, closed-loop supply chains, open-loop supply chains, and CSCs – combining characteristics of both closed- and open-loop supply chains – aligning these archetypes to the current CE debate. The regenerative and restorative approaches and the application of value retention options – such as reduce, repurpose and recycle – in these archetypes are further illustrated through industrial examples. Other than traditional supply chain actors' commitment to successfully managing CSCs, collaboration with stakeholders beyond the boundaries of supply chains is crucial. When designing and planning CSCs, it is essential to understand the compatibility among resource flows to ensure improved sustainability. Scholars and practitioners can benefit from this conceptualization by comprehending the potential and boundaries of CSCs. Further, future research and understanding can empirically validate this work.

**Keywords**

Circular economy · Circular supply chain · Closed-loop supply chain · Open-loop supply chain · Operations and supply chain management · Sustainability

## 1 Introduction

In the last decade, the circular economy (CE) discourse has gained momentum, with increasing attention paid mainly by policymakers and think tanks. Despite the scholarly introduction of CE more than 30 years ago (Pearce & Turner, 1990), the concept is further developing around background notions such as energy consumption, resource depletion, life cycle assessment, waste, and emission generation (Korhonen et al., 2018b). At the same time, CE can be characterized as an essentially contested concept, with many disagreements over its definition and conceptual cornerstones (Korhonen et al., 2018b). Hence, it is vital to bear these different viewpoints in mind when integrating CE into any practical application.

The discourse on integrating CE into operations and supply chains is recent among scholars and practitioners. There are various approaches and strategies linked to CE implementation (Yang et al., 2018). In this regard, it is crucial to understand how circular thinking can be integrated into operations and supply chains (Seuring et al., 2022). While practitioners are initiating new projects to ensure CE implementation in supply chains, scholars are probing deep into these programs and investigating how and what aspects of operations and supply chains need to be different from traditional supply chains. Some of these scholars view these practices in the CE context as modified versions of existing operations (Genovese et al., 2017), while others highlight new practices such as industrial symbiosis integrated through other fields such as Industrial Ecology (De Angelis et al., 2018).

As a result of these differences, there is an ongoing debate over supply chain terminology in the CE context. For instance, new terminology is emerging as circular supply chains (CSCs) to denote the supply chains in the CE context (Batista et al., 2018; De Angelis et al., 2018). However, the supply chains in the CE context are commonly referred to as closed-loop supply chains (CLSCs) in the operations and supply chain management (OSCM) discourse (Taghikhah et al., 2019). Amidst all these terminologies, some have introduced another archetype called open-loop supply chains (OLSCs) (Kalverkamp, 2018), which is also embedded in OSCM discourse (Gou et al., 2008). Given the inconsistency in the use of CE-related terminology in the supply chain literature, it is important to establish a clear taxonomy of supply chains in the CE context. As such, by drawing on current knowledge on supply chains in the CE context and the theoretical foundations of OSCM, we provide an overview on:

1. Integrating circularity into supply chains while identifying and clarifying critiques on CE
2. Identify different supply chain archetypes in the CE context that can form the foundation of CSC terminology

This chapter is structured as follows. First, we will introduce the critiques toward CE and discuss how we can potentially overcome these limitations through our conceptualization. Secondly, we will conceptualize CSCs based on the OSCM theory development by Carter et al. (2015) while addressing the critiques on CE. We will further illustrate this conceptualization through practical applications of CSCs. Finally, while identifying different supply chain partners engaged, a comparison among probable CSC archetypes is presented, elaborating their similarities and differences to view the supply chains in the CE context comprehensively.

## 2 Critiques of the CE

When conceptualizing supply chains in a CE context, it is noteworthy to consider the critiques of the CE concept. One of the main critiques of CE is based on its thermodynamic limits. Even though cyclical resource flows create waste and emission, Korhonen, Honkasalo, and Seppälä (2018a) argued that product reuse, remanufacturing, and refurbishment should be prioritized over recycling as these strategies still offer an opportunity to make material and energy cascades sustainable in a global economy. Agreeing with this argument, Reike et al. (2018) also asserted that short- and medium-term loops should be favored over long-term loops. They categorized these value retention options (also known as Rs) under short-term loops (e.g., reduce, resell/reuse, repair, refuse), medium-term loops (e.g., remanufacture, refurbish, repurpose), and long-term loops (e.g., recycle, recover, re-mine). However, it is still essential to evaluate the contribution of each circular approach to sustainability (Korhonen et al., 2018a), especially given the criticism pointed toward CE regarding its unclear contribution to environmental and social sustainability performance (Corvellec et al., 2021). Hence, we integrate value retention options representing these loops and highlight their contribution to improving sustainability performance in the CSC conceptualization.

The CE is also critiqued for spatial system boundary limitations (Korhonen et al., 2018a). The materials and energy flow through different boundaries of organizations, administrations, and geographies. As a result, sustainability issues in CE approaches can be displaced and shifted across these boundaries. Hence, to overcome the critique on the limitations of spatial system boundaries of CE, we selected examples with local and regional level applications where boundary crossing is limited. We further ensured the sustainability impact of each example while reducing the concerns relating to problem displacement and shifting.

Similarly, there are concerns relating to intra- and inter-organizational management strategies when implementing CE practices. For instance, it is unclear who leads the implementation of CE practices in a network of actors, who takes the responsibility, and how these actors contribute to this network (Korhonen et al., 2018a). Hence, in this study, we considered the viewpoint of the focal firm (mainly the brand owner) as an attempt to overcome this limitation. The focal firm can be characterized by three criteria: (1) designs the product, (2) owns the related brand, and (3) organizes the supply chain (Seuring & Müller, 2008).

The unclear applicability is another critique of CE (Corvellec et al., 2021). This is mainly due to the misalignment among three pillars: policies, organizations, and individual consumers. Hence, when conceptualizing CSCs, we exemplify CE-practices implementation through real-world scenarios. These examples are mainly derived from the case studies published by the Ellen MacArthur Foundation, given the comprehensive and detailed nature of the presentation. We further validated and improved the content of these examples through grey literature. Additionally, we emphasize how these three pillars have been successfully aligned for the CE implementation through each example. As a result, this chapter focuses on understanding how supply chains can be designed by addressing certain limitations toward CE implementation.

## 3 Basis for Conceptualization

The conceptualization of CSCs is based on the following foundational premises presented by Carter et al. (2015) relating to the structure and boundary of supply chains. These premises provide a good starting point for CSC theorization with a comprehensive approach.

- A supply chain is a network with nodes and links, which acts as a Complex Adaptive System (CAS). While a node is an establishment referring to the agent's ability to make decisions and maximize gains within the constraints in which it operates, a link comprises transactions consisting of the flow of materials, finance, and information between nodes. Hence, a node is considered a "supply chain actor," and a link is regarded as a "product/End-of-Life (EoL) product/material flow."

- A supply chain is relative to a particular product/agent. This particular agent related to the supply chain is defined as a focal firm, and a product represents an input to or an output of the agent, which has a physical substance (product/EoL product/material).
- A supply chain is a combination of physical and support supply chains. A physical supply chain consists of "agents with a permanent, physical location where activities occur that add form, place, and/or time utility" to the product flow (Carter et al., 2015, p. 91). In a physical supply chain, there are different agents to be considered, as follows:
  – Traditional supply chain actors (e.g., manufacturers, suppliers, retailers, and end consumers)
  – Nontraditional supply chain actors (e.g., nongovernmental organizations [NGOs], community members, local authorities, and competitors) (Pagell & Wu, 2009; Rodríguez et al., 2016)
  – Supplementary supply chain actors who gather, make changes, or add values to the product/EoL product/material flows (e.g., waste pickers and recyclers)
  – Other manufacturers who are capable of using recovered products/materials other than the original equipment manufacturer (OEM) (Genovese et al., 2017)
- A support supply chain comprises "nodes through which a product (relative to the focal agent) does not flow, but which supports the physical supply chain of that product" (Carter et al., 2015, p. 91), such as financial institutions, brokers, and truckload transportation. Furthermore, actors such as policymakers, industry associations, and research institutes can also be identified under the support supply chain (Liao & Kuo, 2014).
- A supply chain is bounded by the visible horizon of the focal agent. Carter et al. (2015) refer to the agent's awareness (visibility) of "the physical nodes and links that move and add value to the product and the corresponding support nodes" (p. 93). Furthermore, it is noteworthy that the focal agent's visibility can be attenuated due to physical distance, cultural distance, and lack of centrality/closeness.

Based on these premises, we conceptualized the CSCs in the next section identifying the nodes and links in the combined physical and support supply chains as a CAS.

## 4 Conceptualizing CSCs

Different approaches are taken to ensure the efficient use of resources while eliminating waste creation in the CE. One main approach is to improve the circularity of product and resource flows. For example, Bocken et al. (2016) introduced three options: slowing (extending use), closing (reusing), and narrowing (reducing) loops.

These approaches lead to new business models, such as shifting from product ownership to services (De Angelis et al., 2018). Similarly, the focus on how to change the existing linear models to circular models is also gaining attention. As a result, the integration of circularity into supply chains has become inevitable.

Geissdoerfer et al. (2018) defined CSCs as “the configuration and coordination of the supply chain to close, narrow, slow, intensify and dematerialize resource loops” (p. 713). Linking to the already existing terminology in OSCM discourse, Batista et al. (2018) defined CSCs as “the coordinated forward and reverse supply chains via purposeful business ecosystem integration for value creation from products/services, by-products and useful waste flows through prolonged life cycles that improve the economic, social and environmental sustainability of organizations” (p. 446). Other scholars such as Farooque et al. (2019) also acknowledged this definition, given that this work has integrated the regenerative and restorative processes of CE to understand the circularity of supply chains. This chapter’s conceptualization is also in line with this definition, where CSCs can be considered a combination of forward and reverse supply chains (RSCs).

CSC terminology has been criticized due to its clashes with the well-established CLSC discourse. For instance, Mishra et al. (2018) proposed that CSCs can be used “for cases where circular economy principles are explicitly incorporated in CLSC for value creation” (p. 509). De Angelis et al. (2018) further argued that CSCs should be expanded beyond CLSCs, opening opportunities for materials to flow across supply chains. Hence, considering this conflicting scholarly discussion in literature, this chapter’s conceptualization includes the integration between forward supply chains and RSCs.

## 4.1 Integration of Forward Supply Chains and RSCs

Forward supply chains, also known as traditional supply chains, accomplish their mission once the end consumer owns the product (Guide et al., 2003). However, RSCs extend the forward supply chains by bringing the used products back into the system. Hence, RSCs act as “the effective and efficient management of the series of activities required to retrieve a product from a customer and either dispose of it or recover value” (Prahinski & Kocabasoglu, 2006, p. 519). These series of activities performed to retrieve a product can be identified as the key processes in reverse logistics: product acquisition, collection, inspection and sorting, and disposition (Agrawal et al., 2015).

The discussion on integrating forward supply chains and RSCs is well established in the OSCM discourse as CLSCs and OLSCs. OSCM literature primarily focuses on CLSC, where the discussion on OLSC is narrowly addressed (Govindan & Popiuc, 2014). Guide and Van Wassenhove (2009) defined CLSC as “the design, control, and operation of a system to maximize value creation over the entire life cycle of a product with the dynamic recovery of value from different types and volumes of returns over time” (p. 10). Furthermore, over the years, scholars segregated the difference between CLSCs and OLSCs based on the value recovery process in the RSC. The recovery of the used or EoL products by the OEM is categorized as CLSCs, whereas third parties or other manufacturers engaging in this process are classified as OLSCs (Govindan et al., 2013; Islam & Huda, 2018; Rahman & Subramanian, 2012).

If the RSC can bring the EoL products to the source of their production, it can create a closed loop. On the other hand, when the RSC brings these EoL products to different destinations, they create an open loop. Hence, it is evident that the RSC plays a crucial role in closing existing loops and opening new loops. Consequently, based on the recovery activities of the RSC, the engagement of different parties becomes crucial. To overcome most of the uncertainties entailed with the RSCs, such collaborations play a pivotal role (Agrawal et al., 2015).

The crucial role of RSCs is emphasized in the early scholarly attempts to integrate CE into OSCM scholarly discussion. For instance, Genovese et al. (2017) introduced RSCs as both CLSCs and OLSCs in the CE context. While the attention that should be paid to RSCs in the CE context is lacking (Mokhtar et al., 2019), the most commonly used terminology is limited to the term "CLSCs." Therefore, it is clear that a good understanding of the role of RSCs in the CE context is required to reduce conceptual confusion and dive deep into the understanding of supply chains in the CE. Hence, we propose three probable archetypes for CSCs based on three types of RSCs designed for CE implementation drawn upon the value retention options proposed by Reike et al. (2018).

## 4.2 *CSC (Type 1)* with *RSC (Type 1)* Where the EoL Products Are Returned to Their Origin

### Close the Loop with CE motivation – Restorative Approach Through Reduce and Reuse (Short-Term Loops)

We illustrate *CSC (Type 1)* through Example 1 on the universal bottle introduced by the Coca-Cola company and its bottling partners in Latin America (Ellen McArthur Foundation, 2018a). Coca-Cola introduced a reusable plastic bottle that can be used to fill their different soda brands. With the reuse of plastic bottles, the use of virgin materials to produce plastic bottles is reduced. Hence, the life cycles of plastic bottles are extended. Furthermore, with the introduction of the reuse principle, Coca-Cola has *retrofitted* its supply chain; that is, Coca-Cola adopted a new set of practices aligned with CE.

Once the consumers finish the drink, they can hand the empty bottle to the retailer or the point of sale. Consumers will have to pay an indirect deposit for the bottles, which will be received as a discount on their next purchase once they return the empty bottles. The retailers will store these empty bottles and hand them over to Coca-Cola when delivering new orders. Then Coca-Cola will bring these empty bottles and hand them over to the bottling partners to clean the bottles, wash off the paper labels of different brands, and refill and rebrand the bottles with new labels. All parties involved in the physical product flow in the forward supply chain – also known as traditional supply chain actors – are also involved in the reverse process.

Even though this operation seems straightforward, the commitment of various parties to accomplish this approach was quite exhaustive. While the internal departments of Coca-Cola have dedicated themselves to the design process of this universal bottle, the immense support from both supply chain partners and external parties has been crucial. Bottling partners of Coca-Cola have committed to understanding the specific requirements of the universal bottle manufacturing, packaging, merchandising, and distributing while investing in required infrastructure changes. Similarly, external consultancy firms were also involved in bringing in outside expertise. For example, TriCiclos, a Latin American social enterprise, focused on designing and implementing solutions to eliminate waste, provided an independent life cycle assessment of this new production system. Hence, these external consultants assist the product flow and become a part of the support supply chain.

Interestingly, apart from the consumers who return the plastic bottles to the retailers, waste pickers will return the thrown-out or disposed of plastic bottles to the retailers. These waste pickers are also known as *scavengers* who are essential external parties in supply chains. These scavengers can be informal or formal. Informal scavengers are mainly poor and marginalized people collecting waste for survival purposes with inefficient and unhealthy methods, while formal scavengers provide centralized and efficient waste management systems (Zerbino et al., 2021). These scavengers play a major role in collecting waste plastic bottles (Asim et al., 2012). Hence, these waste pickers become a part of the physical supply chain while providing such supplementary support.

We further illustrate this example in Fig. 1, which depicts how the loop is closed. Further, as presented in Table 1, we identify physical and support supply chains

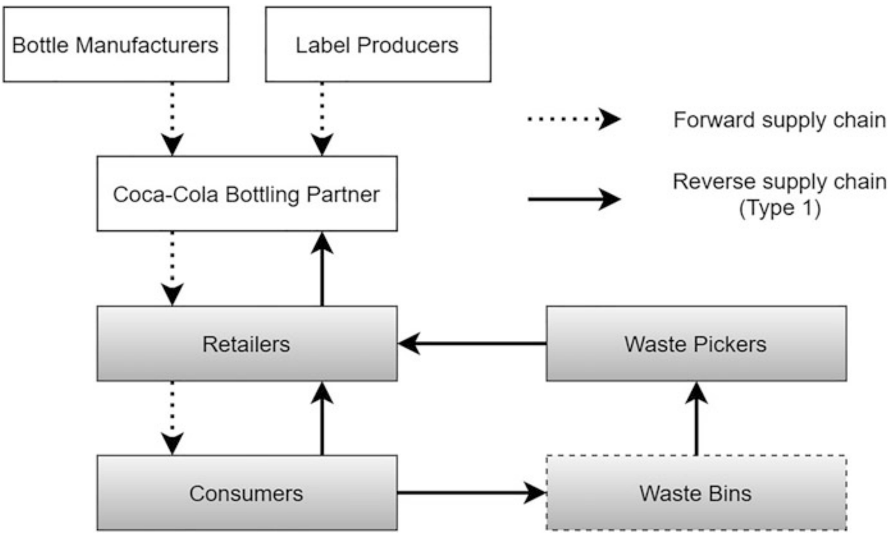


**Fig. 1** Product/EoL product/material flow in CSC (Type 1) in Example 1

**Table 1** Identifying nodes in CSC (Type 1) in Example 1

| | | | |
|---|---|---|---|
| **Physical supply chain** | Traditional supply chain actors | Bottle manufacturers, Label producers, Coca-Cola bottling partners, retailers, end consumers (returning empty bottles to the retailers/throwing the empty bottles into waste bins) | High visibility to the focal firm |
| | Supplementary supply chain actors | Waste pickers | Low visibility to the focal firm |
| **Support supply chain** | Support supply chain actors | External consultants | High visibility to the focal firm |

along with the defined nodes. Besides the waste pickers, Coca-Cola, as the focal firm, has the visibility of other supply chain actors in the *RSC (Type 1)*.

## 4.3 *CSC (Type 2)* with *RSC (Type 2)* Where the EoL Products Are Returned to Another Supply Chain as a Resource

### Open a New Loop with CE Motivation – Regenerative Approach Through Repurpose (Medium-Term Loops)

*RSC (Type 2)* is illustrated through Example 2 on BioPak. BioPak manufactures compostable food service packaging using renewable plant-based materials (Ellen McArthur Foundation, 2018b). This example illustrated how a supply chain can be *circular by design* as the supply chain has already been designed to improve sustainability in CE. Apart from the product design contributing to the CE implementation, BioPak also provides collection and composting services to ensure that circularity is further extended. This service is mainly established in Australia and New Zealand and recently started in the UK. Even though this is a nonprofit effort, BioPak is deemed to understand its extended producer responsibility.

BioPak provides an online platform called Compost Connect, connecting restaurants and locals with composting services in different states in Australia and New Zealand. This service collects compostable packaging along with food waste. The company provides separate bins to collect all the organic wastes without separation. A restaurant or an individual can simply look for a composter in its postal code area, enter the details of the location, and agree on a pickup schedule. While the involvement of restaurants indicates the involvement of traditional SC actors, the engagement of individuals in local communities highlights the active presence of a nontraditional member of the supply chain in the product flows (physical supply chains).

In addition to the businesses such as restaurants and locals engaged in reversing their landfill food waste to compost, BioPak is working with various organizations. Especially, local and industrial composting services, waste management industries, and local governments play a prominent role in improving the composting

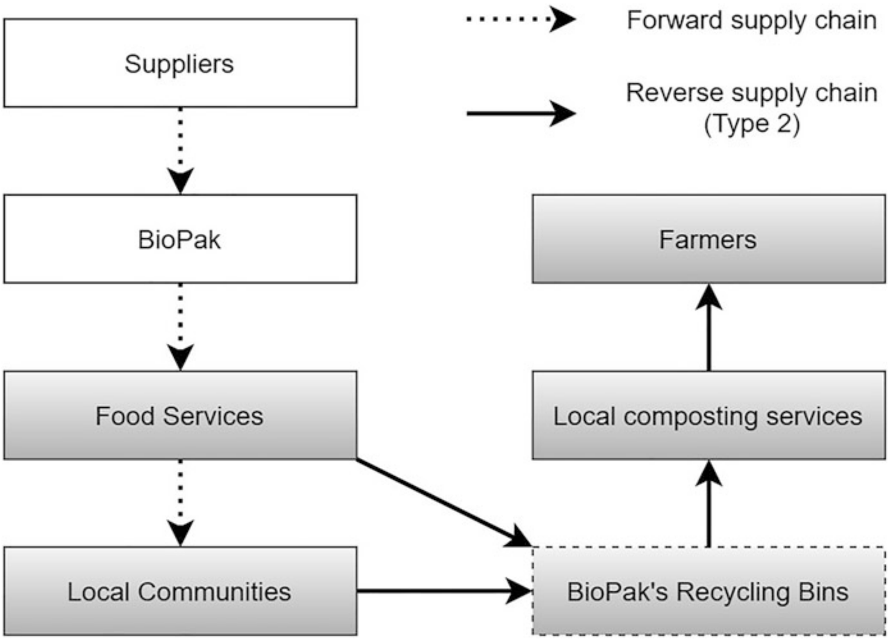


**Fig. 2** Product/EoL product/material flow in CSC (Type 2) in Example 2

infrastructure while scaling up operations. These actors support the reverse flow while being a part of the physical supply chain. Further, these initiatives are already receiving the support of the Australian Organic Recycling Association (AORA), which is a part of the support supply chain.

This scenario is illustrated in Fig. 2, and the nodes are defined in Table 2. BioPak, as the focal firm, knows the supply chain actors in the *RSC (Type 2)*, other than the farmers directly connected to the local composting services.

## 4.4 *CSC (Type 3)* with *RSC (Type 3)* Where the EoL Products Inside and Outside of the Own Supply Chain Are Returned as a Resource

### While Closing Its Own Loop, Several Resources Are Also Brought in Through Another Open Loop – Restorative Through Recycling (Long-Term Loops)

Example 3 is from Renault Group and illustrates the *CSC (Type 3)* with its factory dedicated to CE in mobility. This case is also an example of a *retrofitted* supply chain where Renault has adopted CE-oriented practices to achieve its CE strategy.

**Table 2** Identifying nodes in CSC (Type 2) in Example 2

| | | | |
|---|---|---|---|
| **Physical supply chain** | Traditional supply chain actors | Suppliers, BioPak, Restaurants | High visibility to the focal firm |
| | Nontraditional supply chain actors | Local communities gathering waste in BioPak wastebins | High visibility to the focal firm |
| | Supplementary supply chain actors | Compost partners (local and industrial composting services along with waste management industries) | High visibility to the focal firm |
| | Other manufacturers | Farmers | Low visibility to the focal firm |
| **Support supply chain** | Support supply chain actors | Industry Associations (e.g., Australian Organics Recycling Association) | High visibility to the focal firm |

Re-factory has changed Renault's manufacturing processes (Ellen McArthur Foundation, 2020). One such initiative is recycling copper retrieved from electrical wiring in End-of-Life Vehicles (ELVs), collaborating with its subsidiaries and partners (Communication Department – Groupe Renault, 2020).

INDRA, one such subsidiary, partnered with Suez, which recovers secondary materials for ELVs. Boone Comenor is another company that collaborated to recover metallic scrap materials (e.g., copper wiring) from the automotive industry. These recovered materials are then sent to the recyclers by another Renault wholly-owned subsidiary, Gaïa (Curt, 2018).

MTB Recycling is one such recycler producing 99.9% pure copper out of these wirings (Tse et al., 2016). This recycled copper is then sold internally and externally in Renault's supply chain. Internally, Fonderie de Bretagne (Groupe Renault) uses this recycled copper to produce pearlitic cast iron (Renault Group, 2016). The external parties, such as other auto part manufacturers, also become a part of this supply chain as they get their recycled copper supply for aluminum processing.

The legislative lead from the European Union (EU) was paramount to making this operational change possible with the European Directive on dismantling and recycling ELVs (European Commission, 2000). Similarly, this approach was supported by the research effort of the EU under the EU LIFE Research Program named ICARRE95 (European Commission, 2015).

This product flow within Renault's supply chain and outside in other automobile supply chains is illustrated in Fig. 3. The involved parties are shown in Table 3. As the focal firm, Renault Group has the visibility of most supply chain actors illustrated in Fig. 3, except for the other ELV owners directly linked to INDRA and other auto suppliers who are the customers of MTB Recycling. In this case, the focal firm is missing the knowledge of second-tier suppliers. As a result, this type of supply chain is characterized, overall, by a lower degree of visibility.

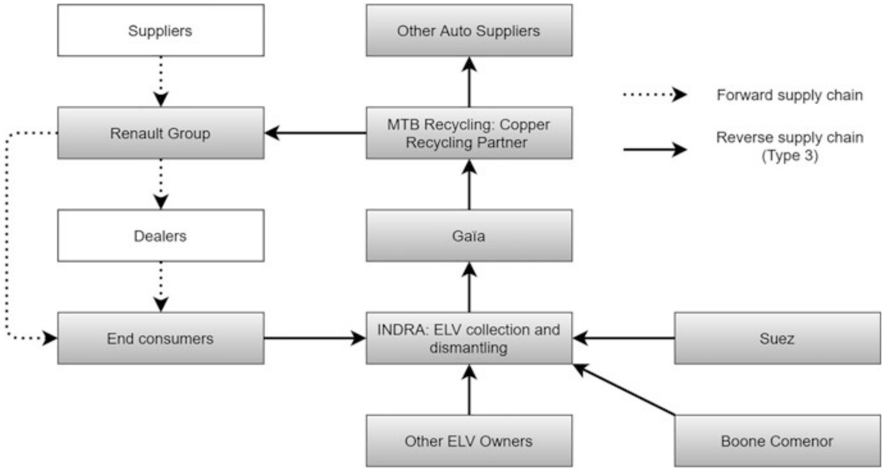


**Fig. 3** Product/EoL product/material flow in CSC (Type 3) in Example 3

**Table 3** Identifying nodes in CSC (Type 3) in Example 3

| | | | |
|---|---|---|---|
| **Physical supply chain** | Traditional supply chain actors | Suppliers, Renault Group, end consumers | High visibility to the focal firm |
| | Nontraditional supply chain actors | Other ELV owners | Low visibility to the focal firm |
| | Supplementary supply chain actors | INDRA and its network with EVL collectors and dismantlers, Suez, Boone Comenor, Gaïa, MTB recycling (Other recyclers) | High visibility to the focal firm |
| | Other manufacturers | Other auto part suppliers | Low visibility to the focal firm |
| **Support supply chain** | Support supply chain actors | EU Directive (European Commission), EU LIFE Research Program (European Commission) | High visibility to the focal firm |

## 4.5 Comparison Among Three CSC Types

Based on the abovementioned three examples, comparisons among the three CSCs can be made in two different ways. Firstly, we make the comparison based on the different parties involved in each CSC archetype, as illustrated in Fig. 4.

Figure 4 depicts how the supply chain partners can be involved in CSCs. When focusing on the circular resource flows, at least one member of the traditional forward supply chain is involved in ensuring the EoL product is returned to the same or any external system. Mostly, this traditional supply chain actor is the end consumer. However, this can even be a producer who implements rigorous, extended

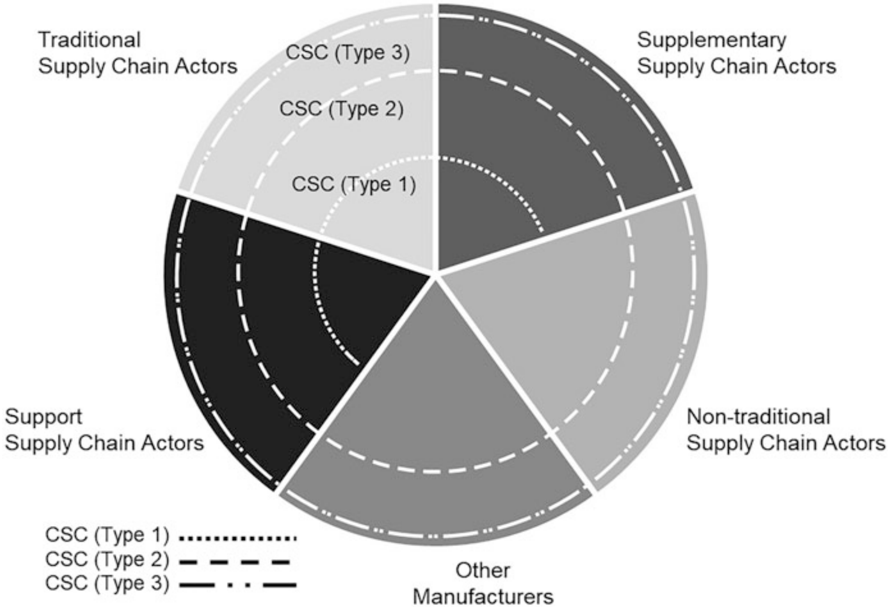


**Fig. 4** Comparison of nodes among three CSC types

responsibility practices. Similarly, it is apparent that when the product or resource flows outside one supply chain (opening new loops), the role of external parties such as nontraditional partners and other manufacturers is crucial. This illustration further proves the importance of collaboration among different parties in the CSCs.

Secondly, we compare the characteristics of these three types, as shown in Table 4.

*CSC (Type 1)* is designed to bring the supply chain's own waste back as resources to the system. Hence, with a restorative approach (return to a previous or original state) within the CE perspective, *CSC (Type1)* aims to develop the product with long-lasting approaches while following effective recovery practices. Whenever one value retention option is no longer feasible, *CSC (Type 1)* can be retrofitted to include an alternative option. *CSC (Type 1)* is driven by the *extended producer responsibility* and direct engagement of the OEM. Hence, the primary return flows are well structured, limiting the knowledge of other supply chain actors.

*CSC (Type 2)* is designed to carry the waste from one CAS to another as resources. As a result, *CSC (Type 2)* is *circular by design* to maintain resource value as long as possible. With a regenerative approach, this is driven by product stewardship. According to Jensen and Remmen (2017), product stewardship evolved from responsible management of hazardous wastes toward a broader focus on resource conservation. Product stewardship agreements have either been driven by government or industry or have involved in some form of collaboration between these two actors. In the CE, product stewardship can help manufacturers to minimize

**Table 4** Comparison among three CSC types

| | CSC (Type 1) with RSC (Type 1) | CSC (Type 2) with RSC (Type 2) | CSC (Type 3) with RSC (Type 3) |
|---|---|---|---|
| **Terminology** | Mostly known as CLSC in OSCM discourse | Mostly known as OLSC in OSCM discourse | Mostly known as CSCs in OSCM discourse |
| **Design** | Retrofitted design | Circular by design | Retrofitted design |
| **CE perspective** | Restorative | Regenerative (if the restorative approach is followed, the impact of circularities needs to be evaluated – e.g., yarns from plastic bottles) | Restorative |
| **Focus** | Long-lasting approaches/designs and recovery practices | Cascading approaches | Long-lasting approaches/designs, recovery practices<br>Cascading approaches |
| **Scope** | Bring your own waste as resources into your system | Ensure that your waste is fully/partly a resource in some other system | Bring the waste in your system as resources to your system |
| **Driver** | Extended producer responsibility | Product stewardship | Extended producer responsibility<br>Product stewardship |
| **Engagement of OEM** | Direct engagement of OEM | Indirect engagement of OEM | Direct engagement of OEM |
| **Engagement of other SC partners** | Mostly the supply chain partners in traditional supply chains | Crucial engagement of nontraditional partners and supplementary supply chain actors | Crucial engagement of nontraditional partners and supplementary supply chain actors |
| **Visible Horizon** | The focal firm has limited knowledge of supplementary supply chain actors, given that the focal firm structures the main return flows | The focal firm has limited knowledge of other manufacturers as they are not directly linked with the supply chain of the focal firm | The focal firm has limited knowledge of other manufacturers, and nontraditional supply chain actors as the former are not directly linked with the supply chain of the focal firm, and the latter are second-tier suppliers |

the environmental impacts of products throughout their life cycle (Jensen & Remmen, 2017).

As illustrated in the *CSC (Type 2)* example, BioPak has already aligned its operations with CE approaches by designing the products. Still, the firm goes beyond its immediate responsibility and tries to link with another supply chain through cascading approaches. As BioPak provides only a digital platform to connect different parties, it is indirectly involved in this CSC as the OEM. However, when studying other examples of opening loops, it is crucial to pay attention to the compatibilities of the connecting loops, given their ultimate impact on sustainability.

For instance, plastic bottle recycling for the apparel industry is getting popular (Cai & Choi, 2020). However, whether this is a sustainable CE loop connection is under discussion. When PET bottles are downcycled to tires, fabric, or toys, the cycle is disturbed as their life extension is limited to a single round before sending to landfills. As a result, the European nonalcoholic beverage industry has already requested amendments to the EU's Packaging and Packaging Waste Directive to give them priority access to the waste PET bottles compared to other industries (Poole, 2021). Hence, it is crucial to remember the inherent goal conflicts to ensure successful circularity in such a resource loop combining approach.

Indirectly, we can identify *RSC (Type 3)* as an amalgamation of *RSC (Type 1)* and *RSC (Type 2)* based on their characteristics. Hence, *CSC (Type 3)* is designed in such a way as to bring the waste in the whole system (in a particular industry) into a CAS and return the restored products not only to the CAS but also to the system. Hence, this CSC type focuses on both long-lasting and cascading approaches driven by the extended producer responsibility and product stewardship. As a result, the direct engagement of the OEM is crucial. Similar to *CSC (Type 1)*, *CSC (Type 3)* can also be retrofitted to include other value retention options.

Hence, it is clear that all the RSC types mentioned above fulfill the requirements to ensure the circularity of supply chains. Thus, this answers our question that a CLSC is a CSC, but CSCs are not limited to CLSCs. CSCs can be based on OLSCs or a combination of CLSCs and OLSCs. Similarly, several parties involved in a CSC profoundly differ from conventional linear supply chain actors. Hence, the visible horizon of the CSCs needs to be expanded even outside the supply chain boundaries to integrate unrelated and new partners such as governmental agencies.

## 5 Discussion

The main issues covered in this chapter are three-fold. Firstly, we identify the distinctive features of CSCs while clarifying the confusion on the terminology. There is no hard and fast rule to define CSCs. However, CSCs should be designed considering the overall sustainability improvement achievable through the circular flows (Korhonen et al., 2018a). Hence, RSC plays a major role in hinting that the circularity can be improved even beyond the boundaries of CLSCs. Especially, the different parties involved in these supply chain archetypes to improve the physical flow of goods and support this process emphasize the importance of collaboration among these parties.

Secondly, we further detailed the CE discourse, hinting at how to design CSCs while addressing the critiques toward CE. Understandably, there is no one way to design a CSC. Each CSC is unique, given the way it addresses the limitations of the CE concept. However, it is equally important to remember that not all limitations can be overcome simply by designing the CSCs with certain boundaries. For instance, a consumer behavior change is required to overcome the rebound effect of CE discussed by Korhonen et al. (2018a). Albeit such hurdles, CE implementation can still be successful with an appropriate CSC design to improve sustainability performance.

Thirdly and finally, a focus on the collaborative perspective in CSCs and the vital role played by the nontraditional supply chain actors in the physical supply chains and supportive actors in the support supply chain are made clear. These non-traditional actors, such as local communities and NGOs, are gaining special attention even in the OSCM discourse (Sudusinghe & Seuring, 2022). Their involvement in CSCs is critical given their direct involvement in the product flows in the RSCs. In addition, supportive actors such as governmental agencies and industry associations are also equally important, given their special knowledge-sharing role in ensuring successful CE implementation (Veleva & Bodkin, 2018). Hence, the engagement of external parties who are not generally part of the traditional supply chains is crucial in designing CSCs, which are truly coherent to an ambitious view of the CE agenda.

## 6 Managerial and Policymaking Implications

Several useful managerial and policymaking implications for CE implementation through CSCs can be drawn from this chapter. Through the comparison among CSC archetypes, this chapter can assist practitioners in deciding which CSC configuration is more suitable for implementing CE practices in their supply chain. This chapter can offer some insights to practitioners in designing their CSC, in order to match with their CE implementation strategies. Furthermore, the detailed illustration of the pros and cons of each CSC archetype can make the practitioners aware of the opportunities and challenges they may face when implementing CE practices in their supply chains.

Similarly, this study elaborated on how supply chain loops can be closed, in a creative manner, in order to ensure the circularity of product flows. Especially in the presence of multiple CE implementation options, the overall effects in terms of environmental performance need to be considered. This is particularly relevant when recycling solutions are involved in closing the loops, as illustrated in the chapter. The awareness and knowledge of such implications can assist managers in making better decisions in the long run to improve the overall sustainability of CSCs.

Similarly, this chapter can provide some guidelines to practitioners regarding the need to expand the visible horizon of the focal firm. This is especially the case when integrating new partners, who are beyond the supply chain boundaries, into the operations in order to implement CE practices. Practitioners should also engage with supportive supply chain partners and other stakeholders, such as NGOs, to share knowledge. Managers can identify such crucial, out-of-scope partners, and pay special attention to them, given their crucial role in the supply chain transformations in the CE context.

Finally, this chapter can also provide useful advice to policymakers on how their intervention could nurture or disrupt CE implementation patterns in supply chains. Clear, up-to-date, strict rules and regulations can lead the progress of linear supply chains to CSCs. Consequently, this progress can thrive with extended support to supply chain partners through collaborative approaches to master the needed knowledge and skills.

## 7 Conclusion

Enhancing the circularity of supply chains requires integrating appropriate product loops to improve sustainability. As a result, with the crucial role of RSCs to ensure the circularity of product flows, engaging different parties who are generally not involved in traditional or linear supply chains is crucial to smooth these circular flows. Hence, CSCs can be designed after modifying the existing supply chains accordingly. While CLSCs and OLSCs ensure the circularity of supply chains, their integration can also be modified to improve the sustainability of CSCs. It is noteworthy to consider the characteristics and limitations of each CSC archetype before employing it.

This chapter has some limitations, and the foundation presented here can be expanded. When selecting the examples, we employed cases with the best illustration. This decision was in line with the need for case-by-case analysis to understand the circularity of application in the CE (Korhonen et al., 2018a). Yet, there are cases where failure and improvements are required, as in most cases, the complexity of CE needs careful evaluation with all the potential contingencies that exist. Future direction and understanding are needed and can be accomplished by empirically testing this conceptualization.

Similarly, CE has many additional critiques and concerns. We do not mention additional ones and do not have frameworks for each critique raised toward CE, such as concerns relating to the possibility of rebound effects (Zink & Geyer, 2017). Hence, further investigation can be conducted addressing such major critiques in more detailed expositions of these issues.

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# Remanufacturing and the Supply Chain

Senlin Zhao, Yunting Feng, and Qinghua Zhu

## Contents



**Abstract**

Remanufacturing offers the advantages of energy consumption reduction, cost savings, and waste reduction. However, barriers exist along remanufacturing supply chains, from the supply of used products to consumers' acceptance/preferences for remanufactured products. Thus, support and coordination activities are needed from supply chain members and related stakeholders. This chapter first introduces the background of remanufacturing, discussing current topics and issues with great concerns by practitioners and researchers such as

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governments' efforts for remanufacturing, and collection of used products. Then, we introduce the topic of "competitiveness and uncertainties," which explores how practitioners in a remanufacturing supply chain should face competition and how to coordinate remanufacturing supply chain players to ensure the stability and development of the remanufacturing supply chain. On the topic of "market acceptance," we introduce how to measure consumers' preferences, use government subsidies more efficiently, and provide an innovative service mode for remanufactured truck engines. This chapter ends by providing an overview of the evolving remanufacturing supply chain concept, significance, and practice.

**Keywords**

Remanufacturing supply chain · Quality selection · Coordination contract · Service mode

## 1 Introduction

Seeking to recover value, reduce waste, and mitigate carbon emissions from products at the end of their life cycle, remanufacturing with a reverse supply chain is one mode of pursuing sustainability. Remanufacturing is pollution-preventive with low-carbon emissions, material-savings, and thus it attracts great attention in both the industrial and academic worlds. The economic, social, and environmental benefits are accrued by participants involved in remanufacturing activities.

Remanufacturing has been an issue of interest in academia and industry in recent years. At present, many human activities are at the cost of consuming natural resources and sacrificing the natural environment. Balancing economic requirements and environmental issues has become an important requirement for enterprises. Remanufacturing increases the value of used products by replacing nonfunctional parts or reprocessing broken parts. Remanufacturing processes help reduce environmental burden by reducing natural resources consumption and waste of used – end-of-life – products. However, remanufacturing faces barriers within supply chains and supply chain management.

The second section of this chapter introduces the importance of remanufacturing to enterprises and countries. This chapter first explains the importance of the remanufacturing industry, and what laws and actions have been implemented to facilitate the remanufacturing industry. Then it further illustrates how enterprises make profits through remanufacturing and how to obtain used products from consumers.

The third section of this chapter introduces the competition and uncertainties of a remanufacturing supply chain. Firstly, in most situations, the original equipment manufacturers (OEMs) prefer high-quality new products if they carry out a trade-in policy. A higher quality level could be harmful to consumer surplus because the cost is directly passed to them. Moreover, if consumers are willing to replace their original products, there exists a competition between the OEM and the third-part remanufactures (TPRs) through a trade-in policy. Interestingly, when the consumer's replacement intention is sufficiently low, the TPRs could be more profitable due to the implementation of the trade-in policy too.

Secondly, knowing remanufacturing uncertainty a coordination contract in a remanufacturing supply chain is introduced. Today's market is constantly changing, and how to deal with the change in the market has posed a great challenge to enterprises. The remanufacturing market may be affected by various factors, so the remanufacturing supply chain should be prepared to deal with market fluctuations. Enterprise attitude toward risk plays an important role during decision-making processes. The stability of the supply chain needs the coordination of different participants, and so does a remanufacturing supply chain. An effective way to achieve coordination among the various participants is to design appropriate contracts. Appropriate contracts can help the different participants of the supply chain make efforts for remanufacturing supply chain stability.

The fourth section of this chapter introduces the issue of consumer acceptance of remanufactured products. Firstly, we introduce how remanufacturers make decisions considering both consumer environmental preferences and government subsidy policies. Remanufactured products have a lower environmental impact. Unfortunately, at present, many consumers are less likely to accept and purchase remanufactured products.

Global markets and governments have realized that remanufactured products play a significant role in environmental protection and energy-saving. Promoting the development of remanufacturing, many governments have formulated relevant policies and provided subsidies for the healthy and sustainable development of remanufacturing supply chain. However, remanufacturers need to make decisions according to consumer environmental preferences and government subsidies.

Secondly, as there are two concerns of remanufactured products – one is after-sales service and the other is the quality of remanufactured products – we discuss the redesign of remanufacturing product service modes, which aims to improve consumer acceptance by alleviating or even eliminating their two concerns. Proposed innovative service modes could be adopted for remanufactured products to meet consumer needs. We describe the development of two after-sale service modes including the extended warranty mode and the free replacement mode, based on the existing conventional product innovation service mode.

The last section of this chapter identifies future research directions for remanufacturing supply chain management. The main content of this part includes some possible research directions in the future and the prospect of remanufacturing supply chain management in the future.

## 2 Business Practices and Policy Support for Remanufacturing

A remanufacturing supply chain at least consists of three parts – (1) collection of used products, (2) a remanufacturing process (including Inspection, Disassembly, Cleaning, New components replenishment, Reassembly, and Testing), and (3), remarketing (including estimation for market acceptance of remanufacturing products and impact of government subsidies) – each having its different questions and challenges.

## 2.1 Get Moving: Collection of Used Products

Collection of used products is the first step in remanufacturing, and people need to build a collection channel and develop reverse logistics before remanufacturing.

Several studies on closed-loop supply chains explored a proper reverse channel for remanufacturing collection activities in different contexts (Atasu & Souza, 2013; Savaskan et al., 2004). The results suggest that the retailer-managed collection channel is the most effective way under certain conditions. However, many manufacturers prefer to outsource the collection activities of used products to third parties (3Ps) (Atasu et al., 2009).

Hosseini-Motlagh et al. (2019) considered a case where a remanufacturer outsources the collection of used products to duopolistic 3Ps under perfect cost information. Zou et al. (2016) studied the performance of remanufacturing outsourcing and authorization, and they found that remanufacturing outsourcing is superior to remanufacturing authorization for a manufacturer. From the retailer's point of view, Wang et al. (2017) evaluated whether a retailer should engage in remanufacturing by itself or authorize this activity to a TPR.

Trade-in is another way for used products collection, as trade-ins can be used to offset the purchase price of new equipment. If the equipment does not have trade-in, or salvage, value, it can be recycled for free. Trade-in rebates involve returning used products, obtaining a price discount, and repurchasing the latest version of the durable products (Zhang & Zhang, 2018; Li et al., 2019). Traditionally, the core collection activity (i.e., returning used products), firms taking back the used products from customers, was generally separated from the repurchase decision. In contrast, trade-in policies naturally connect both the core collection and sales activities. It is, thus, clear that trade-in would enhance the OEM's competitive edge in two ways. Trade-in rebates can encourage customers to change their used products (Van Ackere & Reyniers, 1995) and alleviate the negative effect of customers' mental cost of retiring their used products (Okada, 2001).

Currently, many firms carry out trade-in rebates to improve market demand. More companies are implementing a trade-in policy for durable goods (Xiao & Zhou, 2020). Rao et al. (2009) found that a trade-in policy can soften the negative effects of the lemon problem and increase a firm's profit. Therefore, they attempt to examine the incentives for producers of new durable goods to accept trade-ins as part of the payment. Trade-in rebates to some extent can facilitate consumers to write off the mental cost of retiring their used products (Okada, 2001) and then encourage consumers to re-purchase new products (Van Ackere & Reyniers, 1995). The existence of trade-in policies has also been accepted by consumers. For instance, Xerox implements a trade-in policy as a marketing strategy and covers its collection and disposal expenses (Xerox Inc, 2016). Likewise, Apple's trade-in policy allows consumers to trade in their used equipment offline or online (Apple Inc, 2019).

Moreover, Deloitte Global predicted that there were 80 million smartphones traded with a value of $11 billion in 2015, and 120 million smartphones traded with a value of $17 billion in 2016 (Deloitte Global, 2016).

## 2.2 Governmental Efforts for Remanufacturing Systems Support

Remanufacturing is profitable for manufacturers due to the reclaimable value of used products and reduced energy use (Fang et al., 2020). Many countries are aware of the deteriorating environment, so they have established policies and regulations to facilitate remanufacturing. Europe is one such place where the population and government generally have a strong awareness of environmental protection, and they believe that remanufacturing used products can reduce energy consumption and protect the environment. Therefore, various European countries actively promote remanufacturing activities, and it is estimated that Germany has the largest remanufacturing industry in Europe.

Before 2008, the remanufacturing industry had barely developed in China. Currently, the remanufacturing industry is developing rapidly in China due to policy support. To accelerate the development of remanufacturing, the Chinese government provides at least four kinds of subsidies, which are "subsidy in the initial stage," "subsidy for used products collection," "subsidy for R&D," and "subsidy for remanufactured products."

"Subsidy in the initial stage" is a one-time subsidy that helps to cover the investment in remanufacturing operations and equipment for a new remanufacturer. "Subsidy for used product collection" is a subsidy for the collection agent which helps to ensure a sufficient supply of used products. For example, in December 2008, a "home appliances going to the countryside" policy was announced by the Chinese government. A certain percentage (13%) of financial subsidies will be given to low-income people in poor areas to buy household appliances in the subsidy scope so as to activate those low-income people's purchasing power, expand rural consumption, and promote the coordinated development of domestic and external demand.

"Subsidy for R&D" is a subsidy for remanufacturing enterprises that help to develop remanufacturing technologies, such as dismantling, cleaning, surface repair, and structural strengthening, assembling, and testing.

"Subsidy for remanufactured products" is a policy of the government to reduce the retail price of remanufactured products and increase the remanufacturing capacity. For example, the Chinese government subsidizes 2000 RMB (about 298.6 USD) per remanufactured Steyr engine (336 horsepower).

# 3 Competitiveness and Uncertainties for a Remanufacturing Supply Chain

Increased human awareness of environmental protection has supported rapid remanufacturing industry development with more enterprises entering the remanufacturing industry. Therefore, the competition in the remanufacturing industry is increasing, which brings new challenges for enterprises in a remanufacturing supply chain. This section mainly introduces how enterprises in the remanufacturing supply chain should face competition and how to coordinate remanufacturing supply chain enterprises to ensure the stability and development of a remanufacturing supply chain under an uncertain environment.

### 3.1 Competitiveness Between an OEM and a Remanufacturer

The choice of product quality is an important part of an enterprise's competitive strategy. It is well known that OEMs have to compete with dozens of TPRs that typically have low production cost and attractive price advantages. As a German carmaker said, the quality of their remanufactured products equals that of new ones but at half the cost. In reality, remanufacturing is almost always beneficial for the environment and society, but original equipment manufacturers (OEMs) prefer to prevent any kinds of recovery value by TPRs or refurbishers due to the recovery products decreasing OEM's profit (Chen & Chen, 2019).

According to Rao et al. (2009), a trade-in policy can allay inefficiencies arising from the *lemon* (low-quality vehicles) problem. Hence, OEMs can ward off competition from TPRs through trade-in policies, particularly by offering price discounts to attract existing customers who may be willing to pay for the affordable remanufactured products in the secondary market. For an OEM that also remanufactures used products, it should also determine the quality of remanufactured and new products. Remanufactured products are made from used products, and their quality usually is the same as new products. Therefore, the OEM's quality decisions affect product recovery.

A trade-in policy can stimulate consumer demand and expand product sales. However, this operation also creates additional problems for its offering firms in terms of quality choice and trade-in rebates. On the one hand, a higher quality choice can not only increase consumer perceived value of new products but may also result in high selling prices and low sales volume (Atasu & Souza, 2013). As a result, there is a lower supply of used products that can be collected in the market. Alternatively, high product quality has high durability so that the products can last longer. This situation indicates that a firm's quality choice may directly result in consumers being reluctant to replace their current version of a durable product. Even though a trade-in policy can lure consumers to repurchase new products early, a higher trade-in rebate is needed to compensate for the negative effect of a higher quality choice on a consumer replacement decision. Hence, firms should investigate how to choose new product quality when they intend to adopt a trade-in policy.

Apart from considering the effect of the trade-in policy on quality choice, an OEM needs to consider cannibalization of TPR's remanufactured products. OEMs can vary their product quality to eliminate the TPR's competitive threat (Orsdemir et al., 2014). The quality level of remanufactured products is associated with new ones. Hence, an OEM's decisions on the new product quality can affect a TPR's remanufacturing cost.

While a few papers consider the quality decision of OEMs regarding TPR competition (Orsdemir et al., 2014; Wu, 2013), they do not take the implementation of trade-in policies on the OEM's quality choice into consideration, which is slightly divergent from reality. For example, Apple recovered more than 66% of its devices by trade-in policy and sold them to new consumers, and Apple devotes itself to design for easy recovery (Apple Inc, 2019). In addition, the extant literature assumes that consumers buy new products once (Ferrer & Swaminathan, 2006, 2010; Orsdemir et al., 2014). However, according to research made by Fernandez (2001), the replacement rate of household appliances in America, like washing machines and fridges, accounts for around 75% of annual sales. In 2019, Apple had approximately three-quarters of iPhone online trade-in brand loyalty (BankMyCell, 2019).

It is important to consider consumer replacement decisions for durable goods regardless of whether or not OEMs carry out trade-in policies, which is a significant difference from previous research (such as Feng et al., 2020). Organizations could investigate thoroughly how the OEM quality choice is affected by the trade-in policy, as well as examine how the OEM takes the quality choice as a lever to enhance its competitive advantage in the trade-in policy.

From an OEM viewpoint, the implementation of a trade-in policy often results in a higher product quality in most cases, which is more likely to improve revenues for its offering firms. Under a monopoly situation, the OEM is more sensitive to consumer mental depreciation (the perceived depreciation of the product value) than recovery efficiency. Thus, it is necessary for the OEM to help former consumers accurately understand their used product salvage value. If a consumer's mental depreciation is low, the primary value of the trade-in policy is to achieve better price discrimination, which is much more significant than the purpose of exploiting repeat consumers. In the meantime, under a duopoly situation, the trade-in policy can generally consolidate the OEM's competitive position.

From the TPR viewpoint, implementation of a trade-in policy does not mean TPR profits necessarily decrease, which is more relevant to consumer mental depreciation degree. In particular, when former consumers are less willing to buy remanufactured products, the trade-in policy is also beneficial to the TPR. Alternatively, a higher consumer mental depreciation may lead to a negative effect on TPR revenue if they implement a trade-in policy. Managerially, TPRs should investigate and understand consumer mental depreciation before making decisions regarding quality if they intend to implement a trade-in policy.

From a consumer surplus perspective, consumer replacement intention plays a significant role in evaluating the impact of trade-in policies on consumer surplus. For example, if consumers are hesitant in making their replacement decisions, then the trade-in policies are most beneficial to consumer surplus. For a wide range of mental depreciation, the trade-in policy may be a detrimental factor to consumer surplus.

## 3.2 Uncertainties for a Remanufacturing Supply Chain

### Uncertainties and Contract Coordination

Supply chain uncertainty in remanufacturing supply chain management is noticeable and it poses great challenges. The uncertainty often results in low supply chain performance. In this topic, a comprehensive set of sources related to remanufacturing supply chain uncertainty has been identified and reviewed (Simangunsong et al., 2012); these uncertainties are divided into three dimensions:

1. Uncertainties from the internal organization, which come from the enterprises, such as (Re)manufacturing process, organization issues, multi-dimensions in decision-making, and the wrong use or threats of IT technical error (Sridharan et al., 2005)
2. Uncertainties from the internal supply chain, such as terminal customer demand (Mishra et al., 2009), and demand amplification, which cause the bullwhip effect (Ouyang & Daganzo, 2006), and quality problems
3. External uncertainties, such as government regulations or natural disasters

Deriving from complexity in remanufacturing supply chain management, multi-uncertainty factors could be involved at the same time. Coordination of a remanufacturing supply chain can help the stability and sustainable development of a remanufacturing supply chain, which is very important for today's competitive market environment.

Li et al. (2015a, b) established two pricing strategies for remanufacturing: (1) The FRTP pricing strategy (First-Remanufacturing-Then-Pricing), and (2) The FPTR pricing strategy (First-Pricing-Then-Remanufacturing). They analyzed the sequential decision strategies by considering the remanufacturing production and the demand for remanufactured products as stochastic parameters. They assumed that one firm acquires and remanufactures used products altogether. Supply chain coordination between old products collector and remanufacturer is not considered in retailer-collects-mode in their work. Used products collected have different statuses of use, so accordingly, the remanufacturability rate affects the decisions of participants a lot.

The retailer faces remarketing risk, for example, shortage or overage in uncertain remarketing demand. Considering multi-uncertainty factors in a remanufacturing supply chain, (1) the uncertainty demand when remarketing in remanufacturing market and (2) the remanufacturability rate of old products when they remanufacture products are two uncertainty factors that need to be considered simultaneously. These two factors cause significant difficulty to remanufacturing supply chain management.

Each participant in a remanufacturing supply chain is primarily concerned with optimizing their objectives, and usually, those objectives are different or even conflicting with each other. A coordination mechanism, such as contract design, needs to be designed to deal with those challenges in a remanufacturing supply chain. A reasonable coordination activity like the negotiation for a revenue-sharing contact could be established.

We now briefly discuss the contract coordination issue. Designing a proper contract to coordinate the supply chain is an effective way to improve channel performance. Govindan et al. (2013) overviewed supply chain coordination. Without a properly designed motivation mechanism, the retailer does not have an incentive to order enough products to maximize the profit of the whole supply chain (Li et al., 2013). This is the well-known problem of "double marginalization" (Spengler, 1950).

A contract allows decentralized decisions of supply chain members to perform a centralized decision for the whole supply chain. Studies have explored variety of contract forms (Cachon, 2003) such as wholesale price (Bresnahan & Reiss, 1985), revenue-sharing (Cachon & Lariviere, 2005), quantity discount (Zhang et al., 2014), sales rebate (Taylor, 2002), buyback (Wang & Choi, 2014; Pasternack, 1985; Zou et al., 2008), and quantity flexibility (Tsay, 1999). A revenue-sharing contract can increase economic profits in reverse logistics along with reverse supply chains (Govindan & Popiuc, 2014). Moreover, previous research proposed a dynamic leader-follower game model to examine how a reverse supply chain system for remanufactured printer ink cartridges responds to changes (Mafakheri & Nasiri, 2013).

## Risk Attitudes for Uncertainties

Facing remanufacturing uncertainties, supply chain participants have different risk attitudes including being risk-averse, risk-seeking, or risk-neutral. To address a risk-averse agent coordination problem, Gan et al. (2004) developed contracts under three cases: (1) a risk-neutral supplier and a profit-maximize retailer who are subject to a downside constraint on risk; (2) a supplier and a retailer who both maximizes a mean-variance trade-off; (3) a supplier and a retailer that are both utility-maximize players. In the latter case, they found a contract that yields a Nash Bargaining equilibrium (Explanation of Nash Bargaining equilibrium: Two players demand a portion of some good. If the two proposals sum to no more than the total good, then both players get their demand. Otherwise, both get nothing), and in each case, the set of Pareto-optimal solutions (Explanation of Pareto-optimal solution: Given a set of alternative allocations and a set of individuals, a movement from one allocation to another that can make at least one individual better off, without making any other individual worse off) is provided.

In the area of the Nash-bargaining game, Ma et al. (2012) found a Nash-bargaining equilibrium for a risk-averse retailer and risk-neutral manufacturing under a stochastic demand assumption. They found if the retailer becomes more risk-averse, then the retailer's bargaining power increases. Assuming suppliers are risk-averse, Li et al. (2013) studied the impact of competition intensity and risk attitude in the context of two sequential-moving supply chains. They showed that the retail prices under the wholesale price contract are higher than in the revenue-sharing case. They also compare the Nash-bargaining equilibriums between hybrid and symmetric subgames.

Standard revenue-sharing and buy-back contracts don't necessarily coordinate a supply chain that consists of a risk-neutral supplier and a downside risk-averse retailer (Gan et al. (2005)). To address this issue a risk-sharing contract and providing an agent's respective reservation profits may solve the issue. Wang and Webster (2007) used behavioral principal-agency theory to analyze a supply chain composed of a risk-neutral manufacturer and a loss-averse retailer in a newsvendor environment. Xu et al. (2014) provided a two-way revenue sharing contract under a mean-variance model and show how the risk attitude changes contract parameters. They found that a win-win situation could be achieved.

Choosing the Conditional Value-at-Risk criterion as a measurement index for a retailer's risk-averse level, Li et al. (2014a, b, c) investigated a Nash bargaining problem on the wholesale price, the retail price, and the order quantity between the manufacturer and the retailer who have equal bargaining power. They found that the profit shares under the Nash equilibrium are affected by the retailer's risk-aversion level. Xiao and Xu (2014) show the pricing and product line strategy of risk-averse players and identify the conditions under which the risk-averse players extend product lines or replace the used products with new ones.

#### Information Asymmetry Among Practicers

Currently, many recycling regulations require manufacturers to collect used products and properly dispose of them through recycling, such as remanufacturing or recycling. In order to comply with recycling regulations and take advantage of economies of scale, manufacturers often outsource collection activities to third-party providers (3p's). However, 3p collection efficiency is private information, and the manufacturer only knows how to follow the two-point distribution.

A fundamental challenge of collection outsourcing is the lack of perfect information about 3p collection efficiency and collection cost structure. The challenge is that manufacturers need to understand the collection efficiency of 3p's before signing a contract with a 3p in order to make better decisions. Therefore, manufacturers are motivated to obtain private information from 3p's about their real collection efficiency.

Asymmetric cost information makes consumer surplus worse. This worsening is because, in the case of asymmetric information, the information rent provided to 3p's with low collection efficiency is transmitted to consumers. Worse, setting a higher collection target will damage consumer surplus under certain conditions, that is, remanufacturing is relatively unprofitable for manufacturers. Finally, the emergence of information asymmetry magnifies the adverse impact of the collection target on consumer surplus. Solving the problem of information asymmetry in the remanufacturing supply chain is of great help to improve the efficiency of the supply chain.

Asymmetric information research tends to focus on testing the impact of asymmetric information on enterprise decision-making by using nonlinear pricing contracts. For example, Cao et al. (2013) proposed a wholesale contract to reveal a retailer's true internal variable costs for the manufacturer. Li, Gilbert, and Lai

(2015b) explored the effect of supplier encroachment on firm optimal strategies when the information about the market size is monopolized by the reseller.

Given that process innovation efficiency is a manufacturer's private information, Ni et al. (2021) explored how a supplier designs a nonlinear pricing contract to mitigate the loss caused by asymmetric information.

There are a few studies on asymmetric cost information in closed-loop supply chains. Zhang et al. (2014) considered a manufacturer that outsources the collection activities to a retailer while the collection effort is non-common information for the manufacturer and the retailer. Under an extended producer responsibility legislation, there has been work on extending the collection outsourcing to a situation where an independent collector provides the collection activities to the manufacturer that does not know the information about collection cost (Li et al. (2013).

Manufacturers can make better decisions by effectively collecting private information about efficiency. Thus, manufacturers should be motivated to obtain private information about their true collection efficiency from 3P. A manufacturer may wish to provide nonlinear pricing contracts that have two options for 3Ps with different collection efficiency, where the collecting quantities and purchasing prices of used products are fixed. In practice, many firms offer nonlinear pricing (e.g., quantity discounts) to coordinate their supply channels (Li, Gilbert, & Lai, 2015b). In the literature, nonlinear pricing was also widely used to examine the effects of asymmetric cost information on firms' decisions (Cao et al., 2013; Huang & Yang, 2016).

The collection rates of used products can be regulated by take-back regulations in many countries or regions. These regulations should also be considered in a manufacturer's contract design problem. For instance, the European Waste Electrical and Electronic Equipment (WEEE) Directive sets the collection target at 45% of the electronic products in the market for member states (Esenduran et al., 2016). Lobbying by stakeholders is the main driving force behind the current collection and recycling targets of the WEEE Directive, and whether and how manufacturers can satisfy the targets need more in-depth studies (Atasu et al., 2009; Chen et al., 2019). These factors and concerns have been investigated, for example, in how social planners can set the proper collection and recycling targets for manufacturers under perfect information (Atasu et al. (2009)).

The environmental and economic influences of take-back regulations have been studied (e.g., Atasu et al. (2009)). For example, the collection targets to maximize the total welfare under perfect information can provide insights into influences. However, few studies examine the effect of asymmetric cost information about 3p collection efficiency from an optimal collection target strategy. Esenduran et al. (2017) investigated how a manufacturer utilizes the quantity strategies to compete with an independent remanufacturer in the context of take-back regulations. They demonstrated that the increased collection targets have a positive effect on social welfare when remanufacturing can bring significant environmental. However, this finding may not be true if there is asymmetric cost information among supply chain members.

There are situations when multiple regulatory policies interact to affect remanufacturing. For example, joint consideration of the cap-and-trade and take-back regulations were considered by Chen et al. (2018) who explored a manufacturer's optimal quantity decision in a monopoly situation and the environmental impact of these two regulations. Chen et al. (2020) considered a monopolist manufacturer faces both mandatory carbon emission capacity and take-back regulations. Pazoki and Samarghandi (2020) examined how the take-back regulation influences the manufacturer's eco-design decisions.

### Analytical Models for Uncertainty

Twenty-first-century globalization has resulted in a tightly integrated global economy. Market fluctuations triggered by a single country, economic region, or industry are ever-changing, random, and unpredictable, such as the 2008 global financial crisis in the USA, the "the 311 earthquake in 2011" caused by the tsunami in Japan, and the conflict in Russia and Ukraine in 2022. These uncertainties also influence remanufacturing market uncertainties.

Obviously, the market fluctuation in remanufacturing is random and it is difficult for players in a remanufacturing supply chain to balance supply and demand. Changes in the economic cycle at the macro level or shifts in consumer acceptance or preferences could bring about drastic fluctuations in the remanufacturing market demand. Therefore, the efforts regarding the collection policy of the retailer or the trade-in policy of the manufacturer are difficult to formulate. This uncertainty results in management challenges for practitioners and researchers in the remanufacturing industry. In addition to focusing on increasing profits, an effective market strategy also seeks to eliminate risk, the volatility of profits, which is important for remanufacturing supply chain. For instance, in China, due to broader macroeconomic malaise in 2015, heavy truck sales plummeted by 26%, and the demand fluctuation in the heavy truck engine remanufacturing supply chain is significant (Zhao et al., 2018).

There are different kinds of uncertainties in reverse logistics activities. The main reason for the uncertainty of reverse logistics is that the traditional inventory management models or the pricing and ordering strategies do not apply to reverse logistics. Usually, the remanufacturing capacity is stochastic because the quality of used products and the handling time for used products are uncertain in reverse logistics (Fathi et al., 2015). In a location-allocation problem, Soleimani et al. (2014) assumed that the risk-neutral assumptions are not efficient for uncertain and volatile markets in designing a closed-loop supply chain network. Therefore, they model three risk criteria (i.e., Mean Absolute Deviation, Value at Risk, and Conditional Value at Risk) as the objective function.

Han et al. (2016) examined a remanufacturer's reverse channel selection problem from the perspectives of both robustness and profitability, and they proved that the indirect reverse collection channel has higher robustness than the direct reverse collection channel if the remanufacturing process has operational and disruption risks. As an extension to the traditional risk-neutral inventory models, Chen et al. (2007) incorporated risk aversion into multi-period inventory and pricing models. They proved that the optimal policy for a risk-aversion decision-maker is the same as the case in risk-neutral inventory and pricing models.

Zhao and Zhu (2018) used an actual case to show the game results of a revenue-sharing contract. In their study, mean-variance is the risk measurement parameter, and both the remanufacturer and the retailer are risk-averse. Because of the uncertainty in the remanufacturing market, the remanufacturer and the retailer's risk tolerance prevents them from participating in the cooperative game contract. Their study tried to propose a decision-making strategy for the risk-aversion agents in an uncertain remanufacturing market environment. Apparently, risk attitude or risk tolerance greatly affects the game results of remanufacturers and retailers, and because their risk attitudes are different in the face of severe market fluctuations, they add a risk-aversion factor for both the remanufacturer and the retailer's objective function; considering both perspectives is relatively innovative.

One of the popular areas of remanufacturing is large vehicles, especially heavy truck engine remanufacturing. There are a variety of remanufacturer and the retailer risk attitude or risk tolerance impacts on the number of used products collected, consumer surplus, overall supply chain profit, and revenue-sharing contract parameters. Risk-averse agents gain lower expected profit than "maximum profit" risk-neutral agents when the market demand for remanufacturing is not volatile. For revenue-sharing cooperative contracts, the risk-averse agents could get higher expected profit than "maximum profit" risk-neutral agents for heavily fluctuating remanufacturing demand. Revenue-sharing cooperative game contracts can serve as guides on how to better manage all the remanufacturing supply chain agents under market fluctuations, especially when facing uncertainties from both the demand and supply sides.

Thus overall, managerially considering, and modeling for remanufacturing could consider many dimensions – especially uncertainty and the acceptance of this risk and uncertainty – for the remanufacturing industry. Dozens of models across multiple characteristics were reviewed in this section to show the richness of issues and influences from the variety of game theoretic and analytical models to address these issues. There are additional concerns related to market acceptance, modeling, and organizational concerns that we now discuss in the next section.

## 4 Market Acceptance Issues of Remanufactured Products

Remanufacturing helps enterprises to fulfill extended producer responsibility and support their eco-efficiency throughout their life cycles. However, the market acceptance for remanufactured products is still low, and there exists bias toward remanufactured products, especially among consumers in developing countries with low purchasing power. Areas of importance to address some of these issues include determining how to measure consumer preferences, using government subsidies more efficiently, and finding a suitable business model for after-sales service mode. These issues are difficult to grasp and control for the remanufacturers and policymakers. In this section, we consider some of these issues and what has been addressed.

### 4.1 The Impact of Consumer Preferences and Government Subsidies

Various remanufacturing implementation barriers such as ignorance of consumer preferences and inefficient use of government subsidies make engine and gearbox remanufacturing unprofitable in China (Zhu et al., 2014). These concerns are likely to occur in other places as well.

Previous studies focused on characterizing consumers who are willing to pay for remanufactured products and tried to identify different consumer clusters with similar preferences and acceptance of remanufactured products. The segments among consumers regarding level of green values (environmental values held by the consumers) could affect the profitability of remanufacturing operations. Remanufacturers have little guidance in identifying different types of consumer segments: including price-sensitive, quality-concerned, or green-concerned consumers (Atasu et al., 2008).

A consumer or customer could also belong to multiple consumer clusters or greenness segments. Studies have been completed to evaluate consumer clusters. One example is a survey of 1600 households in Devon, Canada; Gilg et al. (2005) investigated how different sustainable lifestyles relate to each other and whether different consumer preferences could be identified. They found at least four different types of environmental values regarding consumer environmental awareness. There is no doubt that an environmentalist with high purchasing power is willing to pay for remanufactured products. In fact, a properly implemented marketing strategy of environmental friendliness could generate a positive public image, which benefits the shareholders. Yet, it has also been found that a large proportion of consumers prefer to buy traditional-but-new products with attributes such as lower prices, higher quality, and better performance than the green/remanufactured products (Ginsberg & Bloom, 2004).

To increase the market for remanufactured products and general concern for the environment, the governments across the world including the USA, European Union, China, Japan, and Canada have enacted regulations and provided subsidies for remanufacturers. Government subsidy is often seen as an incentive tool that helps enterprises to enter the remanufacturing industry, especially in developing countries.

Initially, subsidy incentives from the government played an important role in remanufacturing market development – a needed influx of investment for the remanufacturing industry. As an example, within China, 14 remanufacturing companies were announced as pilot agents of the truck engine and gearbox by the Chinese government. Since then, the Chinese government has been focusing on auto parts remanufacturing, and a large quantity of remanufacturing of the truck engine was subsided (Wang et al., 2014b).

There are also possibilities for shifting incentives. If subsidies for remanufacturing incentives are transferred to consumers, the cost of collection and remanufacturing may not be reduced. Therefore, an allocation pattern of "subsidy for remanufactured products" among remanufacturers, recyclers, and consumers is a growing and important area of operational and policy studies.

Relatedly, the proportion of green and non-green consumers and their respective willingness to pay for remanufactured products further complicates the subsidy allocation problem. A better sharing of the government subsidy among remanufacturers, recyclers, and consumers may reduce the remanufacturing cost, increasing the supply of used products, and attracting more consumers or growing the market, especially non-green ones.

### Modeling

In the early stages of remanufacturing market development, a remanufacturer faces barriers from used product collection, limitations in the remanufacturing process, and after-sales service. Subsidy policy incentives can help to overcome barriers and uncertainties at the initial stage of industry development (Zhu et al., 2014). With this concern in mind, and using a modeling perspective, Ma et al. (2013) introduced a government consumption-subsidy policy and evaluated its influences on a closed-loop supply chain. They found that the consumers who buy new products, the manufacturer, and the retailer all benefit from the consumption-subsidy policy simultaneously, but the e-retailer, who sells their products or services online, won't necessarily benefit from this consumption-subsidy policy.

Remanufacturers also face channel choices. It was found that offering too much and too few subsidies could make the remanufacturer compete with the manufacturer, rather than cooperate (Wang et al., 2014a, b). Interestingly, higher consumer acceptance of remanufacturing can result in greater competition between manufacturers and remanufacturers.

Some studies went beyond just competitive games to evaluate the remanufacturing decision. The effect of government subsidies on green technology adoption was evaluated using an extension of a price-setting newsboy model with an analysis of the interaction between the supplier and the government (Cohen et al., 2016).

Remanufacturing promotion policies and also be studied as alternative approaches. For example, cash subsidies and carbon regulation can both affect remanufacturing (Zhu et al., 2019). Cash subsidies from the government reflect the direct role of the government in promoting the consumption of specific products, while carbon regulation indirectly promotes the manufacturing of low carbon emission products. The implementation of these two policies both affect the demand for remanufactured products and corporate profits, but the carbon regulation could not work if consumer acceptance is low.

## 4.2 Remanufacturing Supply Chain Service Modes

The last discussion of remanufacturing practices in this section introduces innovative service modes of remanufactured products. Quality guarantees and after-sales service for remanufactured products are often barriers to remanufacturing (Zhu et al., 2014). While developing remanufacturing product service modes, remanufacturers should better learn from the innovative service mode of new products in order to improve their financial results (Chesbrough, 2010). Fierce competition has caused remanufacturers not only to care about the classical 4 Ps (product, price, place, and promotion) of marketing but also other modes such as after-market service.

### Sales and Service Modes for Remanufacturing

By learning from innovative sales and service modes for new products, remanufacturers can reduce or even eliminate such concerns. Within this competitive context, we provide an overview of sales and service modes that can be also used for remanufactured products.

Mode 1: *Leasing instead of selling service mode*. Leasing instead of selling indicates that a manufacturer leases rather than sells to his customers, together with providing repair and maintenance for the product. This mode was used for durable products at the beginning, which can eliminate the possibility of price decline and overproduction by a company (Bhaskaran & Gilbert, 2005). If a product is sold through a distributor, such a mode can be that a manufacturer sells its products to a dealer while the distributor leases the products to customers (Bhaskaran & Gilbert, 2009).

Mode 2: *Free replacement warranty service mode.* In the beginning, the free replacement warranty mode was adopted for expensive products such as aeromotor and armarium that requires specialized labor for maintenance and a malfunction can cause serious losses (Darghouth et al., 2012). During the free replacement warranty period, the OEM replaces any components or the entire equipment with potential malfunction free of charge. If the free replacement warranty period ends, the OEM still provides inspections and replacements service, but the costs are covered by the customer. During the whole life cycle of the product, losses due to product malfunction and their detection are totally or largely covered by the OEM.

Mode 3: *Extension of warranty length service mode*. The extension of warranty length service mode is the mode by which a company provides an extended warranty length if a customer purchases the warranty extension for products, which helps establish an image of good product quality for the OEM. In this case, the company would perform better preventive component maintenance in the warranty period to maximize the total profit and lessen the maintenance cost (Chang & Lin, 2012). Warranty extension does not guarantee better profitability, because the profitability is related to the malfunction rate (defect rate) in the warranty extension period (Kim & Park, 2008).

Mode 4: *Renewable free replacement service mode*. The mode of renewable free replacement can be identified as a combined mode of Modes 3 and 4. For this mode, if a product has a malfunction during the basic warranty period, the OEM guarantees a free replacement with a new one. Meanwhile, the OEM would generate a new warranty called the pro-rata warranty for the customer. When a malfunction occurs within the pro-rata warranty period, the customer needs to pay pro-rata money to the OEM.

In these modes the producer must know or predict the cost of maintenance/ replacement and the malfunction rate during those three service periods, that is, the basic warranty period, the pro-rata period, and the post-pro-rata period (Chien, 2010). The major goal of new sales and service modes is to improve customer acceptance of remanufactured products. If a remanufacturer provides good maintenance service or even a long-term replacement warranty, the concerns about the quality of remanufactured products can be lessened, if not totally, relieved. Therefore, the demand for remanufactured products will increase and more customers are willing to pay a higher price.

Profit optimization is always an organizational and supply chain goal. For a profit-maximizing problem, it was found that in a leasing the product-service bundle along with maintenance control-remanufacturing savings the pricing decision and the length of the leasing duration highly rely on the duration of the product's lifecycle (Robotis et al., 2012). For example, remanufactured truck engines in China are mainly sold to self-employed individual truckers, and the leasing instead of selling service mode (Mode 1) can be impractical. Considering that these drivers need better control of driving time and distance, the renewable free replacement service mode (Mode 4) is also impractical and expensive. Therefore, Modes 2 and 3 can be referred to as new sales-service modes for remanufactured truck engines.

On the basis of previous studies, according to China's heavy truck remanufacturing engine market sales, having extended warranty periods and replacement periods are two reasonable heavy truck remanufacturing engine sales modes. Through empirical analysis and mathematical models, it has been shown that the two sales models are better for remanufacturing engine sales market feasibility of implementation from the qualitative and quantitative levels.

## Observations and Recommendations on Sales-Service Modes for Remanufacturing

A number of observations and recommendations can be made in many remanufacturing contexts. Some of these are now provided.

First, consumers accept the practice that remanufacturers raise prices on the basis of extended warranty and replacement service. Extending warranty service and replacement service solves consumer concerns about the quality of the remanufacturing engine and after-sales service. Additionally, remanufacturers can also provide warranty (replacement) service and improve the sales price, and increase their earnings as a whole. This is a win-win for both remanufacturer and consumer.

Second, for heavy truck engine manufacturers, it is not that the longer the extended warranty period (replacement services), the more the remanufacturer's profit. Although remanufacturers can increase revenue by improving prices, remanufacturers also have to bear the risk of remanufactured engine increased production costs and repair costs due to providing warranty (replacement) service. The remanufacturers must weigh the maintenance costs and sales benefits and set up reasonably extended warranties and replacement service periods to achieve optimal economic returns.

Third, on the premise of remanufacturer profits, extended warranty (replacement services) will likely have a negative correlation with the cost rate. Within the same malfunction rate (defect rate), both under linear and nonlinear demand assumptions, the truck engine remanufacturer economic returns in the replacement service sales mode are more than that in the extended warranty service sales mode. Care should be taken given the demand environment and type of mode.

Last, considering the production cost has a significant impact on remanufacturer earnings, remanufacturers need to improve the level of technology and engine quality standards and reduce the production cost of remanufacturing engine. The failure of components of the remanufactured engine are usually identified and specific parts such as a turbocharger, air compressor, and other components. Vulnerable parts are the main factors influencing the consumer purchase decisions. Manufacturers should focus on extending these vulnerable part warranty periods. Remanufacturers have a choice and should take careful investigation of which mode to invest in and pursue based on product, consumer, market demand, and other characteristics. Many times the answer is not always so clear cut on mode selection.

## 5 Future Prospects and Concerns

Many developments and concerns continue to arise as culture, society, and technology continue to evolve. Different forces will play different roles related to remanufacturing markets, products, and other characteristics. There are many that exist, we identify a few with the knowledge that some things will require quick change and response, while others may take many years to emerge. We now overview some of these emergent concerns and topics.

With continuous development of e-commerce and logistics technology, the transformation from a remanufacturing supply chain to an e-supply chain has become an inevitable trend. A remanufacturing supply chain can rely on the e-commerce platform to realize product sales and recycling. In addition, with the improvement of people's living standards, people replace electronic products more frequently.

For remanufacturers, collecting used products is a very important link in the remanufacturing supply chain, but remanufacturers also face competition from third-party recycling platforms. In the future, the best decision-making for remanufacturers whether to sell products and recycle second-hand products on a third-party platform, and whether to entrust the third-party recycler to collect second-hand products in the fiercely competitive environment is of practical significance. How these decisions relate to providing help for the actual operation of enterprises is necessary to understand.

If remanufacturing enterprises choose to sell remanufactured products on e-commerce platforms, they can improve the popularity of remanufactured products through advertising, but this will also result in additional costs.

Moreover, green/non-green consumers' preferences/acceptance for remanufactured products (so-called used products) are different and ever-changing. so the effect of advertising is also different. Remanufacturers need to consider whether and how to advertise according to the information collected by consumers on e-commerce platforms. This will be related to the asymmetric information between e-commerce platforms and remanufacturers. Considering asymmetric information there is a concern about whether and how much remanufacturers make advertising investments when selling products on e-commerce platforms is a serious concern.

The remanufacturing process can effectively reduce resource consumption and protect the environment. The amount of carbon emission reduction can be used as an indicator to measure the contribution of a remanufacturing supply chain to environmental protection. At present, most studies on the environmental impact of a remanufacturing supply chain only consider the carbon emissions generated in the process of product production, ignoring the carbon emissions generated in the reverse logistics process of second-hand product recycling and the logistics process of the new and remanufactured products. Therefore, expanding understanding and knowledge on the problem of carbon emission reduction to the transportation and sales process can be important for future competitive and market needs. In addition, the remanufacturing supply chain should reasonably lay out the logistics network according to the characteristics of remanufactured products, including warehouse location and inventory control.

Operations management is a vital dimension of supply chain management. The management of a remanufacturing supply chain can be more complex than that of a traditional supply chain. The complexity of remanufacturing supply chain operation and management mainly comes from the uncertainty of second-hand product recycling quality and quantity.

Determining the demand for remanufactured products according to the remanufacturing market is difficult and more complex than ordinary products, because different consumers have different acceptance of remanufactured products. It is very important to study the production, recovery, and inventory plans of the remanufacturing supply chain. These studies can facilitate the remanufacturing supply chain more efficiently and stable so that they will be an important direction of future research.

Remanufacturing enterprises are also very involved in developing their service models according to the characteristics of remanufactured products. These service models are after-sales service models, formulated according to the characteristics of their products. The existing understanding on remanufacturing supply chain service models considers the supply chain consists of a single manufacturer and retailer. At present, most of the after-sales services of remanufactured products are provided by remanufacturing manufacturers. However, with the continuous development of remanufacturing industry, some enterprises will join to provide warranty services, improving competition for the after-sales services in a remanufacturing supply chain. Therefore, future market considerations and complexities that consider the after-sales service mode of remanufacturing under the condition of after-sales service market competition are needed.

A service model is integral to enterprise business model. A good business model can improve the profit of the enterprise, the sales volume of products, and the acceptance of consumers. Constantly improving the business model of enterprises is an inevitable trend of enterprise development. Enterprises have started to incorporate the development of remanufacturing into the formulation of enterprise business model. But many uncertainties exist in remanufacturing, each causing obstacles. How to overcome the influence of various uncertainties and further develop the business model of remanufacturing are important developments and opportunities for further understanding, research, and management practice.

The design of after-sales service mode of remanufacturing enterprises still requires significantly more understanding and development. Yet, remanufacturing enterprises also need to consider the simultaneous impact of product warranty timing, government supervision, government subsidies, remanufactured product quality, and other factors on consumer consumption preferences. As seen in the discussion in this chapter, much of what is being developed and used is still relatively immature. Advances in each of these areas are still needed.

Currently, many modeling efforts on a remanufacturing supply chain assume that remanufacturing enterprises only recycle one product—mainly to keep models tractable. But in practice, remanufacturing enterprises will simultaneously recycle and remanufacture multiple products. Some of these products can be used for remanufacturing, and some do not meet the requirements for remanufacturing, but some parts meet the requirements of remanufacturing. These parts can be used for remanufacturing, which will improve the profitability of the enterprises.

Characteristics of different products and the material requirements of remanufacturing, a remanufacturing supply chain model requires careful consideration in development and implementation of new models. But there are aspects that go beyond basic modeling of costs and operational dimensions.

The impact of consumer behavior and remanufactured product quality level on the remanufacturing supply chain also need further considerations and development. The main dimension of remanufacturing supply chain management is the uncertainty of remanufacturing productivity and the uncertainty of remanufacturing product demand. However, for different second-hand products and remanufactured products, remanufacturing productivity and product demand are certainly not the same, so a more detailed and nuanced understanding on the uncertainty of these two influencing factors is required. In addition, other uncertainties, such as cost, are different for different products. Finally, these factors are linked with the demand for remanufactured products for modeling and analysis.

With the continuous improvement of people's awareness of environmental protection, remanufacturing has attracted more attention. The development of a remanufacturing supply chain needs the coordination of various stakeholders in the remanufacturing supply chain. The development of the remanufacturing supply chain needs to conform to the business model of remanufactured products, and it needs a recycling mode in line with product characteristics. The development of the remanufacturing supply chain also needs to consider government subsidies and consumer preferences. Therefore, the research on remanufacturing and the supply chain needs to explore how the remanufacturing enterprises adopt a reasonable strategy of collecting second-hand products to the selection of determining product quality, from a macro business model to a micro remanufacturing technology.

In the future, the development of the remanufacturing supply chain needs the joint efforts of researchers, remanufacturing enterprises, recyclers, and the government, to continuously develop, better save resources, and protect the environment.

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# Supply Chain Strategizing in New Product Development

## An Interplay of Practitioners, Activities, and Practices

Ewout Reitsma and Per Hilletofth

## Contents



**Abstract**

During the last few decades, supply chain (SC) strategy has become an important focus for manufacturering companies (hereafter referred to as “manufacturers”). This has resulted in the implementation of a wide variety of SC strategies, including, for example, lean, agile, and leagile – the latter being a combination of the first two. All these and other SC strategies aim at achieving a certain level of responsiveness to customer needs. Since the level of responsiveness should match the characteristics of a product, this chapter discusses how manufacturers can engage in SC strategizing in the context of new product development (NPD).

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Through the theoretical lens of "strategy-as-practice" (SAP), SC strategizing in NPD is conceptualized as a dynamic interplay of "practitioners," "activities," and "practices." The chapter also explains that, while managing this interplay, manufacturers should be aware of challenges caused by uncertainty, politics, and learning. Finally, the chapter opens the door for future research that utilizes the SAP lens in order to empirically explore SC strategizing in NPD.

**Keywords**

Supply chain strategizing · Responsiveness · New product development · Strategy-as-practice

## 1 Introduction

Manufacturing supply chains (SCs) have become increasingly complex due to globalization, outsourcing, modularization, shorter product life cycles, and an explosion in product variety. In many cases, manufacturers have changed from sourcing only a few, simple, and separate components from local suppliers to sourcing a high variety of components/systems from globally dispersed suppliers (Handfield et al., 2020; van Hoek, 2020). This development has made manufacturers vulnerable to disruptions. For example, the Swedish home furniture manufacturer IKEA faced SC challenges due to the COVID-19 pandemic (BBC, 2021). IKEA uses suppliers in Asia and is dependent on container ships for distributing its products to warehouses across the globe. The COVID-19-induced lockdowns led to container ships being taken out of service, resulting in an overall reduction in shipping capacity. This caused massive bottlenecks at ports and low product availability at IKEA stores.

This and other examples (e.g., Brexit, the war in Ukraine) have led to SC strategy becoming an important focus area for manufacturers. A wide variety of SC strategies exist, including, for example, lean, agile, and leagile – the latter being a combination of the first two (Mason-Jones et al., 2000). The main challenge of implementing any of these or other SC strategies is achieving the "right" level of responsiveness to customer needs (Richey et al., 2021). Solving this challenge and implementing an adequate SC strategy may thus present two opportunities. First, it can enable manufacturers to optimize their own material flows, which increases both efficiency and customer satisfaction (Harland, 1996). Second, it can allow manufacturers to leverage the capabilities of other SC actors, which reduces inventory requirements in the SC, while also increasing customer satisfaction (Harvard Business Review, 2006).

According to Fisher (1997), it is crucial for a manufacturer's SC strategy to "match" the characteristics of its products. This match requires engaging in SC strategizing in new product development (NPD) (The terms "NPD" and "NPD project" are used interchangeably throughout the text of the chapter.) (Melnyk et al., 2014; Reitsma et al., 2021). Drawing on the literature, the present chapter discusses how manufacturers can engage in SC strategizing early in the product life cycle. This discussion is guided by the theoretical lens of "strategy-as-practice"

(SAP), which conceptualizes strategizing as the dynamic interplay of practitioners, activities, and practices (Whittington, 2006).

The remainder of the chapter is structured as follows. First, the background to the topic is provided in Sect. 2. Second, the theoretical lens of SAP is presented in Sect. 3. Third, through the theoretical lens of SAP, Sect. 4 discusses how manufacturers can engage in SC strategizing in NPD. Fourth and finally, the conclusion and future research direction are given in Sect. 5.

## 2 Background

To provide a background to the topic at hand, this section first discusses SC strategy and then illustrates the importance of manufacturers engaging in SC strategizing in the context of NPD.

### 2.1 SC Strategy

Strategy can be defined as the pattern in the stream of activities that characterizes the match an organization achieves with its environment and that constitutes a determinant for the attainment of its goals (Mintzberg & McHugh, 1985). Many different types of strategy are possible at different levels within a manufacturer.

*SC* strategy can be regarded as an extension of operations strategy. While operations strategy generally focuses on the competitive priorities pursued by a single manufacturer (Miller & Roth, 1994), SC strategy focuses on the objectives pursued by a manufacturer when interacting with other SC actors (Harland, 1996). As stated by Narasimhan et al. (2008, p. 5234), SC strategy can be viewed *as the pattern of decisions related to sourcing products, capacity planning, conversion of raw materials, demand management, communication across the supply chain, and delivery of products.* Thus, when correctly formulated and executed, SC strategy supports manufacturers in coping with operations that involve a variety of internal (i.e., within organizational boundaries) and external (i.e., beyond organizational boundaries) SC actors (e.g., suppliers). SCs have the same distinct life cycle stages as products: emergence, growth, maturity, and decline (MacCarthy et al., 2016). This implies that SC strategy is dynamic and evolves throughout the SC life cycle. For example, while technology and innovation are essential components of SC strategy during SC emergence and growth, enhanced efficiency is important when an SC matures.

There are different typologies of SC strategy (e.g., Fisher, 1997; Mason-Jones et al., 2000), and Narasimhan et al. (2008) suggest that they can have three underlying dimensions. The first concerns SC integration, which includes strategic alliances, collaborative integration, and long-term relationships between SC actors (Anderson et al., 1994). The second concerns just-in-time, which relates to using supplier relationships and contracts to implement a material flow system without excess inventory (Chapman & Carter, 1990). The third concerns SC linkage facilitated by the electronic exchange of information. This relates to using electronic linkages to shift the customer-order decoupling point upstream in order to deal effectively with demand uncertainty while maintaining the ability to respond quickly to customer demands (Berry et al., 1994).

An example of an SC strategy typology is provided by Mason-Jones et al. (2000). The SC strategies associated with this typology include lean, agile, and leagile – the latter being a combination of the first two. First, a lean SC strategy refers to developing a physically efficient value stream focused on eliminating all kinds of waste (Naylor et al., 1999). The main objective of this strategy is to reduce cost and enhance efficiency in SC processes (Womack & Jones, 1997). Lean is typically associated with stable customer demand, mass production, just-in-time, and long-term supplier relationships (Reitsma et al., 2020).

Second, an agile SC strategy refers to *the successful exploration of competitive bases (speed, flexibility, innovation proactivity, quality, and profitability) through the integration of reconfigurable resources and best practices in a knowledge-rich environment to provide customer-driven products and services in a fast-changing market environment* (Yusuf et al., 1999, p. 37). By leveraging capacity buffers and relationships with other SC actors, an agile SC strategy aids manufacturers in providing customer-driven products with unique features to the market quickly, so as to maintain a competitive advantage in a rapidly changing environment (Christopher, 2000; Mason-Jones et al., 2000).

Third and finally, as indicated, a leagile SC strategy refers to combining elements of lean and agile (Bruce et al., 2004). As stated by Bruce et al. (2004, p. 155), *leagile takes the view that lean and agile approaches shall be combined at a decoupling point for optimal SC management.* This means that the leagile strategy involves adopting very different approaches to managing the upstream and downstream activities in a manufacturer's SC. For example, upstream activities can be managed in a cost-effective (lean) manner, whereas downstream activities can be managed in a highly responsive (agile) manner (Bruce et al., 2004).

Despite their individual differences, what all SC strategies and their typologies have in common is that they are linked to the theme of "responsiveness." As Richey et al. (2021) argue, SC strategies revolve around manufacturers pursuing certain levels of responsiveness to customer needs when interacting with other SC actors. Drawing on prior literature, Richey et al. (2021, p. 2) define SC responsiveness as *the process and outcome of organizational adjustments achieved as individual organizations within a SC alter behaviors, norms, and/or policies to help place a SC and its members in a favorable position to achieve customer value under dynamic environmental conditions.*

Similarly, Holweg (2005, p. 605) defines responsiveness as *the ability to react purposefully and within an appropriate timescale to customer demand or changes in the marketplace.* In other words, responsiveness is the ability to modify a course of action through organizational adjustment in response to market and environmental conditions.

## 2.2 The Importance of SC Strategizing in NPD

As the preceding discussion reveals, a core theme of SC strategy concerns achieving the "right" level of responsiveness to customer needs. But what level of SC responsiveness should be achieved? The literature (e.g., Chopra & Meindl, 2007; Fisher, 1997) suggests that the answer to this question depends on the product that flows (or will flow) through the SC.

For example, the "zone of strategic fit" concept argues that the level of SC responsiveness should match the innovativeness of a product (Chopra & Meindl, 2007; Fisher, 1997). Otherwise, significant problems can occur in SC operations. Moreover, Selldin and Olhager (2007) found that manufacturers that match SC strategies with products outperform those that do not. The zone of strategic fit is illustrated in Fig. 1 and subsequently discussed.

Figure 1 includes horizontal and vertical axes. On the horizontal axis, products with low levels of innovativeness have predictable demand patterns, long life cycles, low product variety, low contribution margins, or long lead times. Conversely, products with high levels of innovativeness have unpredictable demand patterns, short life cycles, high product variety, high contribution margins, or short lead times.

On the vertical axis of Fig. 1, SCs with low levels of responsiveness supply predictably and efficiently at the lowest possible cost. Alternatively, SCs with high levels of responsiveness react quickly to customer needs so as to minimize stockouts, forced markdowns, or obsolete inventory. Based on these axes and the zone of strategic fit in Fig. 1, Table 1 lists examples of matches between SC responsiveness and product innovativeness.

The next question that arises naturally is: when to match SC strategies (i.e., level of responsiveness) with products? The literature (e.g., Hilletofth et al., 2018; Reitsma et al., 2021) suggests starting this matching process already in NPD, which is the moment when most product life cycle costs are determined (Dowlatshahi, 1996).

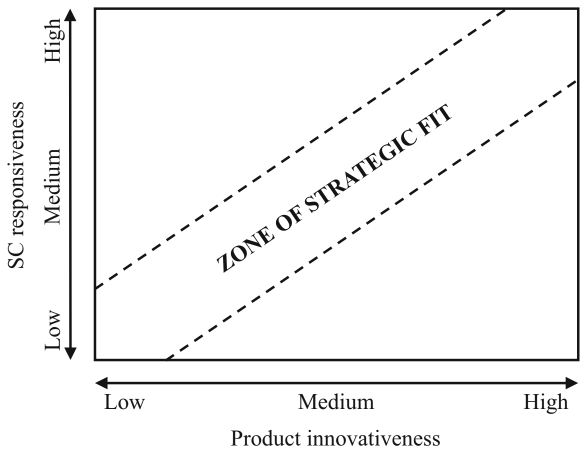


**Fig. 1** Matching SC responsiveness with product innovativeness. (Adapted from Fisher (1997, p. 109) and Chopra and Meindl (2007, p. 35))

**Table 1** Matching products with SCs

| Level of product innovativeness | Level of SC responsiveness | Example |
|---|---|---|
| Low | Low | Products such as toothbrushes require a highly efficient SC, with minimal waste and loss, while retaining the ability to adapt to unexpected delays |
| Medium | Medium | Products such as trucks require an SC that is both efficient and flexible enough to respond swiftly to the changing needs of customers |
| High | High | Products such as new computer chips require a highly responsive SC, with minimal shortages, while retaining the ability to minimize stocked inventory |

Failing to adequately engage with an SC strategy in NPD may lead to problems such as low product performance, low SC performance, and ultimately market failure (Browning & Ramasesh, 2007; Dowlatshahi, 1996; Reitsma et al., 2021). The causes of these problems can be illustrated with an example.

Consider the following situation: a new product is designed based solely on customer needs, thus independently of a chosen SC strategy. After the new product has been designed, SC operations are ramped up and examined for their level of responsiveness. If the performance of these operations is not within acceptable limits, the design of a product may need to be revised until satisfactory performance is achieved.

However, toward the end of NPD, it is not always possible to make product design changes. For example, strict NPD deadlines may prevent exchanging scarce components for ones for which there is abundant supply. In the long term, this can result in an unnecessarily long time-to-market and high product cost due to dependency on a few expensive suppliers with long lead times (Dowlatshahi, 1992; Gokhan et al., 2010).

There are also examples of the benefits of considering SC strategies in NPD. For example, Microsoft intentionally creates a sense of product scarcity when launching a new Xbox by limiting product availability (van Hoek & Chapman, 2006). This is done to create a consumer rush for a product while minimizing tied-up capital in inventories and expensive express shipments.

Furthermore, a globally leading gas turbine manufacturer ensures that a new product's point of differentiation is positioned after the customer-order decoupling point (Bäckstrand et al., 2014). This avoids increasing the level of tied-up capital in inventory through having to manufacture different product variants based on forecasts.

### 2.3 Summary of Sect. 2

This section provided a background to the present chapter by discussing SC strategy and its importance in NPD. This included discussing different SC strategies and "responsiveness," which is the core theme connecting these strategies. Hereafter, the "zone of strategic fit" concept showed that a manufacturer's SC strategy (i.e., level of responsiveness) should match its products. Finally, it was argued that a good match requires engaging in SC strategizing in NPD, which is as early in the product life cycle as possible.

## 3 SAP

Before discussing how manufacturers can engage in SC strategizing in NPD, this section presents the theoretical lens – SAP – that is used to organize the discussion.

### 3.1 Dimensions of SAP

The SAP literature provides a guide for discussing how manufacturers can engage in SC strategizing in NPD. Inspired by practice theorists (e.g., Bourdieu, 1990), this literature proposes practice-based theories of strategy (Fenton & Langley, 2011; Vaara & Whittington, 2012). These theories take issue with the more traditional view of strategy as a "static" property of manufacturers.

Instead, they propose that strategy should be thought of as something continuous that practitioners do (Johnson et al., 2003; Whittington, 2006). Following this rationale, Whittington (2006) introduces the concept of strategizing and its three interrelated dimensions: practitioners, activities, and practices. These dimensions are summarized in Fig. 2 and subsequently discussed.

#### Strategizing "Practitioners"

Strategizing "practitioners" are the actors who shape the construction of practice through who they are, how they act, and what resources they draw upon (Jarzabkowski et al., 2007; Whittington, 2006). Moreover, practitioners are those who make, shape,


**Fig. 2** Strategizing as the interplay of practitioners, activities, and practices. (Adapted from Johnson et al. (2011))

and execute strategy and play an important role when they perform activities that draw upon socially defined practices (Jarzabkowski et al., 2007).

Practitioners disclose a certain understanding of what constitutes good action when conducting strategy work driven by a particular collective end (Tsoukas, 2018). This suggests that practitioner characteristics have major implications for the daily strategy work (Jarzabkowski et al., 2016). Specifically, what can be achieved during this work depends on the practical or social-political skills of practitioners (Rouleau, 2005). For example, they may require cross-functional skills and working knowledge of all areas of the organization in order to understand the collective end driving strategizing.

Furthermore, practitioners from all levels of the organization (e.g., shop floor employees, middle or senior managers) can make a difference in strategizing (Jarzabkowski et al., 2016; Vaara & Whittington, 2012). Practitioners who are external to the organization, such as consultants and regulators, can also make a difference. Thus, strategizing can include practitioners from beyond the managerial ranks and organizational boundaries.

### Strategizing "Activities"

Practitioners do not just think; they act individually or collectively in a world where the object of the activity is related to the needs of the individual (Leontiev, 1978; Vygotsky, 1980). Based on this logic, strategizing "activities" represent practitioner activities with regard to the formulation and implementation of strategy (Reckwitz, 2002; Whittington, 2006). Examples of such activities include recognizing and acting upon business opportunities or threats, analyzing an organization's weaknesses or strengths, and setting or evaluating long-term goals.

Strategizing activities are situated (Whittington, 2006), which means that their ideal performance depends on the particular context in which they are embedded. For example, activities should follow certain standards of excellence (Tsoukas, 2018).

Furthermore, strategizing activities can be planned or unplanned, temporary or long-term, routine or nonroutine, and formal or informal (Adams, 2004). For example, Tsoukas (2010) states that strategizing activities are often not interpreted as "strategic." Practitioners rarely pause to think about strategies or engage in deliberate strategizing, indicating that strategy often simply emerges over the course of routine activity (Jarzabkowski et al., 2016).

In other words, strategies are often merely the result of organizational activities, instead of the rational decision-making process used by senior managers as they develop a strategic plan (Mintzberg & Waters, 1985). This implies that even though strategizing benefits from intention or purposeful goal orientation, it sometimes just happens.

### Strategizing "Practices"

Strategizing "practices" support practitioners in performing strategizing activities (Reckwitz, 2002; Whittington, 2006). Whittington (2006, p. 619) defines practices as *shared routines of behavior, including traditions, norms, and procedures for thinking, acting, and using 'things', this last in the broadest sense.* This implies that practices act as instrumental problem-solvers, information generators, inspirers of social interaction, or constructors of strategy (Jarzabkowski & Kaplan, 2015). Thus, practices include any structured aids, managerial or technical in nature, used for structuring or influencing the management and effective execution of strategizing activities (De Waal & Knott, 2010).

In other words, practices can be conceptualized as instruments of mediation between the varied purposes and interests of practitioners (Jarzabkowski, 2003). Specific examples of practices include cross-functional meetings/teams, routines, decision-making tools, frameworks, or process models (Jarzabkowski & Kaplan, 2015; Whittington, 2006).

Practices can be used at individual, interpersonal, and organizational levels and support different practitioners simultaneously (Stenfors, 2007). Moreover, multiple practices or multiple enactments of the same practice (e.g., repeated meetings of cross-functional teams) may be used for long-term strategizing activities.

When used, practices facilitate continuity or change of strategy by aligning the different practitioners engaging with strategizing activities (Jarzabkowski, 2003; Johnson et al., 2003). While continuity is facilitated by aligning practitioners and activity in the organization, change is facilitated by identifying and mediating contradictions between past and future activity.

### 3.2 Summary of Sect. 3

Using the SAP literature, this section discussed strategizing involving the interplay of three dimensions: practitioners, activities, and practices. First, strategizing practitioners shape the construction of practice and strategy through who they are, how they act, and what resources they draw upon. Second, strategizing activities are practitioner activities regarding the formulation and implementation of strategy. Third and finally, strategizing practices are the mechanisms that support practitioners in performing strategizing activities.

## 4 SC Strategy-as-Practice in NPD

Through the theoretical lens of SAP, this section discusses how manufacturers can engage in SC strategizing in NPD. The section is divided into three subsections. First, the dimensions of SC strategizing in NPD are discussed individually, using the literature. Second, the interplay among these dimensions is examined. Third and finally, challenges of engaging in SC strategizing in NPD are considered.

### 4.1 Dimensions of SC Strategizing in NPD

The SAP literature (e.g., Whittington, 2006) suggests that practitioners, activities, and practices are the key dimensions of strategizing. The present section follows these dimensions to discuss how manufacturers can engage in SC strategizing in NPD.

### SC Strategizing "Practitioners" in NPD

A diverse set of practitioners can play an important role in SC strategizing in NPD. Practitioners from different organizational functions – product design, logistics, demand management, procurement, and transportation – need to share their situated knowledge to achieve an adequate level of responsiveness to customer needs. This knowledge sharing is challenging and requires practitioners with different backgrounds, knowledge, and interests to understand each other and pursue an effective approach to communication.

Practitioners such as product designers need to take a broader perspective than that of product functionality and performance in NPD. They also need the capability to link product design with SC strategy-related challenges such as responsiveness to customer needs. However, such a broad perspective is not one that product designers are trained to use in NPD (Lee & Schmidt, 2017).

In turn, practitioners in more SC-oriented organizational functions – logistics, demand management, procurement, and transportation – are also not trained to fully grasp the implications of product designs on SC strategy. Practitioners need to possess a broad set of skills including behavioral skills, business acumen, and the appropriate engineering knowledge (Lee & Schmidt, 2017). These skills require training, coaching, and possible tag-teaming with peers or even job rotation.

Van Hoek and Chapman (2007) suggest that this expanding knowledge scope should ultimately enable practitioners to:

1. Refrain from unnecessarily using jargon and technical language.
2. Move toward using shared business language that expresses initiatives in terms of shared output objectives and in terms of benefits and priorities in other organizational functions.
3. Communicate the case for initiatives up front, and frequently update peers on progress and results against the shared output objectives.
4. Come to the table proactively with constructive questions and solutions to enhance NPD effectiveness and value.
5. Avoid being perceived as a showstopper for innovation.
6. Ensure that the starting point of discussions related to SC strategies is founded on corporate objectives.
7. Inform about considerations and opportunities related to SC strategies and advance the relevant thinking.
8. Be positive and have expertise about relevant themes (e.g., product design, logistics, demand management, procurement, transportation) that can contribute to NPD.

### SC Strategizing "Activities" in NPD

Section 2.1 explained that SC strategy is a broad concept that, in its widest form, can be understood as the level of responsiveness a manufacturer aims to achieve toward customer needs. Following this conceptualization, practitioners can perform a wide range of different SC strategizing activities in NPD.

These activities have two aims. The first is to identify the desired level of responsiveness to customer needs; the second is to develop and implement the resources, processes, and relationships (within the manufacturer and across the SC) that seek to make the attainment of the desired level of responsiveness inevitable over time (Melnyk et al., 2014).

SC strategizing activities typically relate to a manufacturer's supplier base, supplier relationships, and internal or external material flows. To define a set of SC strategizing activities that can be performed in NPD – while recognizing that this list is not exhaustive – Table 2 draws on the work of Reitsma et al. (2021) and Min and Zhou (2002).

## SC Strategizing "Practices" in NPD

When engaging in SC strategizing in NPD, there is plenty of room for practitioners of one organizational function – for example, product design – to promote its interests as taking priority over that of another, such as procurement. Therefore, carefully chosen practices that facilitate collaboration are needed when practitioners perform SC strategizing activities that require discussion, negotiation, and iteration. Examples of practices discussed in this subsection include decision-making tools, specialized roles, cross-functional meetings/teams, and process models.

***Decision-Making Tools*** The literature (e.g., Blackhurst et al., 2005; Fine et al., 2005) proposes several quantitative decision-making tools that support SC strategizing practitioners in NPD. These tools aim at designing a product together with its SC. In many cases, this reduces the cyclic procedure of designing a product, designing the SC, evaluating the SC, and redesigning the product to a single iteration (Gokhan et al., 2010). This may lead to benefits such as more efficient and effective SC planning, ultimately optimizing the delivery of products to customers (Arntzen et al., 1995).

For example, Blackhurst et al. (2005) propose a tool that stores product, process, and SC data. This enables practitioners to evaluate the lead time consequences of certain product design choices. Similarly, Chiu and Kremer (2014) propose a tool for evaluating different SC scenarios (i.e., centralized and decentralized) during product design. This includes consideration of SC costs such as transportation and inventory costs.

Furthermore, Fine et al. (2005) propose a weighted goal-programming tool that simultaneously solves for the best combination, for each product version, of product design, assembly plan, and SC design. As a final example, Claypool et al. (2015) propose a simulation tool that designs an SC parallel to designing a new product. This tool obtains the optimal product and SC designs while simultaneously analyzing time-to-market and supplier-dependency risks.

***Role Specialization*** The literature (e.g., Lakemond et al., 2001; Van Hoek & Chapman, 2007) further proposes the introduction of a specialized role in NPD, which is responsible for coordinating collaboration between different SC

**Table 2** SC strategizing activities in NPD. (Based on Reitsma et al. (2021) and Min and Zhou (2002))

| Activity (determining the. . .) | Description | Example |
|---|---|---|
| Sourcing approach | Determining the balance between internal and external sourcing in NPD by prioritizing the areas on which to devote internal resources. This includes determining and examining the ideal geographical sourcing locations and balancing single and multiple sourcing | A manufacturer may prefer externally sourcing product items (e.g., components, systems) when suppliers are relatively cheap but highly responsive, flexible, and innovative. In turn, these items can be single sourced when benefits from the use of economies of scale outweigh the risk of supplier dependency |
| Collaboration approach | Determining the extent of collaboration with SC actors in NPD and deciding with which SC tiers to collaborate | Close collaboration with suppliers is recommended when they are responsible for product items or workloads critical for a manufacturer's success. It may also be desirable to collaborate directly with critical lower-tier suppliers |
| Postponement approach | Determining the balance between forecast and demand-driven activities in NPD. This includes positioning the customer-order decoupling point in the SC while simultaneously balancing inventory and service levels | When operating in a configure-to-order context, a manufacturer delays the configuration of final products until orders arrive and customer requirements become known. This increases the flexibility to respond to changing market conditions |
| Network structure | Determining which SC nodes (e.g., suppliers, manufacturing plants, warehouses, and consolidation points) should be utilized in NPD and serve which customers, market segments, and suppliers. This includes selecting transportation modes and their routes | When outsourcing product items or workloads, it is necessary to evaluate and select suppliers based on their capabilities. It may also be necessary to design multiple supply or distribution channels in terms of their length in both distance and time |
| Internal material flow | Determining the material flow layout within SC nodes utilized in NPD. This includes selecting the equipment (e.g., stations and forklifts) needed for material handling (i.e., moving, storing, packing) and allocation of storage areas | A manufacturer can tailor the layout of the manufacturing process to product items. This requires evaluating different process layouts (e.g., job shop or cellular) when setting physical properties (e.g., geometries) of product items |
| Packaging | Determining the packaging needed for inbound product items, work in progress, and outbound products in NPD | Even though a manufacturer is encouraged to use existing packaging formats, it may be necessary to choose new packaging. For example, special packaging may be needed when product items are sensitive and at risk of damage |

(continued)

**Table 2** (continued)

| Activity (determining the. . .) | Description | Example |
|---|---|---|
| Capacity plan | Determining the optimal production (and transportation) capacity at each SC node utilized in NPD to meet changing demands for both new and old products | A manufacturer can plan capacity by setting overall planning objectives and determining appropriate time horizon(s). It is also relevant to consider the product's manufacturing characteristics (e.g., setup time, throughput time) |
| Inventory levels | Determining the levels and locations of stocks throughout the SC in order to maintain an appropriate trade-off between customer service and costs in NPD | When product items are critical for a manufacturer's success and have a short life cycle, the physical efficiency of the just-in-time inventory model can be combined with the responsiveness dictated by product items |

strategizing practitioners. For example, SC performance can be improved by creating the role of new product-introduction forecasting manager (Van Hoek & Chapman, 2007). This role is dedicated to working with various functions in NPD to drive alignment around the forecast. It involves flagging forecasting differences, spotting potentially wrong assumptions, and working across the organization to arrive at appropriate SC capacity plans (Van Hoek & Chapman, 2007).

Similarly, Lakemond et al. (2001) suggest introducing the role of a dedicated SC coordinator when NPD involves a high degree of innovation and a wide variety of product items or workloads. Such a role should focus on ensuring that SC constraints (i.e., possibilities and limitations) are considered in NPD (Lakemond et al., 2001).

As another example, Zolghadri et al. (2008) suggest establishing three roles that focus on SC strategizing in NPD. The first role coordinates the identification of potential critical suppliers, selection of suppliers, and negotiation of supplier contracts. The second role is an independent entity that oversees the work of product designers. The third role works together with the other two to ensure consideration of SC constraints in NPD.

***Cross-Functional Meetings/Teams*** Collaboration between SC strategizing practitioners can be further increased by using cross-functional NPD meetings/teams. Specifically, the literature (e.g., Brewer & Arnette, 2017; Di Benedetto et al., 2003; Dowlatshahi, 1992) suggests that practitioners from all relevant functional areas should be represented in NPD meetings/teams. For example, Di Benedetto et al. (2003) propose permanently including practitioners from SC-oriented organizational functions in NPD.

Similarly, Noori and Georgescu (2008) advise including practitioners from product design, marketing, finance, procurement, operations, transportation, and logistics in NPD meetings/teams. SC-oriented practitioners should especially be permanently included when NPD success is dependent on actors beyond organizational boundaries (Lakemond et al., 2001).

Cross-functional NPD meetings/teams can improve SC performance through facilitating early consideration of SC strategizing activities related to procurement, manufacturing, distribution, and marketing (Brewer & Arnette, 2017). This enables identifying and solving potential problems before SC strategizing activities are initiated. To realize such benefits, a manufacturer must welcome new ways of thinking, encourage high levels of communication, ensure a joint understanding of company goals and strategies, and locate teams in close proximity (Guy & Dale, 1993).

However, in globally operating manufacturers, it may be inevitable that practitioners or functions are geographically dispersed. Therefore, there may also be a need for information technology tools that foster virtual collaboration (Duranti & de Almeida, 2012).

***Process Models*** The work of SC strategizing practitioners in NPD can also be coordinated with process models. Specifically, these models can be used to structure NPD around various stages and gates (Cooper, 2008). The stages reflect the points in time at which NPD activities – including SC strategizing activities – are performed, while the gates act as quality control checkpoints.

This type of activity-based process models links NPD activities to input (objects necessary to carry out an activity) and output (objects produced in an activity) (Nicholas & Steyn, 2008). This way, it becomes possible to establish input-output relationships that provide coordination and interaction of activities.

Process models tend to be either sequential or iterative in nature (Browning & Ramasesh, 2007). When NPD is conceived as a set of planned iterations through all of the major NPD stages and gates, an iterative model is more applicable than a sequential one (Browning & Ramasesh, 2007). Furthermore, different NPD projects do not necessarily pass through the same stages or gates, which means that a process model may require adjustment to individual NPD projects (Cooper, 2008).

## 4.2 Interplay Among Dimensions of SC Strategizing in NPD

Having individually described the dimensions of SC strategizing in NPD, their possible interplay is summarized in Fig. 3 and then discussed.

Figure 3 shows that SC strategizing practices at one level interact with SC strategizing activities in NPD at another. As suggested by De Waal and Knott (2010), a key distinction between these levels is that SC strategizing practices are to some extent generic, whereas the type and number of SC strategizing activities depends on the specific NPD project under consideration.

Within the manufacturer's internal context, the drivers for institutionalizing practices are potential improvements in terms of efficiency and legitimacy (Westphal et al., 1997). Within the manufacturer's NPD context, practitioners tend to select and apply existing or emerging practices based on their knowledge and how suitable the practices are for performing SC strategizing activities.

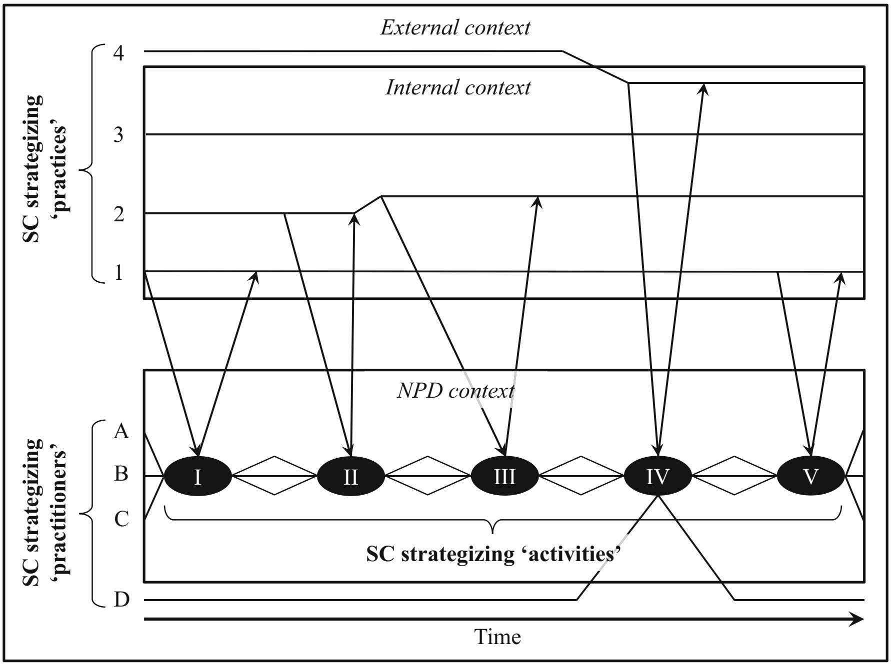


**Fig. 3** Interplay among SC strategizing practitioners, activities, and practices in the context of NPD. (Adapted from Whittington (2006))

The bottom rectangle in Fig. 3 represents the manufacturer's NPD context, which includes a set of SC strategizing activities (I, II, III, IV, V). These activities are performed by three practitioners of the same organization (A, B, C) and one external practitioner (D) in the case of activity IV. Practitioner D can be a partner or consultant from the manufacturer's external context. Figure 3 simplifies reality, since NPD can include more than five activities and more than four practitioners.

The top rectangle in Fig. 3 includes the set of accepted and institutionalized practices that are drawn upon by practitioners as they engage in SC strategizing activities in NPD. Figure 3 simplifies reality by only showing four practices. These practices can be generated locally (within the manufacturer's internal context) or originate from the external context (e.g., introduced by outside partners or consultants) (De Waal & Knott, 2010).

Sometimes practitioners want to modify existing practices in order to perform their activities optimally (Jarzabkowski, 2004), which is depicted by the kink at practice 2 in Fig. 3. On other occasions, practitioners may need to draw upon practices that are new to the manufacturer (practice 4) to successfully perform a certain activity (activity IV) in NPD. These newly introduced practices can be reapplied and amended in the future. Finally, it is also possible that an institutionalized practice is not relevant to a specific NPD project (practice 3).

## 4.3 Challenges of Engaging in SC Strategizing in NPD

Many challenges can occur when managing the interplay of SC strategizing practitioners, activities, and practices in NPD. Three often mentioned challenges relate to uncertainty, politics, and learning.

### Uncertainty Challenges

Several sources of uncertainty can challenge SC strategizing in NPD. For example, products tend to exhibit "emerging" properties in NPD, leading to unexpected interactions when designing and integrating items (e.g., components, systems) into a final product (Hobday et al., 2000).

Demand and supply uncertainties are additional challenges that SC strategizing practitioners may face in NPD. Demand uncertainty occurs when changing customer needs cause unclear goals and increased risks (Davies et al., 2011). For example, panic buying during the COVID-19 pandemic caused unforeseen customer demand spikes in certain industries (Handfield et al., 2020; van Hoek, 2020). Such situations make it difficult to accurately predict demand for new products, plan capacity in the SC, and create supplier contracts for secure and stable supply.

Furthermore, supply uncertainty occurs when manufacturers have become dependent on high-risk suppliers (Vanpoucke & Ellis, 2019). For example, the last two decades have seen the pursuit of lower landed cost, which resulted in many manufacturers switching to suppliers in low-cost regions such as China and Southeast Asia (Handfield et al., 2020). Even though this brought many cost benefits, it also lengthened SCs and exposed NPD to the risk of delivery delays from remote suppliers (Handfield et al., 2020; van Hoek, 2020).

All the identifiable sources of uncertainty that can challenge SC strategizing in NPD should of course be addressed in the best possible way. As Mason-Jones and Towill (1998) argue, *those companies which cope best with uncertainty are most likely to produce internationally competitive bottom-line performances.* In general, uncertainty can be reduced by actively sharing information throughout the SC (Wagner & Bode, 2008). This may require technologies (e.g., RFID, ERP, blockchain) that accelerate information sharing and increase the transparency of material flows (Reitsma & Hilletofth, 2018).

### Political Challenges

As discussed in Sect. 4.1.1, SC strategizing in NPD can involve a diverse set of practitioners. This leads to the need for a political process that involves practitioners with different backgrounds, knowledge, objectives, or orientations (Esper et al., 2010). Throughout this process, there is considerable latitude for practitioners of one organizational function (e.g., product design) to promote their interests as taking priority over that of another (e.g., procurement).

A major reason for this behavior is that functions provide unique resources to an organization, tend to pursue their own goals, do not always share a common understanding, and tend to hold different values (Ellinger et al., 2006). As a result, any change imposed by a function can meet resistance, especially if those changes unfairly disadvantage or threaten the incentive system of another function.

This situation can result in functions protecting their local autonomy and coherence at the expense of other functions' initiatives aimed at reinforcing organization-wide coherence (Narduzzo et al., 2001). Thus, the risk is that SC strategizing practitioners become self-referential, at the expense of relating the outcomes of their work to the changing needs of other practitioners and to the manufacturer's SC goals.

Consequently, cooperation between practitioners from different functions requires tackling the issue of self-referential behavior (Tsoukas, 2018). This issue is also referred to as the social dilemma of individual self-interest versus group efficiency (Gintis, 2014). As Gintis (2009, p. 47) states, *all gain when all cooperate but each one has a personal incentive to defect, gaining at the expense of the others.*

Self-referential behavior can be discouraged by establishing an authority structure and mutually reinforcing expectations among practitioners, so that cooperation becomes the norm (Gintis, 2014). For example, practitioners are keener to cooperate when believing that others are also committed to cooperation.

### Learning and Knowledge Acquisition Challenges

Another challenge when engaging in SC strategizing in NPD relates to learning. Manufacturers should find a way to systematically promote learning within and across different NPD projects and the broader business organization (Prencipe & Tell, 2001). Even though NPD projects can be unique and thus unlikely to be repeated in the future, the challenges faced by practitioners are often similar (Davies & Brady, 2000).

Therefore, the more frequently similar NPD projects are completed, the greater the possibility to predict outcomes based on previous experiences and use learning to preempt problems (Davies & Brady, 2000). This phenomenon is referred to as "economies of repetition" (Davies & Brady, 2000) and enables conducting SC strategizing work more efficiently and effectively.

However, the temporary nature of NPD creates an obstacle to learning and capability development related to SC strategizing. As Davies et al. (2011, p. 12) observe, *[NPD] project teams typically break up after a project is completed and there are no project silos to capture this crucial learning. All too often, commercial pressures to utilize resources fully during the life of the [NPD] project and to reallocate them quickly when a project finishes, prevent systematic learning within phases of a project and from one project to the next.* Thus, NPD is associated with the risk of "learning closure" (Hobday, 2000), which refers to the act of prioritizing the start of a new project over learning from its predecessors.

The risk of learning closure can be mitigated by developing practitioners who learn to think in terms of systems, work purposefully toward a vision, and learn how to collectively and iteratively develop frameworks for thinking (Senge, 2006). As such, learning becomes an intrinsic aspect of the work of practitioners, not something extra that is added. This may ultimately lead to the creation of a "learning organization" (Senge, 2006). In such an organization, practitioners obtain, share, and use accumulated knowledge and transfer it within and across projects in order to meet strategic goals.

### 4.4 Summary of Sect. 4

Through the theoretical lens of SAP, this section discussed how manufacturers can engage in SC strategizing in NPD. This started with individually discussing the three dimensions of SC strategizing in NPD: practitioners, activities, and practices.

First, SC strategizing practitioners in NPD can originate from different organizational functions and have different backgrounds, knowledge, or interests. Second, SC strategizing activities in NPD typically relate to determining the manufacturer's supplier base, supplier relationships, and internal or external material flows. Third, SC strategizing practices are the mechanisms that support practitioners when they perform SC strategizing activities which require discussion, negotiation, and iteration.

Having individually discussed these dimensions, their interplay was exemplified. This revealed that the interplay among the dimensions of SC strategizing in NPD is dynamic and may change over time.

Finally, the section discussed three challenges of engaging in SC strategizing in NPD: uncertainty, politics, and learning. First, uncertainties related to product design, demand, and supply may challenge SC strategizing in NPD. Second, SC strategizing in NPD involves a complex political process in which there is plenty of room for practitioners to promote their interests as taking priority over that of others. Third and finally, the temporary nature of NPD creates an obstacle to learning and capability development related to SC strategizing.

## 5 Conclusion and Future Directions

This chapter discussed how manufacturers can engage in SC strategizing in NPD, by touching upon several topics. First, different SC strategies were introduced. After concluding that these strategies aim at achieving a certain level of responsiveness to customer needs, it was argued that manufacturers should engage in SC strategizing in NPD. Thereafter, through the lens of SAP, it was shown that this engagement can be achieved by managing the dynamic interplay of SC strategizing "practitioners," "activities," and "practices." Finally, while managing this interplay, manufacturers were warned to be aware of challenges related to uncertainty, politics, and learning.

The present chapter also opens the door for future research and practice that utilizes the SAP lens in order to empirically explore SC strategizing in NPD. Such research can create reflexive knowledge by – instead of looking for structural invariants, normative rules of conduct, or predetermined cognitive schema – investigating practitioners, activities, and practices within a community of interpretation (Whittington, 1996).

Future directions for practice and research include further investigating the unfolding nature of SC strategizing in NPD as the interplay of practitioners, activities, and practices. This investigation and integration should provide an interpretative framework in which a particular approach to SC strategizing in NPD "makes sense" in a manner that may be unique to that time and place. Instead of searching for theories of general validity, future research can contribute particularly meaningfully by stating the context and conditions in which a particular approach to SC strategizing might be appropriate in NPD.

As suggested by Tsoukas (2009), the value of such work lies *not* in its generalizability but in the understanding provided of the means and mechanisms through which SC strategizing in NPD occurs in a specific situation and in practice. Even though the goal is not to generalize in a statistical sense, the provided insights can be of considerable interest for other contexts. By presenting the results in such a way that readers may interpret the relevance of the findings in other contexts, the notion of "transferability" (Lincoln & Guba, 1985) rather than "generalizability" becomes more relevant in future research.

Despite not delivering "actionable knowledge" (Jarzabkowski & Wilson, 2006) in the sense of providing (deterministic) guidelines for acting, the proposed type of research should be capable of helping practitioners do their work differently. Utilizing the SAP provides an opportunity to focus attention precisely on what is easily taken for granted by practitioners (Vaara & Whittington, 2012). This understanding may contribute to the creation of "reflective practitioners" (Schön, 2017), who will hopefully become more subtle and sensitive when engaging in SC strategizing in NPD. Thus, future research is invited to provide practitioners with resources enabling them to consider their work in a different light, thus creating new or alternative ways of working.

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# Viewing Supply Chain Ambidexterity (SCX) Through Paradox Theory and an Innovation Framework

Mehmet G. Yalcin and Muhammad Hasan Ashraf

## Contents



**Abstract**

Ambidexterity explains why companies engage in seemingly contradictory strategies in their effort to improve competitiveness. In supply chains, the literature provides neither a generally accepted definition of supply chain ambidexterity (SCX) nor a proper measure of relevant constructs. In addition, scholars have argued that ambidexterity is only an academic concept with no practical implications. This chapter evaluates supply chain integration (SCI) and supply chain agility (SCA) as antecedents to SCX. A conceptual framework consisting of four theoretical components, concept of ambidexterity (CoA) in conjunction with

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paradox theory (PT), theory of constraints (TOC), institutional theory (IT), and resource-based view (RBV) – resource-advantage theory (R-A), is proposed as a meta-theoretical guide for research, teaching, and practice. The chapter first introduces this Sustainable Innovation Capability Framework (SICF), explains its components, and then outlines the relevance of SCX in supply chains. A concept of an ambidextrous growth mindset (AGM) is also introduced with relevance to sustainability and innovation.

**Keywords**

Supply chain ambidexterity (SCX) · Sustainable innovation capability framework (SICF) · Concept of ambidexterity (CoA) · Paradox theory (PT) · Ambidextrous growth mindset (AGM)

# 1 Introduction

> Traditional approaches to business will collapse, and companies will have to develop innovative solutions. That will happen only when executives recognize a simple truth: Sustainability = Innovation. (Nidumolu et al., 2009, p. 9)

Establishing a strong scholarly connection between innovation and sustainability from the perspective of supply chain management (SCM) motivates this chapter, where efforts are directed to develop a practical framework for guiding theory development around sustainable innovation. Numerous theories provide an opportunity to show how supply chain ambidexterity (SCX) could be employed toward *creating value sustainably* in all aspects – i.e., social, environmental, and economic. We present a general framework that consists of four select theoretical components that link to creating value sustainably: the concept of ambidexterity (CoA) in conjunction with paradox theory (PT), theory of constraints (TOC), institutional theory (IT), and resource-based view (RBV)/resource-advantage theory (R-A) where the latter two theories are nested within TOC. This guiding framework offers an overarching meta-theoretical pathway for research, teaching, and practice toward sustainability and innovation (see Fig. 1).

Over the past few decades, all aspects of sustainability – such as the triple-bottom-line (TBL), corporate social responsibility (CSR), and environmental, social, and governance (ESG) metrics – revealed fresh challenges for organizations around the globe. Supply chains have become intertwined with one another to create a spectrum of smoothly-to-haphazardly dovetailed networks, and therefore, managers are concerned more than ever regarding matters beyond their supply chains. Translated into organizational processes as constraints, these challenges are root causes for continual assessment of risk faced by supply-demand networks (Arlbjørn & Paulraj, 2013) amid increased connectedness through enhanced technologies. Once addressed and adopted, the sum of all outcomes relating to these constraints is transformed into competitive/comparative advantages that sustain the networks

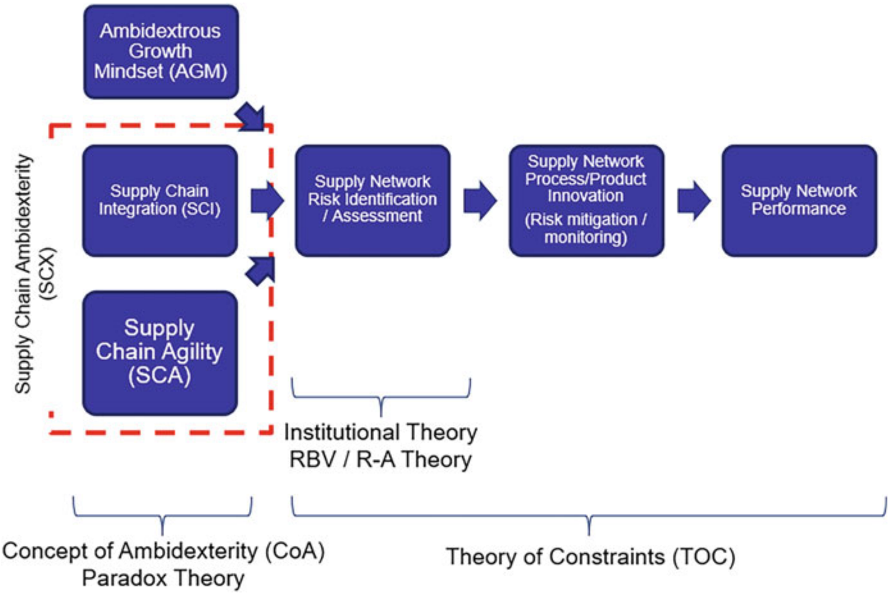


**Fig. 1** Sustainable Innovation Capability Framework (SICF): A meta-theoretical guide for research, teaching, and practice. (Source: Authors)

into the future. In this chapter, these outcomes are synonymous with innovation – defined within a broad spectrum where even the slightest (incremental) and the most leap-frogging (radical) improvements are acknowledged as innovations.

TOC states that networks tend to focus on challenges perceived as bottleneck/constrained processes. Defining the scope of SCM as an end-to-end phenomenon that extends from the first supplier to the consumer – including all the stakeholders along the way – and back, assessing where constraints reside now or could possibly appear in the future, requires impactful use of available resources and continuous effort by network players. A critical and plausible assumption can be made where constraints are defined as *uncertainties that matter* for a supply chain/network. In other words, anything that affects supply chain goals has the potential to become a relevant constraint and, therefore, may need to be addressed within the supply chain risk management context. The following sections briefly explain each component in the proposed framework – from Fig. 1.

## 2 Theory of Constraints (TOC) and Risk Management

Kern et al. (2012) define supply chain risk management using three sub-components – risk identification, risk assessment, and risk mitigation (Wagner & Bode, 2009; Kleindorfer & Saad, 2005; Tang, 2006). They suggest that continuous improvement and risk management need to occur simultaneously over the long term because of the vulnerabilities that arise upon changes in the environment. In their empirical study, the authors find that superior identification of risk leads to subsequently better risk assessment and mitigation performances (Kern et al., 2012). Without proper risk identification, supply chains might manage irrelevant risks. If supply chains continue to integrate their operations and exercise agility simultaneously – which we define as SCX – their supply chain's risk identification ability can improve.

TOC (Goldratt & Cox, 1984; Goldratt, 1990) prescribes identifying the constraint – the process creating a bottleneck – in a system and then exploiting it. All other processes should play a subordinate role to the bottleneck process, then elevate the capacity of the constraint as needed, and restart the cycle by identifying any new constraint or bottleneck process. Global efforts toward exercising more sustainable solutions require operations to incorporate new constraints into their organizational strategies as they are expected to perform under conditions that are more stringent.

Trying to operate under such conditions, acquiring the right resources, and managing them in an efficient and effective manner have become more challenging due to increased competitiveness. Organizations are continuously evaluating their supply chain networks in conjunction with the constraints that they confront. This evaluation creates a link where the supply chain performance is influenced by risk management, with potential threats and opportunities to an organization being identified and addressed to maximize future gains. Whether imposed through rules and regulations or due to self-motivation for improvement, the new constraints – or new constraint combinations – trigger action and help improve processes and product-service offerings.

Thinking of a firm or a supply chain network as an entity that has unique characteristics, any new venture for improvement could be assumed to be an innovation – for example, implementation of best practices, importing practices from other industries, innovating with resources that reside within. Adding more constraints to firm or supply chain network operations introduces additional challenges for managers.

TOC explains the overall procedure of selecting the relevant constraint that is ripe for improvement and advises eliminating its bottleneck status. The focus of this chapter is not to explain the innovation process but to examine the nature of "bottleneck constraint selection" by identifying its determinants. Strategically, a firm will want to pick a constraint that will either pose a threat or opportunity – since both are uncertainties with risks – for mitigation, evaluation, and further improvement. Determinants of this selection procedure would talk much about the firm's intent. However, some firms might be forced to select certain improvement programs.

## 3 Supply Chain Ambidexterity (SCX) for Risk Identification

CoA explains why companies engage in seemingly contradictory strategies when seeking to improve competitiveness. CoA's theoretical support comes from paradox theory – where contradictory elements are termed *paradoxes* (Schad et al., 2016;

Smith et al., 2017). CoA explains why operational activities within the same organization appear to be diametrically opposed but collectively improve performance (Andriopoulos & Lewis, 2009; Raisch & Birkinshaw, 2008; Smith & Lewis, 2011; Birkinshaw & Gupta, 2013; O'Reilly & Tushman, 2013; Turner et al., 2013).

This chapter uses Schad et al.'s (2016) interpretation of paradox and defines ambidexterity as a "persistent contradiction between two interdependent elements." While interdependent and contradicting elements appear to collectively create value, this dynamic is a dilemma for practitioners and researchers. CoA includes various paradoxical dichotomies such as adaptability and alignment, integration and responsiveness, exploration and exploitation, differentiation and low-cost strategic positioning, and global integration and local responsiveness (Gibson & Birkinshaw, 2004).

These dichotomies describe drivers of seemingly irreconcilable operational tensions (Adler et al., 2009) that exist between short-term efficiency and long-term adaptability (Abernathy, 1978). These paradoxical tensions are what operations and supply chain managers must routinely address (Adler et al., 2009; Ashraf et al., 2021; Zhang et al. 2020) – including flexibility versus efficiency (Adler et al., 1999), exploitation versus exploration, and just-in-time versus traditional manufacturing (Quinn & Cameron, 1988). Organizations that successfully manage these tensions use them to improve and sustain performance (Raisch et al., 2009; Birkinshaw & Gupta, 2013; Schad et al., 2016; Smith et al., 2017).

Most of the CoA discourse focuses on the exploitation and exploration dichotomy (Birkinshaw & Gupta, 2013; O'Reilly & Tushman, 2013; Turner et al., 2013; Zimmermann et al., 2015; Smith et al., 2017) and posit that when organizations employ both exploitation and exploration type activities in their operations, they achieve greater levels of performance than companies that focus on a single dimension.

Ambidextrous SC strategy is often described and measured through the simultaneous existence of exploitative and explorative SC activities (Kristal et al., 2010; Lee & Rha, 2016; Rojo et al., 2016). No generally accepted definition of ambidexterity within supply chain context exists (Yalcin, 2017). However, an operational definition of ambidexterity through the lens of paradox theory and supply chain management can be developed. Identifying antecedents of SCX can assist practitioners and researchers in creating it in their organizations. Additionally, while the literature anecdotes that ambidexterity can provide tangible benefits, Birkinshaw and Gupta (2013) argue that it is currently only an academic concept. As a result of this issue, operationalizing SCX by creating measures to examine the concept empirically is important (Yalcin, 2017).

To extend SCX application beyond just being an abstract concept requires that it be useful to SC scholars and practitioners. To do so, SCX requires a greater level of definition, measurement, and experimentation. The exploitation and exploration ambidextrous relationship is conceptually close to supply chain integration (SCI) and supply chain agility (SCA) in the SC context. SCI and SCA can be jointly examined to investigate their relationship to SCX. Similar to exploitation and exploration, an overemphasis on either SCI or SCA, to the detriment of the other, can weaken organizational competitiveness. SCA refers to the adaptability of the supply chain to capitalize on new opportunities. SCI refers to the level of cooperation and collaboration among supply chain partners to increase efficiency. Both concepts have been treated separately in the literature and have individually shown to improve competitiveness. This individual treatment suggests that the two concepts are distinct due to their differing activities and effects on competitiveness (Yalcin, 2017).

Paradox theory suggests that positive synergies between apparently opposing activities can create interactions that are complementary to competitiveness. This suggestion may not be evident superficially, but it provides conceptual support for testing the concepts together. For example, SCA increases adaptability to new opportunities, which in turn can improve efficiencies through SCI. Alternatively, SCI can free up resources and capacity that support greater adaptability through SCA. The presence of both factors indicates SCX.

Since SCI and SCA are concepts used in practice, this suggests that SCX is more than an abstract academic concept and can explain many of the practical industrial outcomes. The SCX term may not be well-known among practitioners, but SCI and SCA are well-known and have been shown empirically to individually improve SC performance. No studies have examined SCI and SCA for their combined effect on performance – also known as *combinative competitive capabilities*, which CoA suggests (Yalcin, 2017).

Similar to exploitation and exploration activities, SCI and SCA together can increase SCX. As a result, identifying antecedents to SCX at the firm level is important. In this chapter, a measurement model is proposed. For practitioners, identifying SCX drivers could lead to better SC management and performance (Yalcin, 2017).

## 4 Concept of Ambidexterity (CoA) and Paradox Theory

Smith et al. (2017) arguably tie the concept of paradox to ancient philosophy while citing that paradox research increased by 10% per year between 1990 and 2014. It is built on early scientific research conducted in psychoanalysis, communications, and macro sociology disciplines. Demonstrating the continuing debate about paradoxes, Harris (1882) analyzes Hegel's deep commitment to his way of paradoxical thinking as a philosopher.

More recently, the paradoxes and complexity are recognized in works such as Stacey et al. (2000) that draw from Hegel, Mead, and Elias by focusing on a better understanding of organizing instead of organizations as human-made tools in their discussions about stability and change. While Nilsson and Gammelgaard (2012) elaborate on the increasing advantages offered by complexity approaches over the systems approach, Nilsson (2019) explains how the complexity paradigm helps generate research through the study of paradoxes (Nilsson & Christopher 2018) that are better aligned with real-life logistics.

Smith et al. (2017) also add a collection of studies that advance the paradox theory. These studies are rich in the explorative nature of paradox and posit that interdependent contradictions are inherent in human nature, its environment, as well as the constructs that humans build – for example, life-death, knowledge-ignorance, self-other, expansion-constriction, independence-dependence, time-space, particles-waves, stability-change, empowerment-alienation, flexibility-control, diversity-inclusion, exploration-exploitation, social-commercial, competition-collaboration, learning-performing, profits-purposes, and novelty-usefulness.

Johnson (2014), through a *polarity map*, practically illustrates how each paradox dimension (e.g., group cohesion and individuality) brings something positive to the innovation process and how each dimension becomes a liability without the other dimension to complement it.

In the context of SCM, paradox theory is still in its early stages but is gradually gaining popularity. For example, Maalouf and Gammelgaard (2016) identify organizational paradoxes that emerge when firms implement lean practices and present a range of managerial responses used for dealing with the emerged paradoxes. Similarly, Ashraf et al. (2021) identify paradoxes that became salient during COVID-19 in the logistics industry and propose managerial responses to address them. Xiao et al. (2019) show how purchasing and sustainability managers make sense of and respond to paradoxical tensions in sustainable supply chains. Van der Byl and Slawinski (2015) show the potential of paradox theory to understand the nature of tensions in corporate sustainability and generate creative approaches to address them. Jarzabkowski et al. (2013) develop an empirically grounded process model and show how managers experience paradoxes and their approach to cope with them over time. Sandberg (2017) explores the applicability of the paradox theory in the global sourcing context, and Zhang et al. (2020) apply the paradox lens to identify the elements of paradox in the literature. Ashraf et al. (2022) introduced the concept of the Braess Paradox in the supply chain domain, arguing that capacity building counterintuitively may lead to a decrease in performance.

From another viewpoint, Duncan (1976) found that to be competitive; successful organizations need to possess two separate structures; one that encourages exploitation and the other, exploration. In the 1990s, the term "ambidexterity" was coined to describe these structures, and its use gained momentum in organizational behavior (i.e., March, 1991; Levinthal & March, 1993; Ghoshal & Bartlett, 1994; Tushman & O'Reilly, 1996). In the 2000s, the literature began to describe it as the CoA (i.e., Gibson & Birkinshaw, 2004; Birkinshaw & Gibson, 2004; Raisch & Birkinshaw, 2008; Raisch et al., 2009; Simsek, 2009; Lavie et al., 2010). Recent scholars began a consolidation of CoA (i.e., Birkinshaw & Gupta, 2013; O'Reilly & Tushman, 2013; Turner et al., 2013) and applied it to firm and SC performance (i.e., Tokman et al., 2007; Im & Rai, 2008; Adler et al., 2009; Kristal et al., 2010; Blome et al., 2013; Narasimhan & Narayanan, 2013; Lee & Rha, 2016; Rojo et al., 2016; Eltantawy, 2016; Yalcin, 2017; Aslam et al., 2018).

CoA's dominant utility has a time dimension that is perceived as performance, hinging on an organization's ability to manage exploitation vs. exploration activities simultaneously (Gibson & Birkinshaw, 2004). While CoA is primarily studied within organizational science, it has been gaining attention among SC scholars. Recent research has investigated CoA by using elements of cooperative relationship portfolios of small-to-medium-sized enterprises (Tokman et al., 2007), long-term inter-organizational relationships (Im & Rai, 2008), and supply management sustainability performance (Eltantawy, 2016). Also, CoA has been applied to explain a manufacturer's *combinative competitive capabilities* (Kristal et al., 2010), SC disruptions via SC sensing (an approach to visibility), SC seizing (a form of agility), and SC reconfiguring (their term that is synonymous with flexibility) (Lee & Rha, 2016). More recently, CoA has been used to explain SC flexibility and SC competence (Rojo et al., 2016); supply chain efficiency and responsiveness (Aslam et al., 2018); supply network knowledge and innovation (Narasimhan & Narayanan, 2013); organizational governance and innovation (Blome et al., 2013); and supply chain ambidexterity (SCX) (Yalcin, 2017). This extensive use demonstrates that CoA is an emerging area of study in SCM.

## 4.1 Relevance of Ambidexterity in Practice

The work of Birkinshaw and Gupta (2013), O'Reilly and Tushman (2013), and Turner et al. (2013) provide the basis of a contemporary view of CoA. While all three studies provide valuable insights regarding CoA, Birkinshaw and Gupta (2013) provide the broadest perspective with an *efficient frontier* approach similar to that used by Boumgarden et al. (2012) and Porter (1996). They find that CoA is not necessarily opposing but includes orthogonality with relationships that are interactive – less than 180° angles between vectors – instead of diametrically opposed relationships (180° relationships). This observation suggests that an interaction between two interdependent elements in supply chains may explain the benefits of SCX as long as they have some degree of persistent contradiction between them – not fully parallel and thus interactive.

Birkinshaw and Gupta (2013) admit that despite it being a vital and attractive phenomenon, CoA is ill-defined, and its applicability to organizational research is primarily anecdotal. While the authors assert that CoA offers another theory to explain organizational behavior, they highlight the difficulty in measuring competing objectives that must be traded off, reconciled, managed, or balanced in the industry (Yalcin, 2017). The current literature is not clear on which opposing or complementary objectives exist.

Upon developing a new construct called ambidextrous SC strategy, Kristal et al. (2010) discover odds with the "tradeoffs scenario" between exploitation and exploration and propose that ambidextrous SC strategy may describe a complementary relationship between realizing efficiencies and concurrently evaluating new prospects. In support, Birkinshaw and Gupta (2013) argue that measuring exploitation and exploration as separate dimensions is crucial, but treating them as opposing points a priori as a strict trade-off is unwarranted. Applied to the broader SC, the work by Kristal et al. (2010) captures constructs that are loosely defined and not SC-specific. Lee and Rha (2016) introduce a plausible model, but their factors are not SC-specific, and the linkages have not been examined within an SC context (Yalcin, 2017). Because CoA has been treated as an academic construct lacking demonstrated industry relevance, Birkinshaw and Gupta (2013) have concerns about CoA becoming a fad. They argue that refocusing and rethinking the direction of the current literature is needed.

## 4.2 Supply Chain Ambidexterity (SCX)

Ambidexterity theorists acknowledge the definitional issues as the main source of uncertainty in meaning and measurement (O'Reilly & Tushman, 2013; Turner et al., 2013). So far, the literature provides neither a generally accepted definition of SCX nor a proper measure of relevant constructs.

Simsek (2009) classifies CoA definitions under three views: structural, behavioral, and realized. The *behavioral view* examines organizational CoA under a single entity, whereas the *structural view* approaches CoA from higher abstract levels. While there are issues with all three viewpoints, they show an especially poor consensus on the definition of the *realized view*, which focuses on attainments through duality's actions. The realized view applies not only to single organizational units but also to SCs. Unlike the behavioral and structural views, the realized view is about a state where CoA behavior is actually taking place and not just the endeavor to achieve a hypothetical, idealized level called *ultimate ambidexterity*. The realized view captures the entire spectrum of levels of CoA.

It is risky to apply CoA to a wide variety of contrasting concepts because the theory can lose its meaning (O'Reilly & Tushman, 2013), especially from the SC perspective. Birkinshaw and Gupta (2013) and O'Reilly and Tushman (2013) recognize that the unit of analysis should be moved from the firm level to an SC level; however, this might not be possible unless SCX occurs at the firm level first. Therefore, by focusing on a definition from the realized view, a transition of CoA is necessary from the firm to the SC level to claim that SCX exists. Recent CoA-related research in SC supports this argument (Yalcin, 2017).

Aslam et al. (2018) conveniently incorporate SCX without developing the construct. Although the elements, supply chain efficiency and responsiveness, in this construct are plausible, they are haphazardly put together to carry on their analysis of a bigger model. Because the SCX strategy is a relatively new construct, SC researchers began to develop measurement items built around the commonly used exploitation and exploration variables. The ambidextrous SC strategy, developed by Kristal et al. (2010), is the only construct that synthesizes CoA with SC. It encompasses the simultaneous pursuit of both supply chain exploitation and exploration practices from a manufacturer's perspective.

While SC exploitation practices refine and extend existing skills and resources, exploration practices pertain to the development of new supply chain competencies through experimentation and acquisition of new knowledge and resources. SC exploitation mainly focuses on obtaining lower costs and higher reliability through improved efficiencies. In contrast, the goal of SC exploration is to seek new knowledge and ideas within SC relationships to better support organizational decision-making.

Flynn et al. (2010) define SCI with three factors in a manufacturing setting as opposed to other forms (e.g., Wiengarten & Longoni, 2015; Yuen & Thai, 2016): customer, supplier, and internal integration and show linkages to operational and financial performance. Flynn et al. (2010) show that supplier, internal, and customer integration all have different effects. Further, in their findings, Flynn et al. (2010) explain that the best-performing manufacturers were effective with internal, customer, and supplier integration. Consensus in measuring SCA is not as further-established (i.e., Fayezi & Zomorrodi, 2016) as in measuring SCI.

Gligor et al. (2015) provide details on measuring SCI and building on SCA items developed in earlier studies (i.e., Christopher, 2000; van Hoek, 2001; Swafford, 2003; Li et al., 2009; Braunscheidel & Suresh, 2009; Gligor, 2013; Gligor et al., 2013). Gligor (2013) conducted an empirical study on the effects of firm SCA on performance outcomes from an efficiency and effectiveness perspective. Until then, Gligor (2013) suggests that the theory development for SCA had been limited, evident by the underdeveloped elements and linkages related to agility. For instance, agility and flexibility were used synonymously (i.e., Giachetti et al., 2003; Li et al., 2008; Almahamid et al., 2010). While their research led to a consensus definition for agility, Gligor et al. (2015) established a measurement instrument by identifying the dimensions of agility within the SC field. They reveal five distinct dimensions of SCA that are categorized under cognitive (alertness, accessibility, decisiveness) and physical (swiftness, flexibility) classifications. The former is linked to information processing, and the latter is linked to action-taking.

Tse et al. (2016) find that SCI positively influences SCA, which then positively influences a firm's performance by fully mediating the SCI's effect on firm performance. This observation suggests that an interaction effect may be present on SCX. Gligor (2013), while investigating the effect of "alertness," stops short of acknowledging possible confluence of SCI such that after being "alert," the failure of internal integration might appear as the root cause holding back the firm's decision-making process. Birkinshaw and Gupta (2013) suggest that this situation may indicate a relationship that is similar to the efficiency-frontier-like idea within these dualities. Whether through reconciling, balancing, or trading off, the components of dualities influence one another (Yalcin, 2017). It is possible that further agility might bring new resources into and make them an operational component of the organization and thus help the organization exceed a certain threshold with its integration efforts. Similarly, SCA could possibly enable further SCI.

## 5 Linking Supply Chain Integration and Supply Chain Agility via Paradox Theory

Employing a multi-method approach that uses a Literature Review, Expert Panels conducting Q-sorts, Semi-structured interviews, and a Grounded Theory (GT) type approach, a study was conducted, incorporating academics and practitioners, to

**Table 1** Steps followed to verify supply chain integration (SCI) and supply chain agility (SCA) as antecedents of supply chain ambidexterity (SCX) (Yalcin, 2017)

| Step | Method | Aim | Potential Outcomes (bold occurred in this study) |
|---|---|---|---|
| 1 | *Expert panel* of four judges conducted an initial measurement item level analysis | Determine *any* similarities among exploitation, exploration, SCI, and SCA measurement items | If the measurement items are *identical*, then stop research<br>**If the items display similarities, then expand the expert panel and employ Q-sort method for improved accuracy**<br>If *no* similarities among the items, then SCI and SCA may or may not have a paradoxical relation |
| 2 | *Expanded panel* of expert judges to conduct measurement item level analysis via Q-sort method | Find the *degree* of similarities among exploitation, exploration, SCI, and SCA measurement items | If the degree of similarities among the items are *high* (interdependence), then the items can be considered almost identical, so stop research<br>**If the degree of similarities among the items are not high or low (interdependence), then proceed with further exploration of the SCI and SCA relationship**<br>If the degree of similarities among the items are *low* (no interdependence), then SCI and SCA may or may not have a paradoxical dynamic |
| 3 | *Interviews* with expert panel of academics and practitioners conducted under three phases | Shed *further light* on SCI and SCA measurement items and explore the interplay between SCI and SCA | ***Persistent* contradicting nature between SCI and SCA (*trade-off*)**<br>***Temporary* contradicting nature between SCI and SCA (*balance*)**<br>***Non*-contradicting nature between SCI and SCA (*reconcile* and *maximize*)** |

develop a new theory by linking the SCI and SCA constructs (Yalcin, 2017). Table 1 summarizes the main steps of the process used and some outcomes.

Reconciliation between SCI and SCA activities is important. For instance, a recent decision to push for further vertical integration efforts with their suppliers in a company was presented with caution by some practitioners in the study, mentioning the need to monitor and nurture the existing agility efforts that are already in place with the fear of slowing down supplier innovation (Yalcin, 2017).

Many times, organizations have to sacrifice either SCI or SCA activity for the sake of the other. Examples include a limitation of resources such as funds, time, and human resources rather than the strategic ability that the managers or the organizations possess themselves. The intensity of the argument for lack of resources seems to vary depending on the functional departments, organizational units, or initiatives. There is a strong appeal to the trade-off perception in the SCI and SCA interaction by practitioners (Yalcin, 2017).

Balancing SCI and SCA activities is significant to scholars who seem to be more comfortable articulating their views of the applicability of balancing organizational activities. Practitioners seem to refrain from being able to strike a proper balance between SCI and SCA. While the statements of academics with industry experience resemble those views of the practitioners, they believe in the achievability of balancing more than the practitioners. Arguments revolve around different SCI and SCA activities occurring in proper amounts and importance, such as nurturing existing customers and gaining new customers. In lieu of persisting over time, the contradictions are observed to display a temporary nature (Yalcin, 2017).

## 6 Future of Supply Chain Ambidexterity (SCX)

Per the typology of conceptual contributions suggested by MacInnis (2011), "*integration*" represents the connections among previously unconnected phenomena that are explained; in this case, the relationship between SCI and SCA through CoA. By operationalizing the relevant constructs and extending (Kilduff, 2006) the CoA into SCM, further empirical research can be enabled and linkages established.

With the introduction of the proposed SCX model, not only the theory-practice gap is bridged (Waller et al., 2012), but also the scientific community is helped to anticipate an important need that the business and social organizations have (Corley & Gioia, 2011). Using established constructs and procedures to achieve clear definitions and relations between constructs, the model elaborates on the operating conditions of these relationships and explicates with reasons as to why these relationships exist (Hedström & Ylikoski, 2010; Suddaby, 2010). CoA in the SCM context improves the explanation of orthogonal dualities via SCX (Yalcin, 2017). It increases the legitimacy of SCM discipline and advances interdisciplinary connectivity, and contributes back to CoA.

This chapter focuses on bringing about the relationships between SCI and SCA constructs and explaining them with similar underlying mechanisms that lie in CoA (Chen et al., 2005). Overcoming the confusion over deciding which SC activities should be considered exploitative and which ones are explorative, academics and practitioners could have a better idea of how to manage SCX (Yalcin, 2017). It seems that the level of SCI can better measure one aspect of the SCX, while the degree of SCI depends on the degree of SCA, which represents the other aspect of SCX (Yalcin, 2017). SCI and SCA interaction enables an operational definition of SCX through the lens of paradox theory and SCM. This operationalization would allow further examination of the SCX concept empirically and help fine-tune the definition and measurement and related experimentations.

## 7 Supply Chain Ambidexterity (SCX) Outcomes and Observations

Paradoxical elements in strategies and activities do exist in the industry, and using the term ambidexterity, as it is defined in this study, is appropriate. Paradoxical elements can be complementary, although this is usually only recognized after-the-fact, suggesting that companies are not yet viewing SCX strategically. Significant resources are required to reconcile SCI and SCA activities. This involves not only internal operations but also extending to suppliers and customers. The efforts to reconcile the paradoxical elements must be intentional but are often conducted below the strategic level. There can be several opportunities where SCI and SCA activities can be non-contradictory in nature.

On the other hand, managers moving beyond the consensus of the coexistence of SCI and SCA activities rarely encounter a situation where some form of trade-off is not required. Even when complementary, the sacrifice of SCI or SCA activities is common. These may be in the form of trade-offs between human resources versus technology, short-term versus long-term benefits, or limitations due to deadlines. Again, these tradeoffs hold below the strategic level, which the theory of SCX indicates, leading to sub-optimal competitiveness. The intensity of the argument for lack of resources varies depending on the functional departments, organizational units, or initiatives, further suggesting that companies need to recognize this at a strategic level. This shows that SCX is a concept used in industry and applies to real organizational processes and resources, although the SCX terminology is not used.

It is evident that SCI and SCA are antecedents to SCX, meaning that companies must seek greater integration and agility simultaneously to achieve a level that can be described as ambidextrous (Yalcin, 2017). To achieve this at an SC level, SCX must occur when a firm incorporates it internally and with external partners with customers and suppliers. In relating SCX to the efficiency-frontier idea, the interaction effect of SCI and SCA is perceived in four stages by the practitioners, i.e., (i) as reconciliation, where firms only acknowledge the need to simultaneously pursue both the elements of SCX, (ii) as a trade-off, where firms are forced to sacrifice either element of SCX for the sake of the other, (iii) as balance, where firms pursue both the elements of SCX in proper amounts and importance, and (iv) as maximizing, where firms proactively manage the elements of SCX toward innovation and growth. Figure 2 shows the four emerging perceptions.

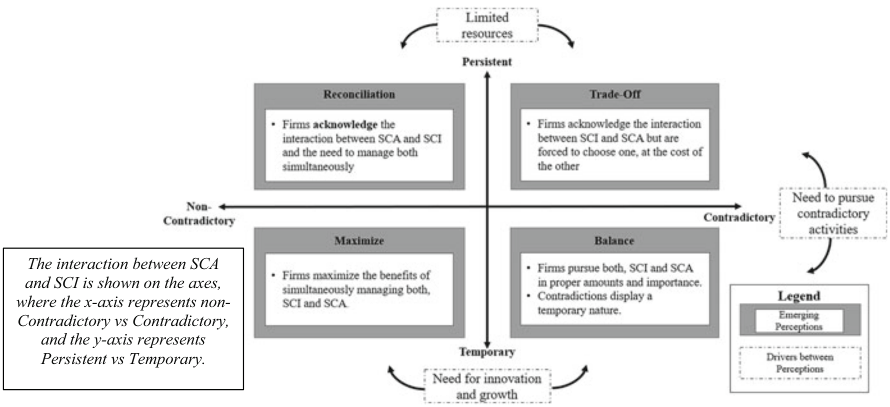


**Fig. 2** Emerging perceptions of how the interactions between SCI and SCA occur. (Source: Authors)

Practitioners who strictly focus on either SCI or SCA are intentional with their unidirectional approach, even though it may stifle innovation and further growth. Reconciliation starts with the vision of putting SCI and SCA on a Cartesian plane, and then accommodating tensions that emerge between the two. Balancing requires action on addressing the emerging tensions, where the practitioners develop proper means and methods to keep the tensions balanced. Maximizing would entail proactive management of these tensions toward innovation and growth.

Following the introduction of the measurement model for SCX, there is a need to elaborate on how this duality is achieved or practiced by managers in the industry (Yalcin, 2017). For instance, it is possible that many established firms try to capture either SCI or SCA perspectives through mergers and acquisitions. Rather than developing the needed capability in-house, they try to fill the gap that they see via the purchasing mechanism. Also, there is a need to investigate and test the measurement model that is proposed and developed in this chapter in a follow-up large-scale empirical study. The proposed linkages in the measurement model need to be hypothesized. Statistical significance ought to be established to verify and strengthen the SCX theory and then generate further insights for developing a meaningful analytical model.

## 8 Ambidextrous Growth Mindset (AGM) and Supply Chain Ambidexterity (SCX) Management Model

Based on the explanation of Birkinshaw and Gupta (2013), when the management capability is analyzed within the ambidexterity context, leadership and human resources-related studies reveal further insight into the construct that seems to have an influence on the dynamics between interdependent yet contradictory elements. It is suggested that ambidexterity generally represents successful management of both sides (Anderson et al., 2014). This perspective, therefore, holds potential for future studies, most notably into leadership effects in innovation processes (Rosing et al., 2011).

Mom et al. (2007) investigate the relationship between different knowledge flows in conjunction with management ambidextrous activities. Zimmermann et al. (2015) attempt to answer the reason behind this behavior by showing that the bottom-up version of the ambidextrous behavior of frontline managers can complement the top-down ambidextrous behavior of upper-level managers. This combined ambidextrous behavior enables organizations to be more responsive due to the frontline action in lieu of awaiting orders for action from top levels of management. Havermans et al. (2015, p. 1) "show that in responding adaptively to environmental stimuli, leaders shift between practices. . .and their enactments are bounded by the conditions of keeping. . . *them* simultaneously high" (paraphrased in italics), suggesting an optimum balance between the ambidextrous elements with the analogy of "approaching a moving target."

Since proper measures do not exist in the literature, the focus should be to invest efforts into developing the managerial capability/human resources construct to

**Ambidextrous Growth Mindset (AGM)**

1. What is the combined organizational belief/culture system that dominates the firm's supply chain: more of a fixed or a growth mindset? (Dweck, 2006)
2. What are some of the different ways for managing an ambidextrous relation between supply chain integration (SCI) and supply chain agility (SCA)? Based on potential answers as following (Yalcin, 2017):
   a) The managers' abilities to manage an ambidextrous dynamic between SCI and SCA in a maximizing manner.
   b) The managers' abilities to manage an ambidextrous dynamic between SCI and SCA in a balancing manner.
   c) The managers' abilities to manage an ambidextrous dynamic between SCI and SCA in a trade-off manner.
   d) The managers' abilities to manage an ambidextrous dynamic between SCI and SCA in a reconciling manner.

**Fig. 3** Theoretical underpinnings for the proposed ambidextrous growth mindset. (Source: Authors)

ensure its contributing/complementing influence within the SCX model. Dweck's (2006) research suggests that the growth mindset (as opposed to a fixed mindset) enables continuous improvement in self, through the teams, and then organizations by utilizing the power of people's beliefs. Synthesizing the above arguments present the ambidextrous growth mindset (AGM) construct (see Fig. 3). Dweck states that the growth mindset is based on the belief that an individual's basic qualities are things that she/he can cultivate through her/his efforts. In contrast, individuals with a fixed mindset believe that their qualities are carved in stone, which creates an urgency to prove themselves repeatedly.

Here, the growth mindset is a prerequisite of an AGM. At the same time, the other dimension focuses on addressing solely the management style of an ambidextrous dynamic between SCI and SCA (see Fig. 4).

## 9 Sustainability, Supply Chains, Theories, and AGM as a Resource

Sustainable supply chain management (SSCM) helps in further refining SCX and AGM. Here a parsimonious approach is preferred with two theories that function as opposite sides of the same coin, namely, institutional theory (IT) and resource-based view/resource-advantage theory (RBV/R-A theory) in addressing sustainability (going back to the framework in Fig. 1). The premise for the two-pronged approach is that depending on a variety of SCM-related factors, the sustainability phenomenon could either be perceived as a strategic resource that can be embraced and leveraged by a firm or a burden that the firm has to tackle or eliminate based on the market segment(s) that the firm is servicing. The degree with which the AGM dovetails with the SCI and SCA efforts (i.e., SCX) helps determine the organization's path toward

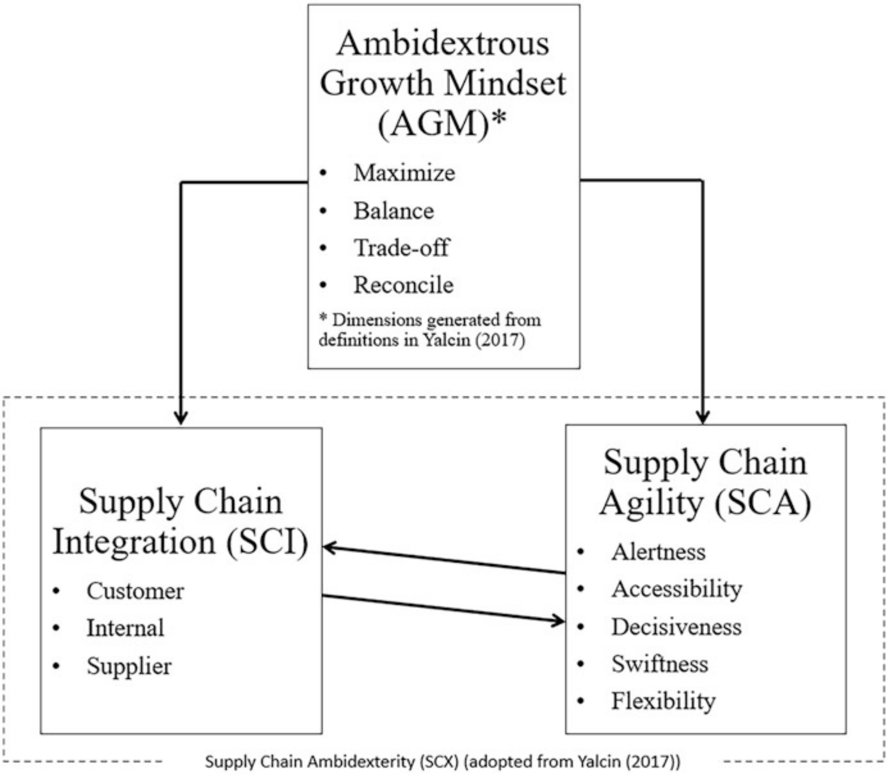


**Fig. 4** Proposed SCX management model. (Source: Authors)

robustly identifying "the uncertainties that matter" as well as boldly internalizing those relevant risks that are identified in their strategic and operational plans and activities. The reason for this lies behind the main assumption that the supply chains cannot improve indefinitely in isolation from their supply networks. While some organizations opt to wait/survive until networks improve, others choose to take on a more active role to influence the networks around identified risks (i.e., uncertainties that matter).

The dynamism in sustainability practices and the rapid evolution in the markets force firms that are at the extremes (i) to eventually adopt sustainable practices due to institutional pressures or (ii) to proactively embrace the foresighted up-and-coming AGM. Between these two extremes, firms straddle and navigate through the change with different speeds and techniques depending on the characteristics of the imposed change, some firms with fear of entrapment over time in mind and some others with no concern for long-term survival at all.

AGM is not only instrumental in ensuring that SCX is enacted but also weighs heavily in exploiting and elevating the bottlenecks (i.e., risks/uncertainties that matter) during the improvement/innovation process. Value creation through innovation motivated via AGM is a central theme. Arlbjorn and Paulraj (2013) define innovations within the supply chain network as “an incremental or radical change in process, structure, and/or technology that takes place in the supply chain network so as to create value for all stakeholders” (p. 4).

“The Discipline of Innovation,” a Harvard Business Review classic by Drucker (2002), outlines the potential sources of innovation within a firm or its industry as (i) unexpected occurrences, (ii) incongruities, (iii) process needs, and (iv) industry and market changes; while demographic changes, changes in perception, and new knowledge are considered as additional sources of opportunities for innovation that reside outside the firm. AGM reveals itself as a comprehensive phenomenon encompassing all internal and external potential sources of innovation that Drucker presents.

With every additional consideration or constraint that is included in optimization or decision-making process, supply chains devise new ways of realigning themselves in order to move forward. Therefore, “The discipline of innovation” by Peter Drucker establishes a solid foundation for an opportunity to relate sustainability from all three of its pillars (environmental, social, and economic) to systematic innovation. Based on this view, additional nodes of stakeholder requirements or perspectives within the supply chains serve as individual opportunities for motivation to innovate. It is at this juncture where “AGM” is operationalized.

Importing the resources into any operational setting invites the adoption of the definition that Hunt (2000) provided because it includes the demand-side perspective with an assumption of heterogeneous and dynamic nature (Hunt & Davis, 2008, p. 13): “the tangible and intangible entities available to the firm that enable it to produce efficiently and/or effectively a market offering that has value for some market segment(s).” AGM (tangible with sustainable inputs, production, output and intangible via knowledge, strategy) can be considered as an entity that “at times” can enable the firm to produce efficiently and/or effectively a market offering (manage its supply chains) that has value for the market segment(s) in which the firm is competing. For those other times when AGM is not valuable for the firm under the above conditions, as the resource definition would not apply, and for convenience, AGM is labeled as a burden.

Two paths seem to exist for organizations for handling uncertainties: those firms that are active and embrace the AGM along with its practices and develop competitive advantages, and others that are relatively reactive or manipulative and consider the AGM as a burden which only reduces the flexibility of the firm by squeezing the incumbent resources that feed competitive advantages. Relevance is a “competitive advantage” perspective; however, it is worth elaborating on the “burden” perspective to assist with clarifying/setting boundaries in the sustainable value creation spectrum. While institutional theory would view AGM as a burden, we focus on AGM as a competitive advantage in this chapter. Timing and the operational details of introducing the sustainability constraints are often unpredictable, proven by rich historical evidence (loss of market shares, competitive advantages, and bankruptcies). The economic pillar of sustainability is usually portrayed as the dark side; however, cost consciousness prevents resources from being expended prematurely if sufficient premiums are assigned to the resources. The real reason holding back genuine sustainability efforts is simply not knowing enough about the uncertainty; in other words, the inability to define the “uncertainties that matter” or the relevant risks to organizational processes. Through abductive reasoning, SCX offers a plausible alternative to assist supply chain managers in identifying uncertainties that matter to them the most.

## 10 Conclusion

The purpose of this chapter is to explicate Supply Chain Ambidexterity (SCX) and Ambidextrous Growth Mindset (AGM) in conjunction with Sustainable Innovation Capability Framework (SICF): A Meta-theoretical Guide for Research, Teaching, and Practice. In doing so, a thorough review of ambidexterity in SCM is also provided for proper grounding of the concepts employed.

In other words, we explained how SCX is operationalized via AGM through risk identification and theoretical considerations at the interface of sustainability constraints and innovation performance. While definitional concerns about ambidexterity are addressed from an SC perspective, we propose a definition that can be used as a practitioner construct, so the improvement claim by the ambidexterity researchers is better understood by practitioners (Yalcin, 2017).

Adams et al. (2016, p. 199) think that the managers need to be equipped “with tools for innovative solutions to sustainability challenges” and reveal that the relevant academic literature have been too diverse and fragmented. In a similar vein, while it is believed that succeeding against the sustainability challenges introduce different operating models by adding complexity to the supply chains, Simpson et al. (2015, p. 94) assert that “Sustainability will cease to be seen as some sort of specialism by ‘tree-huggers’ and will instead be a central point within the range of operations and supply chain managers’ many tasks,” therefore the need is critical “for managers to be experts in making the best possible use of very limited resources within globally competitive environments.” To that extent, we hope that our efforts in this chapter via introducing SICF offer some help to move the needle forward.

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# Operations and Supply Chain Planning

Marcus Brandenburg

## Contents



**Abstract**

Supply chain planning is a crucial factor for operational excellence and competitive advantage. Related concepts and approaches were already designed in the last century and are now implemented by most firms in almost every industry sector. Advanced planning systems that provide decision-support for supply chain planning were conceptualized and developed several decades ago and are still in place and used by planners in their daily work. However, progress in information technology and megatrends of sustainability and digitalization as well as global crises and disasters considerably change the business environment in which companies and supply chains operate. Supply chain planning processes and systems must be extended, adapted, and amended to reflect these developments and transitions. This chapter summarizes the fundamental concepts of supply chain planning and advanced planning systems and outlines which changes and advancements are needed to ensure that processes and tools remain

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strong contributors to business success for firms and supply chains. Practitioners may gain insight about fundamental developments and trends in supply chain planning while scholars may find stimuli for further research and future studies on this topic.

**Keywords**

Supply chain planning · Operations planning · Business planning · Advanced planning systems

## 1 Introduction

Supply chain planning is decisive for operational excellence and financial success of a firm. For several decades, researchers have developed and amended supply chain planning concepts which are used worldwide by firms from all industry sectors to execute planning processes efficiently and effectively. In parallel, software vendors and scholars have designed and developed sophisticated software packages and advanced planning systems (APS) that support supply chain planning and decision-making. These information technology (IT) tools are implemented by many companies and now represent global state of the art.

However, the area of supply chain planning still emerges. Progress in IT and radical innovations in computers and software offer potential for substantial improvements and enhancements of APS. Sustainability as a global megatrend affects supply chains worldwide and is reflected comprehensively in concepts and tools for supply chain planning. In addition, firms and supply chains are exposed to new challenges and threats that arise from human-made crises including political instability or wars and from natural disasters such as global pandemics or climate change.

Supply chain planning approaches have to reflect these changes in the business environment. Therefore, continuous improvements and advancements of related management concepts, business processes, and system solutions are needed. Hence, the relevance of supply chain planning for scientific research and management practice remains unbroken. The chapter at hand introduces the fundamentals of supply chain planning and suggests possible directions for the future development of this topic.

The remainder of this chapter is structured as follows: Sect. 2 lays the terminological basis and provides a brief introduction of supply chain planning concepts and characteristics and an outline of properties and functionalities of IT systems for supply chain planning. Section 3 reveals existing gaps and points toward future directions of supply chain planning from a scientific perspective as well as from a practitioner's point of view. It tackles issues of how to augment processes and enhance models and systems for supply chain planning and elaborates on the question how supply chain planning concepts should emerge due to global changes in the business environment. Section 6 discusses practical issues with regard to supply chain actors that execute supply chain planning processes and software vendors that develop and distribute IT systems for supply chain planning. Section 7 ends the chapter.

# 2 Background

## 2.1 Terminology and Foundational Concepts

A supply chain is a network of organizations that are linked by internal and external relationships and flows of goods, finances, services, and information (Stock & Boyer, 2009). In today's business, competition has shifted from the company level of single firms to the network level of supply chains (Christopher, 2005). Such networks comprise not only a company and its immediate suppliers and customers – the *direct supply chain* – but also subsuppliers and customer's customers – the *extended supply chain*. Organizations involved in upstream and downstream flows of goods, finances, and information from ultimate suppliers to ultimate customers – an *ultimate supply chain* – represent the broader perspective (Mentzer et al., 2001).

Supply chains exist whether they are managed or not (Mentzer et al., 2001). However, supply chain management has gained attention for business practice and has become an important factor of competitive advantage and a strong lever for competitiveness of firms and their supply chain partners (Brandenburg, 2013). Characterized by process orientation, customer focus, and collaboration, supply chain management strives to improve efficiency and effectiveness of functions and activities which add value to a firm and its customers and partners up- and downstream in the supply chain (Stock & Boyer, 2009).

Temporally, the tasks of supply chain management are split into present-related supply chain execution and future-oriented supply chain planning. Supply chain execution comprises all processes that have to be carried out at the present time to operate the supply network (Shu & Barton, 2012). The Supply Chain Operations Reference (SCOR) Model distinguishes between six major management processes for *Plan*, *Source*, *Make*, *Deliver*, *Return,* and *Enable* (APICS, 2017), where planning is the first major process.

Supply chain planning covers all preparatory activities that have to be executed to configure or operate the supply network in order to meet future customer service requirements by coordinated release of materials and resources (de Kok & Fransoo, 2003). Supply chain planning is closely related to sales and operations planning, which is performed as a "process to develop tactical plans that provide management with the ability to strategically direct its businesses to achieve competitive advantage on a continuous basis by integrating customer-focused marketing plans for new and existing products with the management of the supply chain" (Pittman & Atwater, 2019).

## 2.2 Concepts and Characteristics

Using categories of decision relevance and planning horizon length, the tasks of supply chain planning can be grouped into three categories (Fleischmann et al., 2015, p. 72): First, **strategic decisions** on the supply chain configuration are made in **long-term planning** of several years. Second, **tactical decisions** on operating the supply chain are made in **midterm planning** over several months or quarters. Third, **operational decisions** on supply chain execution in the near future are made in **short-term planning** for a few days or weeks.

Strategic supply chain planning determines how the supply chain is configured, i.e., which organizations form the network and which property, plant, and equipment are available and located at which place. Tactical and operational planning determines which processes and activities the supply chain actors shall perform at which point in time in the mid and near future. These tactical and operational decisions determine rough quantities and times for the flows and resources within the network and may, in the midterm horizon, reflect effects of seasonality.

Long-, mid-, and short-term supply chain planning represent different levels of a holistic supply chain-planning concept. Trying to solve a monolithic supply chain planning problem in which all required decisions are made simultaneously would not be feasible due to the high complexity of the numerous decisions that have to be made and the various constraints that have to be considered (Stadtler & Fleischmann, 2012, p. 22). Instead, a **hierarchical planning** approach **decomposes** the overall supply chain problem into smaller (sub-)problems on the strategic, tactical, and operational level in such a way that the (sub-)problems can be solved independently.

Adequate **coordination** of hierarchical planning ensures that the results of the planning (sub-)problem of one level are reflected when solving the planning (sub-)-problems of the other planning levels – for example, network configuration decisions made in strategic supply chain planning are considered in the subsequent planning runs of tactical and operational supply chain planning. In addition, feedback mechanisms ensure that results obtained from planning at the lower level serve as input for the higher-level plan execution. This divide-and-conquer concept is adequate to handle the complexity of supply chain planning which is reduced further by **aggregation** performed on the dimensions of time and entities (Stadtler & Fleischmann, 2012, pp. 21–24).

The planning horizon is split into different time buckets with larger time buckets occurring at higher planning levels, such as monthly buckets for strategic long-term planning. Smaller time buckets occur at lower levels – daily buckets for tactical mid-term planning. For example, product variants for operational short-term planning are aggregated to products for tactical mid-term planning and furthermore clustered to product groups for strategic long-term planning. Similarly, supply chain equipment can be (dis-)aggregated – for example, from single trucks to transport fleets or from single machines to whole production plants and vice versa. In addition to decomposition, aggregation, and hierarchical coordination, there are two more important elements of hierarchical planning, namely, model building and

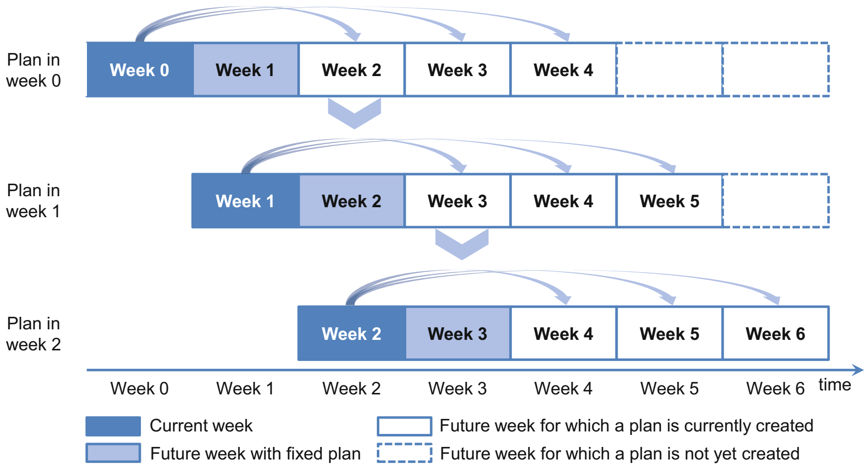


**Fig. 1** The concept of the rolling planning horizon (own representation)

model solving (Stadtler, 2015, p. 24). These elements will be described later in Sect. 2.3.

Discrepancies between reality and corresponding planning results occur frequently and have to be corrected by revised plans. For this purpose, supply chain planning is performed based on a **rolling planning horizon** (Fleischmann et al., 2015, pp. 73–74). The planning horizon, which is split into different time buckets, is iteratively shifted forward by one bucket in each planning run. For example, a planning horizon of 6 months is shifted from the months January till June to the months February till July as the planning calendar progresses. The first buckets of the planning horizon may be declared as a frozen zone in which planning decisions made in earlier planning runs must not be modified by later ones – see Fig. 1 for a rolling planning horizon (Stadtler & Fleischmann, 2012, pp. 26–28).

Supply chain planning tasks differ depending on function. Strategic supply planning, for example, determines the pool of potential suppliers while strategic production planning decides upon factory locations in the manufacturing network. However, the planning results of these function-specific planning tasks strongly affect each other. For example, decisions in manufacturing planning will remain suboptimal if the distribution plans are unconsidered and production scheduling results define planning goals (time and quantity) for raw material purchasing. **Integrated supply chain planning** reflects these interdependencies and links the different function-specific planning tasks in such a way that functional silos are overcome.

Integrated supply chain planning is conceptualized in the **supply chain planning matrix** (see Fig. 2) which is a framework that spans across the strategic, tactical, and operational levels and covers the different supply chain functions. In the horizontal dimension, it covers the different supply chain sections from supply- to demand-side in the direction of material flow downstream the supply chain while the different

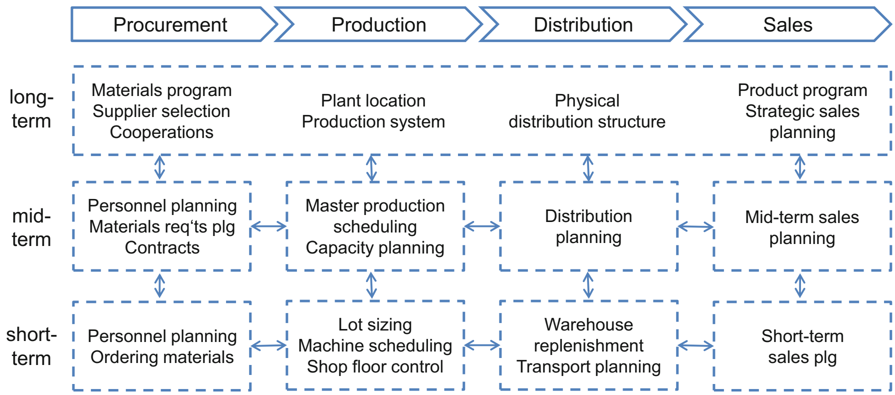


**Fig. 2** The supply chain planning matrix (Fleischmann et al., 2015, p. 77)

planning levels are reflected in the vertical dimension (Stadtler & Fleischmann, 2012, p. 29). The matrix contains the different tasks of supply chain planning and illustrates their hierarchical relationships. These tasks differ in the length of the planning horizon (long-, mid-, or short-term) and the type of decisions (strategic, tactical, or operational) and, as a consequence, in the impact of the planning results which may affect the whole company, larger parts of it, or only limited areas or single units (Stadtler & Fleischmann, 2012, p. 29). Hence, the tasks also vary with regard to their level of detail and responsibility, respectively (Stadtler & Fleischmann, 2012, p. 30): Strategic planning decisions are made by upper management based on aggregate data while local planners may be responsible for decision-making in operational planning based on detailed information.

In addition to connecting function-specific decision-makers in a centralized or decentralized decision structure within a single firm, supply chain planning should also involve suppliers and customers (Calvete et al., 2016). Hence, integrated supply chain planning crosses the organizational boundaries between different companies and ideally spans across the firms that cooperate within the supply network (Stank & Goldsby, 2000). However, due to the large complexity of today's supply networks – usually, firms are members of many different product-specific supply chains – this ideal state of integration is hardly achievable in business practice and, thus, nearly always must remain a theoretical utopia.

**Collaborative Planning, Forecasting and Replenishment** (CPFR) is a powerful approach to overcome this shortfall from the ideal state by integrating business logistics systems of different members of the supply chain (Panahifar et al., 2015). According to Seifert (2003, p. 30), CPFR is "an initiative among all participants in the supply chain intended to improve the relationship among them through jointly managed planning processes and shared information."

CPFR is enabled by a high level of trust and information sharing between the collaborating supply chain partners and inhibited by various factors including uncoordinated or disrupted information flows, lack of budget and expertise in information technology, or missing partner trust (Panahifar et al., 2015). Adequate partner selection and incentive alignment are crucial success factors for CPFR which – if implemented successfully – considerably increases the performance of all involved firms (Panahifar et al., 2015). An event study conducted by Hill et al. (2018) illustrates that CPFR has substantial positive impacts on inventory levels and sales and that it may improve operational and even financial performance of companies and supply chains.

In addition to the discussed functional, organizational, hierarchical, and time-based links, supply chain planning has process **interfaces to supply chain execution**. On the operational level and at a certain point in time, the supply chain plan must be executed by operations and execution activities: Planned purchase orders lead to receiving transactions, planned shipments result in transportation of products and pallets, and planned changes in inventory levels are realized by goods movements in warehouses. Supply chain planning ends when supply chain execution begins.

The business environment of functions, firms, and supply chains is highly dynamic and shows many, sometimes radical and dramatic, changes over time. As a consequence, supply chain planning is exposed to considerable **uncertainties** which cause **risks** in supply, demand, information, and products (Tang, 2006). Deviations between plan and reality most often lead to slight disturbances of operational processes and, thus, cause minor efficiency detriments and value losses. Typical examples include demand uncertainty and forecasting errors or the vagueness of fluctuating product yield (Fildes & Kingsman, 2011).

Unpredicted or unwanted events can also result in strong supply chain disruptions that cause long-lasting supply shortfalls, manufacturing breakdowns, and delivery failures which in turn may end in large losses in sales and market share (Norrman & Wieland, 2020). Major supply chain glitches often show considerable negative impacts on shareholder wealth (Zsidisin et al., 2016). To encounter challenges of uncertainties and risks, supply chain planning strives for incorporating aspects of resilience and robustness (Durach et al., 2015).

Jonsson, Rudberg, and Holmberg (2013) analyze the **prerequisites and effects** of supply chain planning. Their case study of a global furniture company shows that functional products, vertical integration, implementation-enforced organizations and their management, and the use of critical planning data and information are imperative for successful supply chain planning. Benefits include improvements in supply chain integration, standardization, and specialization as well as learning effects while human and organizational factors as well as software and data issues represent major obstacles for supply chain planning.

## 2.3 IT Systems, Models, and Solution Approaches

Although supply chain planning concepts follow complexity-reducing divide-and-conquer approaches, the numerous tasks are too difficult to be solved manually. Moreover, planning data and results must be exchanged rapidly to fully leverage the advantages of transparency and information exchange. These aspects call for IT systems to enable supply chain planning processes and to support related decision-making.

Progress in computer technology enabled the development of IT-support for supply chain planning which comprises systems for **materials requirement planning** (MRP), **manufacturing resource planning** (MRP II), and **enterprise resource planning** (ERP) (Kurbel, 2013). ERP systems are accounting-oriented information systems for enterprise-wide resource planning and controlling in manufacturing, distribution, and service companies which can considerably improve firm performance (Hendricks et al., 2007).

SAP AG, a German business software firm headquartered in Walldorf-Baden, developed the market-leading ERP system which consists of several modules for SC-related applications in procurement, manufacturing and logistics, and other business functions including finance and accounting or marketing and sales (Kurbel, 2013). SAP-based system solutions for supply chain management support planning, execution, and analysis of processes and activities to design the supply chain, to manage demand, supply, and service parts, and to facilitate transactions for procurement, manufacturing, warehousing, order fulfillment, and transportation (Knolmayer et al., 2009).

**Software packages for supply chain execution** complement the ERP systems. These tools comprise manufacturing execution systems (MES), logistics execution systems (LES), and warehouse management systems (WMS) that support company internal transactions. There are also software planning and execution systems for supplier relationship management (SRM) and customer relationship management (CRM) which help manage the inter-organizational flows of information, material, and finance within the supply network (Haulder et al., 2019).

The set of IT systems for supply chain management is complemented by **advanced planning systems** (APS), which support decision-making activities in supply chain planning at the long-term strategic, mid-term tactical, and short-term operational level (Stadtler, 2005; Stadtler & Fleischmann, 2012). An APS is a hierarchically structured system for integrated planning of the entire supply chain with exact or heuristic optimization methods of various planning problems that are defined by alternatives, objectives, and constraints (Fleischmann et al., 2015, p. 74). APS model the physical planning problem, use an engine to calculate the consequences of planning decisions based on the model, and depict the use of resources and materials over time via a graphical user interface (de Man & Strandhagen, 2018). Moreover, APS allow supply chain planners to modify the plan and make the implications of these changes transparent (Berning et al., 2002). As illustrated in Fig. 3, APS consist of different software modules which correspond to the different planning tasks of the supply chain planning matrix (Stadtler, 2005).

To solve the highly complex planning problems, commercial APS incorporate **mathematical models** and sophisticated solution algorithms which determine the quantities to be produced, stored, transported, and procured in the supply network (Stadtler, 2005, 2015). For each planning unit, mathematical models formally describe the decision situation by (i) variables that represent the different decision

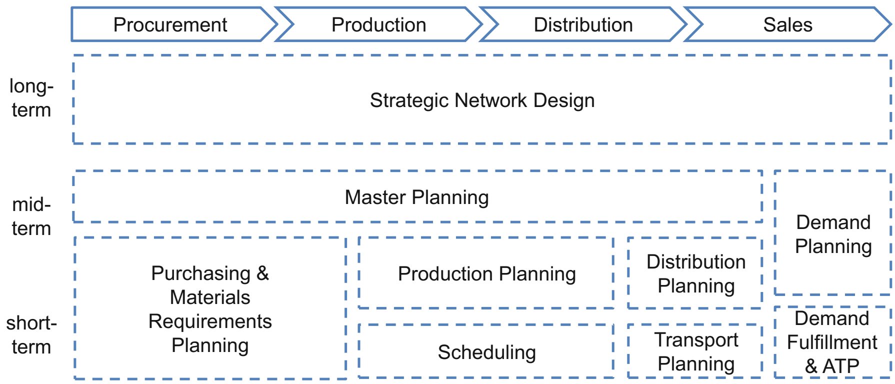


**Fig. 3** The APS modules covering the supply chain planning matrix (Meyr et al., 2015, p. 100)

options, (ii) constraints that specify the limits of the decision options, (iii) objective functions that express the planning goals and targets, and (iv) parameters that formalize the constraints and objective functions (Stadtler & Fleischmann, 2012, pp. 24–25).

APS comprise prescriptive models to determine optimized planning decisions, descriptive models to simulate different planning scenarios and their performance implications, analytic models to evaluate different supply chain plans, and statistical models to predict future product demands and to forecast future sales (Shapiro, 2007). Problem instances for the specific planning situation are parameterized by master data, such as parameters that remain unchanged over a longer time period, and transaction data, such as parameters that vary from planning run to planning run. Data have to be managed carefully, because the data quality strongly affects the quality of the planning results (Haug & Stentoft Arlbjørn, 2011).

APS contain **algorithms** to solve the complex instances of the supply chain planning problems and to execute calculations in supply chain planning routines. These mathematical procedures range from simple heuristics to sophisticated meta-heuristics to exact optimization algorithms (Stadtler & Fleischmann, 2012, pp. 25–26). If solving a large and complex planning problem to optimality is impossible – this is the most common case – nature-inspired metaheuristics come into play to determine a good or at least feasible supply chain plan (Turken et al., 2020).

In addition to metaheuristic approaches, various other methods of artificial intelligence (AI) such as expert systems, machine learning (ML) techniques, neural networks, or fuzzy logic are applied for supply chain planning (Rodríguez et al., 2020). These techniques have proven their suitability to cope with uncertainty, vagueness, or often changing information (Rodríguez et al., 2020). Simulation approaches, which unlike optimization techniques do not determine an optimized solution to a planning problem but mimic the behavior of a supply system over time, complement the catalogue of mathematical procedures that are applied for supply chain planning (Almeder et al., 2009). Simulation and optimization techniques can

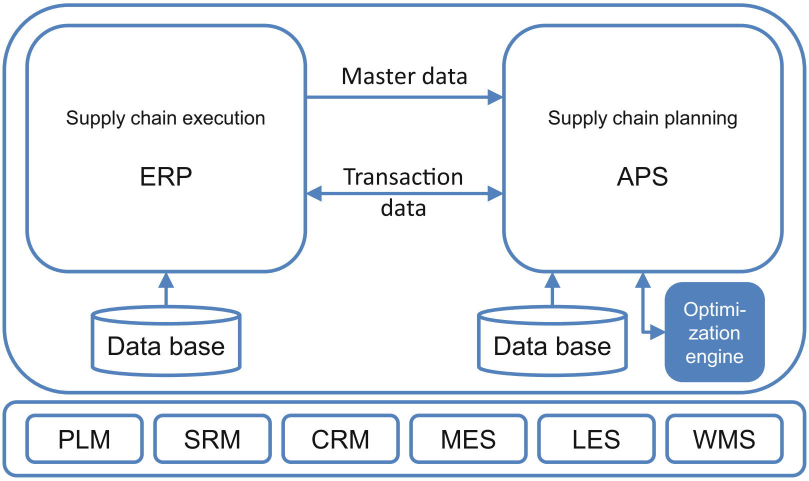


**Fig. 4** The IT system landscape for supply chain planning (own representation)

be combined to hybrid approaches in order to leverage the full potential of both methods (Figueira & Almada-Lobo, 2014).

As depicted in Fig. 4, ERP and APS are embedded into an **IT system landscape** for supply chain planning that is complemented by software packages for supply chain execution. A core interface enables the required exchange of master and transaction data between ERP and APS. In addition, an optimization engine is employed to solve the mathematical planning problems.

The application of APS for supply chain planning has considerable **positive impacts** on operational and firm performance. Case examples illustrate that applying APS has numerous substantial advantages in business practice (Jonsson et al., 2007). Rudberg and Thulin (2009) list three main benefits of employing an APS. First, higher throughput is achieved at lower cost and improved delivery reliability with reduced capacity and less inventory. Second, coordination and communication are improved due to increased visibility and transparency within the supply chain. Third, more time-efficient and proactive supply chain planning processes can be executed at a higher level of cross-functional integration.

Using APS considerably reduces the number of exceptional situations and helps to maintain business in a standard mode of operation thereby achieving swift and even flows of material, cash, and information (Schmenner & Swink, 1998).

## 3 Concerns, Outstanding Research, and Future Directions

For several decades, scientific research and business practice have conceptualized, developed, and implemented sophisticated approaches and advanced systems for supply chain planning. Many approaches currently represent a global standard in numerous industry sectors. However, from a research perspective as well as from a practitioner's point of view the topic of supply chain planning is far from being closed. New management concepts and progress in IT development offer opportunities to enhance planning processes and systems. Changes in the business environment force the need to consider additional factors and altered frame conditions of supply chain planning or to substantially refine planning processes and procedures. The following subsections will outline related future research perspectives and give practical guidelines.

### 3.1 Augmented Processes for Supply Chain Planning

The overall task of supply chain planning is to design the supply network and to decide how it shall be operated. In most cases, decision-making in supply chain planning is limited to determining future quantities and times of purchasing, production, storage, and distribution (Stadtler, 2005). Since a supply chain plan that violates cash constraints cannot be executed (Lainez et al., 2009), the exclusive focus on operations needs to be complemented by the finance perspective which considers investments, cash, and other financial factors in supply chain planning (Hahn & Kuhn, 2012b). Volume-based supply chain plans need to be translated into financial terms, adjusted for cash and budget constraints, and aligned with the financial targets of a firm.

Enhancing the well-known volume-based concepts to more comprehensive **value-based approaches for supply chain planning** would link supply chain planning to financial performance management and strengthening the integration of different yet separate planning processes within firms and across supply chains (Brandenburg, 2013). Such a value-based supply chain planning process would combine demand and supply planning with business planning thereby enabling improved managerial decision-making (Dougherty & Gray, 2006).

Integrating supply chain planning with **supply chain performance management** and **supply chain risk managemen**t is a key lever to substantially increase shareholder value (Hahn & Kuhn, 2012c). However, related concepts and processes are scant. Development perspectives include risk-aware or uncertainty-focused supply chain planning or the risk evaluation of supply chain plans based on risk measures such as VaR or CVar (Brandenburg et al., 2014).

The most comprehensive reengineering of supply chain planning would lead to **integrated business planning** which links sales and operations planning more closely to CPFR and financial planning (Willms & Brandenburg, 2019). Integrated business planning is an advanced form of sales and operations planning which embeds cross-functional planning of sales, operations, marketing, and finance into corporate strategy and combines it with inter-organizational integration up- and downstream the supply chain (Schlegel et al., 2021). Since integrated business planning enables substantial improvements of financial and operational performance, its implementation may be interesting for managers from business practice (Kepczynski et al., 2018, pp. 9–10). From a research perspective, comprehensive concepts need to be developed that seamlessly connect isolated application for volume- or value-based supply chain planning to holistic approaches for truly integrated business planning.

## 4 Changes in the Business Environment

Megatrends of sustainability and digitalization as well as megathreats arising from global crises and natural disasters substantially change the business environment in which firms and supply networks operate. These events have to be adequately reflected in supply chain planning. New challenges and technological advancements may also trigger or enable progress in concepts, processes, and tools for supply chain planning.

**Sustainability** is one of the megatrends that definitely alter supply chain planning. Supply chain sustainability requirements to which a firm is exposed are propagated from customer markets and constrained by technical possibilities (Seuring & Müller, 2008). To meet these requirements and to manage and improve supply chain sustainability, environmental factors and social criteria need to be integrated into supply chain planning approaches and models (Boukherroub et al., 2015).

The imbalance between the three sustainability dimensions in supply chain planning has to be resolved, because social aspects are strongly underrepresented in related models (Brandenburg et al., 2013). Supply chain planning needs to assess decision options and analyze resulting plans under consideration of sustainability objectives, and supply chain planning decisions must be consistent with sustainability performance criteria and the related goals and targets (Boukherroub et al., 2015; Stindt, 2017). For this purpose, supply chain planners and their decision-support systems need to orchestrate different mathematical methods including multiobjective programming, simulation, and analytic models (Stindt, 2017). Concepts for sustainable supply chain planning can comprise methods to capture customer and technological requirements which enable planners to conduct analyses under consideration of socioenvironmental aspects (Zhang & Awasthi, 2014). Consideration of broader stakeholder needs and requirements should be integrated into planning systems within a sustainability-focused environment.

Concepts like the supply chain planning matrix that are designed for the downstream material flows in forward supply chain have to be extended to approaches that reflect reverse material flows upstream the supply chain (Das & Posinasetti, 2015). To enable truly sustainable supply chain planning in business practice, these extended concepts and sophisticated mathematical approaches need to be implemented in processes, tools, and IT systems. Models and algorithms for planning in reverse and closed-loop supply chains may be helpful in this regard (Akçalı & Çetinkaya, 2011).

**Digitalization** is another megatrend that affects concepts and tools for supply chain planning. Digital technologies such as AI and ML or big data and business analytics allow companies to improve and enhance their planning, sourcing, and procurement planning and execution (Bigliardi et al., 2022). Logistics 4.0, for example, enables planning by digital technologies that lead to changes in automation, connection, and decision-making (Bigliardi et al., 2022).

Business analytics and in particular supply chain analytics can improve supply chain planning and increase the quality of supply chain plans thereby strengthening supply chain performance (Chae et al., 2014). Application examples in supply chain planning include the analysis of market data to predict trends of product and service demand or inventory replenishment activities that are supported by business analytics (Trkman et al., 2010). Big data, for example, allows real-time information collection concerning movements of goods, customer preferences, or purchasing habits thereby improving the data base for supply chain planning (Bigliardi et al., 2022). Big data analytics may also enable integrated business planning (Schlegel et al., 2021). These powerful approaches need to be leveraged to enhance supply chain planning performance.

AI is a powerful technique that can make a substantial difference in future supply chain planning. AI applications are suitable to improve supply chain network design and supplier selection as well as inventory and demand planning (Sharma et al., 2022). Moreover, manufacturing planners can predict seasonal effects and mitigate the bullwhip effect by improved resource planning based on AI (Sharma et al., 2022). AI technology may also help reflecting the social dimension of sustainability and considering pandemic situations in supply chain planning (Rodríguez et al., 2020). New developments at the human-machine interface improve the communication between supply chain planners and the APS, e.g., by ML methods which enable the APS to learn from plan adaptations made by human planners (Willms & Brandenburg, 2019).

In times of **global crises and disasters**, supply chain planning may also help obtain agility, contingency, resilience, and robustness of global value chains and supply networks. In the event of a global pandemic, supply chain planning needs to broaden the perspective from the resilience to the viability level which ensures the mere survival of the supply chain (Ivanov & Dolgui, 2020).

Time-series analyses and AI/ML methods may help predict the growth of a pandemic and the resulting supply chain disruptions (Nikolopoulos et al., 2021). Moreover, supply chain planning must consider the availability of labor during times of a pandemic (Nagurney, 2021). Supply chain planning should also reflect the relationships between firms and the state representatives, governmental organizations, and legal authorities that govern global supply networks (Siebert et al., 2020). Recent examples have shown that political instability or war may considerably disrupt global supply chains (Simchi-Levi & Haren, 2022). In such cases, global supply chain scenario planning may be conducted to understand the impact of commodity inflation in supplier and customer contracts, to update inventory policies and planning parameters for critical materials and to prepare for disruptions in operations in the conflict region (Kilpatrick, 2022). In addition to these short- and midterm disasters, supply chain planning should also reflect impacts and risks that arise from the long-term climate change (Ghadge et al., 2020).

## 5 Enhanced Models and Systems for Supply Chain Planning

In model-based supply chain planning, optimization techniques dominate while the potential of **simulation modeling** remains underexplored (Ivanov, 2017). To perform sensitivity analyses in supply chain planning, usually several optimization runs are executed for separate planning versions with minor variations of selected problem parameters. Since simulation models are more capable of capturing the behavior of complex systems (Peidro et al., 2009), simulation can be used for what-if analyses of various planning scenarios with major differences in the overall setting (Terzi & Cavalieri, 2004). This analysis would help evaluate and quantify the benefits and issues of decision options when the overall frame conditions of business-making (seem to) undergo substantial changes – such as in cases of worldwide disasters or major disruptions in global business and trade (Ivanov, 2017). These approaches would enrich the intersection of supply chain planning and supply chain risk management.

For optimized supply chain planning, **goal programming** could be applied to attain prespecified performance target values instead of optimizing plans according to selected objectives (Broz et al., 2017). This modeling approach of satisficing instead of optimizing would strengthen the connection between supply chain planning and supply chain performance management. Possible applications include, but are not limited to, strategic supply chain planning (Broz et al., 2017), tactical supply chain configuration for new products (Brandenburg, 2015), and operational production planning (Broz et al., 2019).

Despite the fact that ERP and APS are developed, offered, and used for several decades, practitioners still need to be encouraged to **adopt, implement, enhance, and complement** the **available system solutions** for supply chain planning. First and foremost, spreadsheet applications still dominate over ERP and APS as the main support for planners in their daily work (de Man & Strandhagen, 2018). Taking into account that employing ERP and APS for supply chain planning substantially contributes to operational and firm performance, this observation is surprising.

With regard to system enhancement, the perspective to reflecting the economic, environmental, and social dimensions have to be addressed comprehensively and holistically. Decision-support systems for supply chain planning need to be redesigned and developed further to enable value-based management (Hahn & Kuhn, 2012a). Moreover, extending decision-support systems by socio-environmental factors is required to fully reflect all three dimensions of sustainability in supply chain planning (Reefke & Sundaram, 2018).

## 6 Managerial Implications

Managerial implications and practical issues of supply chain planning arise for supply chain actors such as manufacturing companies, wholesalers, distributors, or retail firms who operate (parts of) supply networks as well as for software vendors who develop and distribute APS. Practical guidelines for further system development are related to joint development initiatives under participation of researchers and supply chain planning experts from academia.

**Supply chain actors** may want to advance from focused volume-based supply chain planning to combined volume- and value-based supply chain planning and even further to integrated business planning. Socioenvironmental factors need to be considered for sustainable supply chain planning. In addition, supply chain actors should establish and strengthen planning partnerships with their suppliers and customers to push forward the inter-organizational integration and collaboration in supply chain planning.

Laggards in APS implementation who still conduct spreadsheet-based supply chain planning are urgently advised to replace these outdated tools by more sophisticated system solutions in order to close the gaps to leaders who in turn should not hesitate to conceptualize, develop, and implement the next generation of APS.

**Software vendors** may want to continue their work to develop further their software packages. New digitalization techniques and methods of AI and ML could be integrated into upgraded and enhanced APS. Moreover, software vendors may want to continue and increase their effort to conceptualize and develop integrated decision support systems for supply chain planning, supply chain performance management, and supply chain risk management. The work on the human-machine interface of APS is also worth being intensified, e.g., to enable a feedback mechanism that allows the machine to learn from plan adaptations which the human planners execute frequently in their daily work.

Software vendors and supply chain actors could form **strategic development partnerships** for the next generation of APS in order to leverage the development effort. Such strategic initiatives may result in faster advancement and more sophisticated system solutions. Involving **scientific experts from academia** into the joint system development would ensure that state-of-the art concepts from academia are considered in the design, development, and implementation of the next generation of APS.

As digitalization of systems and tools may cover multiple organizations and stakeholders – such as with blockchain technology, which includes smart contracts – planning models and technologies need to consider this evolving environment. Integrating legacy systems and planning information in these multiorganizational supply chain planning systems may require training, investment, and significant collaboration across supply chain partners and external stakeholders.

## 7 Summary and Conclusion

This chapter has shown that supply chain planning concepts and systems represent powerful business solutions that contribute to a firm's success and, thus, are considered state of the art in many industries. This chapter has also illustrated that the development of the next generation of supply chain planning approaches and tools has just begun and is far from ending soon. Companies that operate in supply chains as well as system vendors that provide IT solutions for supply chain planning must not stop their efforts to develop further and implement the concepts, approaches, and systems. Researchers may find opportunities for further conceptualization and development of supply chain planning processes and instruments. Hence, a new phase of scientific research and management practices invites to participate.

This chapter may be helpful to gain a basic understanding of fundamentals, developments, and trends in supply chain planning, but the topic is too broad and comprehensive to be fully covered in a single book chapter. Hence, the interested reader is referred to a large body of literature that will not stop growing continuously in future.

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# Part II

# Operational Issues

# Production Management and Supply Chain Integration

Pourya Pourhejazy

## Contents



**Abstract**

Digitalization not only improves individual performance but also helps orchestrate supply chain partners to serve a bigger goal. To fully benefit from supply chain digitalization, a high level of integration across supply chain activities is required. This chapter introduces major interactions between production management decisions and the supply chain strategy, structure, and performance to explore supply chain integration (SCI). For this purpose, the design and development issues of production management are first investigated. On this basis, decisions with a strategic nature, including product design (what), material and technology selection (which), process design (how), and facility layout (where) optimization are analyzed. Next, the planning and control issues, including production scheduling (when), quality management, resource management and supervision (who), and planning for disruptions are explored, which have a rather

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tactical nature with short- to mid-range goals in response to the aggregate plan (why) of the supply chain. Every section is concluded by suggesting rooms for pursuing SCI.

**Keywords**

Supply chain strategy · Product and process design · Production planning and control · Interactions · Performance improvement · Operations management · Process integration

## 1 Introduction

The fourth industrial revolution, widely known as Industry 4.0, has transformed research and practice in many fields; supply chain management is no exception to this trend. Industry 4.0 is formed around digitalizing processes, making them interconnected, and interoperable, while ensuring that they occur in a smart environment enabled by real-time data-driven decision-making (Gunnarsson et al., 2006). Industry 4.0 and its enabling technologies have the potential to improve individual performance in every corner of the supply chain by improving productivity and flexibility, resource and energy efficiency, as well as waste reduction. However, the effective integration of processes and activities is essential to fully exploit the advantages of supply chain digitalization at a systemwide level (Ghobakhloo et al., 2021).

Achieving greater degrees of integration requires considering the impact of individual decisions on the performance of other players. Individual decisions can be well-informed and aligned with the bigger goal of visibility across supply chain collaborators. In addition to reduced costs and response time, enhanced integration has implications for improving supply chain quality, flexibility, and resilience (Danese et al., 2020; Tiwari, 2020).

Supply Chain Integration (SCI) refers to the extent to which a company and its supply chain collaborators work together to more effectively manage intra- and interorganizational processes and improve the flow of products, material, information, and funds (Zhang et al., 2015). In this definition, the activities, and processes from the acquisition of raw material and sourcing to those involved in producing and distributing the final goods interact. Some of the interactions are more notable than others, making it necessary to simultaneously plan/optimize their associated operations.

As a major process in the manufacturing supply chain, production interacts with many logistical functions – inventory, facility, transportation, and sourcing. Questions regarding what to deliver, who, when, where, and how to complete the operations should be answered considering both supply chain and production management aspects of operations.

Whether an organization strategically targets cost-effectiveness, responsiveness, or it wants to differentiate its products and services from those of rivals, production management decisions can help adjust the operational capabilities to establish strategic fit. Production management decisions should also be aligned with the supply chain strategy. For example, a cost-effective supply chain is mostly concerned with enabling low-cost operations. In this situation, the way the production operations are handled influences the performance of downstream players and the supply chain cost as a whole. Production operations can also be significantly impacted by the performance of the upstream collaborators, which may have a different competitive strategy. This interaction manifests itself in both macro- and micro-managerial decisions. Therefore, it is important to understand the underpinnings of production management decisions and the way they influence supply chain operations.

This chapter elaborates on the interactions between the major production management topics and supply chain structure, strategy, and performance. For this purpose, the managerial decisions pertinent to the development and design issues, as well as planning and control issues are considered to investigate the possible interdependencies. Section 2 discusses the design decisions and the way they interact with supply chain strategy, structure, and decisions – that is, when and why to enter a market and what to produce (product development), how to produce the products (process design), which technologies and materials to use (technology selection), and where to do the operations (facility layout and location planning). Section 3 elaborates on the question of when to conduct the operations (production scheduling), quality control issues, who should conduct the operations (resource management and supervision), as well as planning for possible disruptions. The chapter is concluded in Sect. 4 with major remarks and managerial insights.

## 2 Development and Design Issues Relationships to Supply Chain Management

### 2.1 Product Development

Supply chain performance depends on many factors – one of the factor relates to product characteristics (what). A continuous evaluation of the efficiency and effectiveness of the products portfolio and adjusting them is necessary to maintain the supply chain's competitiveness. Well-informed product design or redesign decisions are a managerial tool to help improve supply chain performance by reducing inventory times (e.g., the use of standard modules), transportation volume (e.g., the postponement of assembly operations), and, overall, the operational cost (Handfield et al., 2020).

Product development and supply chain management capabilities counterbalance each other (Morita et al., 2018). In addition to product design elements for mass customization, such as modularity and multi-skill employees, high supplier involvement and the supply chain design are required to ensure the best outcomes (Ye et al., 2018). For example, companies can reduce the time-to-market if they include supply chain partners in the product development process. On the other hand, the bargaining power of suppliers and customers (Porter, 2008), as well as the strategic partnerships, should be considered in the product development process.

It is also suggested that new product development (Reitsma et al., 2021), and other product management decisions, such as product revitalization and discontinuation, should be made considering supply chain-related factors (Pourhejazy, Thamchutha et al., 2021). These interdependencies emphasize the impact of product management decisions on supply chain strategy and performance.

Supply chain operations are influenced by product design decisions both at the network and node (entity) levels (Reitsma et al., 2021). From a network-level perspective, the product design decisions interact with the supply strategy: whether to outsource certain parts or services to a third party or keep them in-house. They also define the extent supply chain partners, particularly suppliers, should be involved in the design process. If the parts or products are planned to be outsourced, certification or training of third-party actors will be necessary. Otherwise, if the operations are decided to be completed internally, which manufacturing facilities should produce the product and what operational capabilities are needed for these facilities should be determined. Additionally, companies should select the most appropriate transportation mode considering the product features, compartments, and needs.

Overall, these aspects both directly and indirectly influence supply chain fixed and variable costs. Supply chain reconfiguration for managing risks in time of new product development is another strategic topic at the intersection of product development and SCI (Sabzevari et al., 2019).

From the node-level perspective, packaging operations are impacted the most by the product design. For example, a fragile product requires more rigorous packaging; in this situation, alternative material and design approaches that increase the robustness of the product reduce packaging costs.

Taking IKEA's approach to product design as an example, postponing the final assembly until the point of consumption is a paradigm shift in the supply chain of furniture and home appliances. In addition to reducing the transportation cost and inventory times enabled by increased modularity, the downstream supply chain nodes do not require assembly-related capabilities, such as space, machine, or workforce further reducing fixed costs.

In addition to the node- and network-level activities, product design decisions have an impact on supply chain planning, in particular demand forecasting, capacity planning, and inventory management (Reitsma et al., 2021). For example, the use of common parts in the design of products reduces the variety of required inventory, which alleviates the warehousing complexities and reduces sensitivity to the forecasting outcomes (Jha et al., 2017).

In addition to improving organizational financial performance, integrating product development and supply chain management helps improve less-tangible aspects of supply chain performance, such as open innovation, supply chain trust (Rahmanzadeh et al., 2020), visibility, responsiveness, and risk (Khan et al., 2016). This integration also has implications for a circular economy (Burke et al., 2021), and the adaptation of Industry 4.0 (Benzidia et al., 2021), among other examples. Alleviating profit-loss due to remanufacturing and improving environmental performance were recognized as major advantages of integrating product design into green supply chain management (Liu et al., 2019).

There are barriers to integrating product development and supply chains. These barriers include loss of intellectual property, which may be worrisome for companies who seek vertical integration, especially high-tech and sensitive products, like chip manufacturing. The situation may be a challenge for international companies with offshore production activities in distant locations to take full advantage of product design and SCI. New technologies such as virtual reality and 3D printing can help to bridge the gap.

Product design has an impact on technology and material selection and the design of production processes (Marsillac & Roh, 2014), like handling and storage of the incoming and outgoing materials and the flow of materials on the shop floor, which are the determinants of internal logistics performance. I will delve deeper into these subjects in the next subsections.

## 2.2 Technology and Material Selection

Given the characteristics of a company's products, production managers are responsible for selecting the right technology and material before designing the production processes. As a strategic production management decision with long-term implications, technology selection should be done considering the capabilities and requirements of the supply chain partners (Farooq & O'Brien, 2012). These requirements are pertinent to the cost of the material/parts, their quality, delivery speed, the flexibility of the technology to adjust to the changing market needs, and the commitment of the corporations for innovativeness. Additionally, the selected technology should be compatible with those of the partners, their technical constraints, and the available supply chain infrastructure.

A production (or logistics) technology alternative that best serve the supply chain strategy and goals should receive a higher priority than the technology that maximizes individual performance. A cost-effective supply chain benefits from well-established and mature technologies that reduce fixed and variable costs. An original part manufacturer that selects expensive technologies, which produces high-end parts but cannot offer a competitive price, may not fit in a cost-effective strategy. Alternatively, responsiveness and differentiation-oriented supply chain strategies require new technologies with higher degrees of innovativeness to stay ahead of the competition.

Depending on the corporate strategy and the type of product or market, organizations may prioritize their technology investment plans for a particular supply chain function; this may limit the budget for the rest of the company-owned facilities. From the perspective of the competitive forces (Porter, 2008), the supply chain players should be concerned about what technologies are used by the existing and potential rivals, otherwise, it may be hard to stay competitive.

Depending on the market, customers may be willing to pay for the products and services that are produced using the latest technologies. The type of technology used in production and logistics processes also plays a major role in the sustainability of supply chains; a supply chain with old technologies may have a higher overall carbon footprint than supply chains with state-of-the-art machinery. Selecting greener technologies is especially important for corporations seeking to promote a green image. Overall, technology is an enabling factor for the supply chain's competitiveness regardless of the competitive strategy.

Adaptation to new technology may require a change in the supply chain structure, especially when it emphasizes a disruptive innovation. In this situation, delivery time, cycle times, labor cost, manufacturing cost, inventory levels, and required production capacity are impacted (Coronado Mondragon et al., 2017).

As an example, with additive manufacturing (3D printing), production sites can be more distributed and located closer to the point of consumption or in remote areas. These technologies can change supply chain partnerships. For example, 3D printing service providers can have shorter supply tiers and be involved in the production of semi-finished materials, components, and structures. Blockchain technology for regulating the information and funds flow is another prime example of disruptive technology with implications for SCI. In particular, the adaption of smart contracts can streamline procurement formalities, time, and address the legal issues and partnerships. These examples further highlight the role of technology selection in SCI.

Technology selection literature has been well supplied by decision-making frameworks including supply chain-related considerations (Xia et al., 2017). Relatively limited attention has been directed toward incorporating technology selection variables in supply chain optimization. Supply chain network design considering location and technology selection (Marvin et al., 2013) may be the most relevant integration scheme considering that both decisions have a long-term and strategic nature.

Supply chain tactical decisions, like planning and coordinating demand and supply, as well as managing inventories in a supply chain are also interrelated with manufacturing technology selection decisions but require additional investigation. For example, the optimal level of product availability may vary across production technologies where the speed at which a unit of product is produced and the required skilled staff for running the processes are different.

Material selection has received relatively more attention in the supply chain context, especially because it is closely relevant to supplier selection. The characteristics of the selected material determine the operational requirements. For example, distribution and warehousing facilities should be equipped with refrigeration gear for handling perishables; selecting materials with milder requirements reduces the supply chain fixed costs and its operational complexities.

Packaging and storage costs may be minimized by selecting the material with the right physical state. In the upstream supply chain, selecting materials that are subject to less supply process complexity, like tariffs, local and international regulations, and those with alternative supply sources are likely to be preferred. The power of suppliers is another relevant aspect that emphasizes the role of material selection decision variables in supply chain optimization; selecting material from monopolized markets increases supply risk and reduces the control of the focal company over price and quality aspects.

Similar to technology selection, material selection should be well aligned with the supply chain strategy. Cost, quality, and delivery speed of the final product are directly impacted by the material type, while it also can hinder or facilitate operational flexibility and innovativeness. From a supply chain sustainability perspective, selecting materials with a lower carbon footprint and avoiding materials with negative environmental and health impacts have become a necessity.

Material selection also has implications for supply chain structure and reverse logistics activities. As an example, selecting recyclable materials facilitates closing the supply chain loop, making it easier to take them back into the production cycle (Ndiaye, 2012). In contrast, the use of non-sustainable materials may exacerbate the complexities involved in the corporate social/environmental responsibility in the supply chain. The characteristics of the selected technology, material, and the requirements determined by the product development and design process are used as inputs to *process design*, which is discussed in the next subsection.

## 2.3 Process Design

Activities that add value – and their associated preparations – represent the production process. The overall goal of the production process is to transform inputs, such as raw material and energy, into outputs, products, and services. Conversion, fabrication, setup and preparation, machining, assembly, and quality control are some typical operations for production processes.

Production process design considers the following inputs to decide the sort of required operations and sub-processes: flexibility of the available equipment, labor, the selected technology, inputs from product development and management, the required variety of the products or services, and the expected sales volumes from the forecasting department.

Selecting processes to be executed in a facility is a strategic production management decision with implications for supply chains. This decision is influenced by physical limitations in the upstream supply chain. For example, access to raw materials and suppliers, skills and knowledge, technology, and low wages can make a location more desirable for certain production processes (Pourhejazy & Ashby, 2021). Technical requirements may necessitate certain processes to be performed together, within a certain time period, or in a certain climate condition due to product characteristics. Intellectual property-related factors are other examples that influence the selection of processes and their location.

Process structure, or production setting, is another strategic-level decision production process design. This decision is based on operational characteristics such as product variety and volume. Selecting the process structure determines the pattern of material movements in the manufacturing plants. Job shop, flow shop, and open shops are seminal examples of different process structures. The flow shop category requires all the items to go through an identical sequence and number of machines and processes; it is suitable for high-volume production of similar or standard items. When the product variety is high and the required production volume is low, a job shop may be the best alternative. Under the job shop setting, the items should be processed on every machine but in a different order. Finally, in an open shop, the items can be processed in an arbitrary order – there are no fixed precedence constraints and may have a different number of machines or processes. Other production settings, like hybrid and flexible flow shops, combine the above major categories to better match the case-specific industrial needs; they will be discussed in more detail in Sect. 3.1.

The logistical requirements for the above production settings may vary. For transportation on the shop floor, the production process in open shops is subject to irregular movements, which is in contrast with flow shops where less intensive and more regulated material movements are prevalent. That is, internal logistics in flow shops can be handled using more automated means of transportation while this level of automation may be infeasible or economically less viable in the job shop and open shop settings. It is not clear that there is a significant difference in the inventory level on the shop floor for different production settings.

In terms of external logistics, given that flow shops deal with a high volume of standardized products, the economy of scale plays a significant role in their supply chains when compared to the job shop and open shop productions. In this situation, the continuous flow of inbound and outbound logistics highlights the need for advanced decision synchronization, information sharing, and collaborative performance systems (Simatupang & Sridharan, 2008) and more effective supply chain collaboration and coordination.

Each of the production process structures has different facility investment requirements. In a job shop, general-purpose machinery is required to ensure the flexibility of the operations and the labor should be multi-task and highly skilled. Flow shops do not require these but may need a higher process continuity and automation level. Overall, flow shops require relatively higher investment (Mohammadi & Forghani, 2017); therefore, they are economically viable when a highly stable market in terms of demand and variety is targeted.

If the production process is designed in isolation, small fluctuations in the supply and demand sides of the supply chain can be amplified as they progress along the chain (Blackhurst et al., 2005). Given the significance of this amplification effect, integrating the production and supply chain process design elements should be mainly investigated from the material flow perspective. In the upstream supply chain, extreme demand fluctuations may put pressure on the manufacturing and procurement cycles. In the downstream supply chain, delays in the production process can interrupt the replenishment and customer order cycles.

Disruption propagation across the supply chain (i.e., the *bullwhip effect*) emphasizes the interdependencies among supply chain operations and entities, suggesting that the supply chain-related decisions, like the number of deliveries– both inbound and outbound – and the time interval between them (Chung & Wee, 2012) should be considered when designing the production process structure. Such integration helps reduce inefficiencies (Geismar et al., 2008), improves organizational performance, and environmental factors (Khanuja & Jain, 2019), and facilitates supply chain digitalization (Tiwari, 2020).

In addition to the above considerations, the process design should account for less-tangible tactical and operational factors like maintenance and the inspection mechanisms. These factors should consider logistical elements within the supply chain – including inventory management and distribution operations. For example, production downtimes can be planned considering the state of the logistics elements and in coordination with the supply chain partners.

The integration of production process design and supply chain can also be investigated from a quality perspective. Traditionally, logistics operations are designed assuming that the products are perfect while, imperfect quality items are hard to avoid. Reworking the imperfect quality products helps reduce the total costs (Ouyang & Chang, 2013). However, returned items may be burdensome to the supply chain if the reworking processes and logistics are not well coordinated. Alternatively, the quality of raw materials may be deteriorating, which makes it necessary to manage them in an integrated manner.

Another relevant aspect is the integration of reverse logistics and the design of the production process. In particular, an integrated design of the collection and disassembly processes helps alleviate the impact of the uneven and uncertain flow of returned materials in the production continuity and cost.

## 2.4 Facility Layout Design and Optimization

Material movement affects the productivity of manufacturing and logistics operations, design [and optimization] of facility layout impacts supply chain performance. This impact is mostly related to the connectedness of individuals in the supply network, where improving the efficiency of the individuals results in reduced supply chain time, cost, and enhanced agility in the long run. Industry 4.0 and the need for higher degrees of automation further highlight the importance of connecting the internal and external material flows in smart facilities. Despite the benefits of including facility layout variables in the supply chain context, it is largely overlooked by academics and practitioners.

Facilities should be designed considering the production process, selected technology/machinery, expected production capacity, and the supply chain strategy. The first three determine the material flow while the last specifies the broader objective and needs a facility should serve. Recalling the process design subsection, a *flow shop* setting is best suited if high-volume standardized products are produced, otherwise, other production settings may be preferred. Within this general framework, the details of positioning may differ depending on the company's desire to run a cost-effective system or seek high levels of responsiveness and flexibility. Having designed the facility layout, the managers can determine the optimum level of product availability and the aggregate plan based on the actual production capacity, the available inventory-carrying space, as well as the market situation.

In manufacturing facilities, buffer zones for storing raw material, parts, and work-in-progress are limited. Sound layout design decisions help maximize the space utilization and make room for keeping inventories. Additionally, an optimum layout helps smooth material flow on the shop floor, which, in turn, reduces the operational cost and improves agility. This situation helps avoid bottlenecks in the supply chain network where an interruption in material inflows to one value-adding entity due to lack of space or inefficient movements inside the facility may spread downstream in the supply chain. Integrating the facility layout variables into supply chain risk and optimization models helps address disruption among other operational uncertainties caused by poor synchronization.

As another supply chain network element, warehouses are often necessary to provide the right quantity of materials, parts, and products available at the right time and location. Otherwise, managing supply and demand mismatches in a volatile market becomes a prohibitive task. Simultaneous determination of warehouse layout and inventory control policies, such as storage policies and inventory routing, have implications for supply chain performance improvement (Roodbergen et al., 2015).

Internal material handling – movements and storage – have increasingly used automatic guided vehicles, optical guidance systems, and robots to load-unload incoming and outgoing trucks. In this situation, the major facility elements, like the unloading gates, recharging stations, sorting, and buffer areas, as well as waypoints and optical paths for the navigation of automatic guided vehicles, should be optimized. This optimization should consider inbound and outbound flow variables to reduce avoidable delays (Ribino et al., 2018).

More advanced supply chain practices, such as *cross-docking* have been used in certain industries to streamline the response time to customer orders. Given the dynamics in cross-docking facilities, real-time data collection, synchronization, and analysis should be used for dynamic reconfiguration of the storage area to better integrate the inbound and outbound flows (Vis & Roodbergen, 2011).

From a supply chain information flow perspective, considering historic data on supplier performance and customer demand patterns facilitate well-informed layout optimization in the upstream and downstream supply chain facilities, respectively. For example, the layout design of retail stores, as the interface component between customers and goods in a supply chain, can be dynamically adjusted by investigating less-tangible operational needs extracted from historic demand data (Ozgormus & Smith, 2020). This situation may call for strategic positioning of products in the store.

Another example relates to the seasonal supply chains or those expected to experience occasional but dramatic changes. Massive demand variations for a company with many products necessitate operational strategic adjustment of the production processes for which updating the facility layout may be necessary. Layout redesign considering supply chain parameters and product demand variations for disaster relief operations is a good example of this type (Tayal & Singh, 2019).

Finally, decisions for resizing, repurposing, or moving strategic functioning blocks across the existing supply chain facilities are another relevant production manager responsibility. The location-allocation and network optimization problems are well addressed in the supply chain context (see (Eskandarpour et al., 2015)) but assigning departments to different supply chain facilities and moving them has received limited attention.

The Research & Development and Engineering Design departments are prime examples of more intangible units of a corporation; they are often located in closer proximity to the production sites and the focal company. Intellectual property, access to state-of-the-art technologies, knowledge, and resources, as well as geopolitical considerations may be in favor of relocating or decentralizing sensitive departments. Such decisions result in long-term and sustainable outcomes if made considering wider optimization goals. Overall, layout design and determining the location of the departments within and across facilities require both financial and nonfinancial supply chain considerations in addition to optimizing cost and productivity.

This section discussed the major design and development topics and their interactions with supply chain management. Planning and control issues and their supply chain implications are presented in Sect. 3.

## 3 Planning and Control Issues Relationship to Supply Chain Management

Long-term supply chain strategy integrates aggregate planning, which is required to direct the business activities over an intermediate time horizon. Aggregate planning sets a tactical framework for demand fulfillment decisions; it uses forecasting to determine the production, inventory, outsourcing, and backlog quantities to manage costs and profitability (Chopra & Meindl, 2015). Production managers use aggregate plans to determine production schedules, organize available resources, and address quality control issues at the factory level. This section elaborates on these production management topics and the way they interact with supply chain structure, strategy, and decisions.

### 3.1 Production Scheduling

Once an aggregate plan is developed by supply chain managers, production managers are responsible for scheduling the operation at the level of individual production units. Production scheduling consists of determining the order of jobs to be dispatched to production such that the available time and resources are used efficiently. Production scheduling can be categorized into single-machine, parallel-machine, flow shop, job shop, and open shop settings; several other variants combine two or more of these production settings, which would be considered hybrid settings. There are many extensions to each of the main production configurations, which are proposed to address case-specific industry situations, and practical needs, and facilitate the real-world applications of scheduling theory.

Given a set of jobs to be completed on a set of different machines (production stages), all jobs in a flow shop require an identical sequence of operations. In a job-shop environment, jobs go through a prespecified but different sequence of operations with precedence constraints. In an open shop, the sequence of operations for every job is different but arbitrary with no precedence constraints. In the job- and flow-shop constructs, each operation should be completed on a specific machine while in the flexible variant of these production settings, the operations can be assigned to any machine from a given set. Finally, in the parallel machine setting, machines are either identical or uniform and jobs should go through one of the available parallel machines for a certain number of stages, which can be different from one job to another.

In addition to the operational characteristics that determine the type of production setting, supply chain considerations may have an impact. For example, the supply chain may require assembly operations to occur within the same facility where the parts are manufactured, which can be modeled as distributed two-stage assembly scheduling (Pourhejazy, Cheng, et al., 2021). Otherwise, assembling at a separate facility should be modeled using the distributed assembly permutation flow shop scheduling (Ying et al., 2020). As another example, a responsive supply chain may require a set of machines in each production stage – redundant capacity instead of a single machine – to better respond to demand surges. This situation may make flexible flow shop and job-shop more viable settings. The desired flexibility in the production process – single versus multi-purpose machines – is another relevant supply chain factor with implications for scheduling.

Recent studies recognized the need for a supply chain-oriented view toward production scheduling. These models can be categorized into distributed scheduling problems and production routing problems. In the distributed scheduling situation, production operations across distributed manufacturing facilities are scheduled simultaneously. Extending production scheduling from an isolated optimization approach to an integrated one, this category emphasizes coordination between different production units for fulfilling global demands while optimizing system performance. Distributed blocking flow-shop, distributed no-wait flow shop, distributed no-idle flow shop, distributed parallel-machine, distributed job shop, and distributed flexible job shop scheduling problem are some of the recent variants of supply chain-oriented scheduling problems. Such models can incorporate order assignment variables for better integration of customer order and manufacturing cycles. In so doing, the possibility of rejecting an order and backlogging them may be of interest to certain use cases. Alternatively, procurement-related decision variables can be incorporated into distributed production scheduling with release dates to take into consideration the possibility of delays in receiving raw materials and parts.

Production routing problems focus on the concurrent planning of sequential – and heterogeneous – operations along the value chain, that is, across production and distribution activities. In the traditional approach, production scheduling solutions are used as inputs for optimizing distribution operations, which may result in a number of planning issues. First, distribution operations may be planned based on infeasible input data, for instance, the delivery may be scheduled for an order that is experiencing a production delay. Second, a lack of coordination between the two processes may result in suboptimal solutions. For example, a customer order with less urgency may be prioritized in the production stage earlier than more urgent ones, which results in poor responsiveness, operational burden, and unnecessary cost. Third, integrated planning of the production and distribution processes is important for maintaining product quality in the supply chain of time-sensitive and perishable products (Ullrich, 2013), while a stand-alone approach may not effectively account for this requirement.

Scheduling variants are predominantly developed in response to case-specific and technical production requirements. For example, the no-wait setting indicates that a work-in-progress job should proceed to the next operation immediately after finishing the current one. In the no-idle setting, the focus is on the idle time of resources, where machines must start processing new jobs immediately after completing a current task without delays. In addition to these technical features, operational requirements, such as setup time and due dates, are considered in form of mathematical constraints to better reflect the real situation.

The optimization criterion for distributed scheduling models is directly influenced by supply chain objectives. The maximum completion time of all jobs – also known as the *makespan* – determines the response time for new demand. The number of tardy jobs and maximum lateness are service-oriented measures, and total weighted tardiness prioritizes more urgent demands. These measures support the strategic management of responsive supply chains. Alternatively, total completion time performance metrics emphasize better resource utilization and total flow time concerns minimizing the work-in-process inventory. These various objectives and related functions are suitable for supply chains with a cost-efficiency goal.

There are other opportunities for extending production scheduling to improve SCI. From a market perspective, the product mix and the demand size in various regions are dynamic. An optimal location-allocation solution for a certain period may not remain optimum in a dynamic multi-period environment. In this situation, facility transfer is a possible option for adjusting the supply chain.

Facility transfer adjusts the factory cell formation and production capacity, which have an impact on production schedules in different planning periods. Given the mutual relationship between facility location – using a supply chain network optimization decision – and the production planning considerations, that should be optimized simultaneously (Liu et al., 2018).

From an operational viewpoint, make-to-stock supply chains require real-time coordination between production and inventory management (Dong & Maravelias, 2021). That is, producing additional units of products should be subject to inventory variables and limitations. On the other hand, rescheduling might be necessary to boost production and reload the product inventory. Finally, production scheduling can be extended to consider product defects and account for possible reworks, in particular, considering its interactions with the transportation variables (Gheisariha et al., 2021).

Tactical plans, such as production scheduling, provide production managers a boundary of control for managing their operations and determining whether operations are being performed as tactically planned. Another control topic that interacts with supply chain decisions, quality management issues, is discussed next.

### 3.2 Quality Management

Quality is the main determinant of supply chain strategy. A cost-effective supply chain may not emphasize high-quality materials, parts, and services. A cost-effective strategy favors minimizing investment in resources and selecting less costly logistics operations – such as slower modes of transportation and less frequent replenishments – which may have negative consequences for quality. Product quality and safety may be compromised if the supply chain overemphasizes responsiveness, for example by relaxing the quality control measures. Downstream and upstream supply chain partners should adopt a coordinated quality control system that serves as a supply chain competitive strategy (Jraisat & Sawalha, 2013).

From a supply chain structure perspective, more distributed facilities may be better for the quality of perishable goods, where a shorter distance to the supply and demand nodes reduces the odds of spoilage and degradation. In other cases, centralized facilities may benefit from economy of scale and more delicate quality control tools and approaches. The absence of integrated quality control/visibility over the supply chain partners may put supply continuity at risk. Quality assurance may favor supply chain vertical integration and in-house production of parts and components – such as using additive manufacturing – where the manufacturer has better control over the quality of raw material and parts.

The quality of products a supply chain offers depends on various aspects including input materials, workforce skills, the state of machinery, tools, and production processes. Continuous evaluation and improvement of these elements facilitate better design, optimization, and management of supply chains (Grenzfurtner & Gronalt, 2021). The interactions between quality management and supply chain should consider the roles of material, man, machine, and methods in production management.

*Material.* When it comes to the procurement of raw materials and parts, the main interaction happens between the quality control aspect of production management and the pricing element – both of which are regulated by the supply chain strategy. As an intersection between production and supply chain management, material quality has been well investigated in the academic literature (Chen et al., 2014). Integrating quality control variables into inventory optimization models allows for addressing uncertainties from an operational perspective. New inventory management strategies (e.g., consignment stock and vendor-managed) have been introduced as a result of this integration; such strategies extend the supplier's responsibility for the quality of the product until the consumption point (Alfares & Attia, 2017). The cost (time) of quality control operations is another production management aspect that is investigated from a supply chain optimization perspective (Cogollo-Flórez & Correa-Espinal, 2019).

Expectedly, less attention has been directed toward the intersection of quality control with the transportation and facility elements of the supply chain. This situation is particularly relevant for the logistics of consumer goods and perishables, where time and ambient conditions impact the product quality. Supply chain information technology and quality relationships require access to real-time data on the status of materials, parts, and products to help improve quality control. The role of blockchain in confirming the source of the material (i.e., suppliers of suppliers) is a prime example of disruptive technologies with implications for quality control and counterfeit issues.

*Machine.* In addition to the quality of incoming materials and parts, using calibrated and well-maintained equipment for processing these inputs has a positive impact on the quality of the final product. There is a bidirectional interaction between the reliability of different supply chain stages and product quality, which should be considered in the maintenance of machinery in multi-stage systems (Zhou & Lu, 2018). Channel coordination in machine maintenance practices by individuals in a supply chain enhances the machine capacity, and product quality, and reduces production costs (Chong et al., 2012). These, together, increase supply chain profitability under certain coordination strategies (Jiang et al., 2020). More rigorous preventive maintenance operations may be required in supply chains with a responsiveness strategy. Alternatively, emphasizing reactive maintenance may decrease the individual short-term costs – when compared to preventive maintenance – but can hurt supply chain performance even if the supply chain pursues a cost-effective strategy. From a supply chain structure perspective, centralized production reduces the cost of maintenance services; this may improve the effectiveness of quality control activities and enhance product quality.

Integrating maintenance decisions in supply chain tactical planning improves optimization outcomes (Fatehi-Kivi et al., 2019). Additionally, supply chain optimization can benefit from integrated quality control and maintenance (Jiang et al., 2020). From an information viewpoint, the recent advances in big data analysis and machine learning help predict possible failures by early detection of anomalies in the real-time data collected using sensors (Cheng et al., 2021); this situation facilitates quality control along the value chain. Maintenance information and quality history of material or parts from across the supply chain can also be used for optimizing product quality and lifecycles (Madenas et al., 2015).

*Methods.* Production processes along the value chain are another determinant of the quality of materials, parts, and products. Process control and improvement are necessary for maintaining quality to the desired expectation. The production manager in each manufacturing unit is responsible for reacting to anomalies detected through process information analysis (Schiefer, 2002).

The complexities of the process control system depend on the supply chain structure. In a highly distributed manufacturing setting, coordinated process control is necessary to enable the supply chain managers to trace anomalies to prevent the propagation of quality loss and delays in a timely fashion. As a means of improving process and product quality, *lean* and *six-sigma* concepts have been widely adopted for process improvement in supply chains (Chugani et al., 2017).

Classical supply chain optimization models and methods have been extended to account for process control-related variables. For example, inventory models are improved by including the variables pertinent to production process adjustments (e.g., stopping production and performing setups) in case of quality issues (El Saadany & Jaber, 2008). From an information flow perspective, radio frequency identification (RFID) technologies can assist lean production to further improve the transportation, storage, and retrieval processes in a supply chain (Chen et al., 2013). In addition to improving product and service quality, process improvements reduce scrap, and reworks, among other types of waste, which help the company to stay competitive by lowering the final prices they offer in the market.

*Manpower*. There is consensus on the positive impact of supplier development programs on the quality of materials and parts (Karaer et al., 2020). As production management practices, employee training, development, and performance management within company-owned facilities have seen little progress in the supply chain context despite its significant impact on supply chain quality and innovativeness (Haq et al., 2021). With a strategic view towards quality, the integrative, exportive, or adaptive human resource practices help create synergy and improve individual performance should it follow a supply chain-oriented approach (Lengnick-Hall et al., 2013).

Regardless of supply chain strategy, successful SCI requires training, development, and performance management of the employees (Menon, 2012). The objective of these human resource practices may vary depending on the supply chain strategy. Overall, integrating human resource and supply chain management helps boost the competitive strategy and organizational performance (Jena & Ghadge, 2021). The next subsection elaborates on the organization and management of its resources.

## 3.3 Resource Management

Rapid changes in consumer preferences and shortened product lifecycles have added to demand volatilities and supply process complexities. Within this context, resources should be managed effectively to meet demand at the lowest operational cost. While material resource management is closely related to handling the physical flow in the supply chain, other resources, including the capital, manpower, machines, land, energy, and water, are managed at the factory level. How decisions on managing these resources interact with supply chain strategy, structure, and performance is now discussed.

Supply chain management is mostly concerned with managing supplier and customer relationships while manpower capital plays a pivotal role in integrating operational elements. At the factory level, production managers are responsible for the supervision and organization of workforces in close collaboration with the human resource department. Labor supply practices – such as recruitment, planning, and training – are essential for maintaining desired and necessary operations.

Shortage of skilled workers in individual production sites propagates along the supply chain and results in an array of operational issues, from quality degradation to delays. An integrated view toward manpower resources and supply chain management, therefore, improves corporate performance while being largely overlooked (Jena & Ghadge, 2021).

Supply chain strategy directs the recruitment, planning, and training programs. A cost-effective supply chain emphasizes highly repetitive routines while a responsive supply chain strategy requires multiskilling and workforce empowerment. Supply chains that compete on differentiating their products and services often tend to spend more on training programs. Supply chain structure is impacted by manpower resource considerations, like access to skilled workers, cheap labor, work culture, and social sustainability issues.

From an operational perspective, the organizational interdependencies between the workforce across supply chain entities and departments make it necessary to consider manpower resource shortage along with the physical resources to mitigate the disruption effects (Aviso et al., 2018). Given the less tangible nature of decisions on the organization and supervision of workforces, limited integrations of such variables can be found in the supply chain optimization context. Integrating decision variables related to worker types for executing certain production tasks – by considering their competencies – into supply chain network planning and optimization models (Paquet et al., 2008) and reverse logistics operations (e.g., electronics waste collection (Pourhejazy, Zhang, et al., 2021)) are examples.

In managing machinery and equipment, resource redundancy – excess capacity – is a safe way of coping with demand fluctuations. Supply chains with a responsiveness agenda typically use excess resource management strategies while cost-effective supply chains are mostly cognizant of maximizing the utilization of the available resources. *Line balancing* can be used to balance machine time and adjust the production rate for demand fulfillment – especially when the production system has tight utilization rates and constraints on machinery resources. For line balancing, the number of machines (and operators) assigned to each task is rebalanced to adjust the production rate. This kind of optimization approach provides decision support to production managers, but it can result in better outcomes when coordinated with supply chain variables.

Integrating assembly and disassembly line balancing variables into the supply chain network optimization and closed-loop models is a good example of a broader supply chain integration (Yolmeh & Saif, 2021). New technologies, like additive manufacturing, make it easier to manage resources and adjust to demand changes. Besides, the use of big data analysis and machine learning approaches helps improve resource management by reducing non-value-adding activities and addressing less-tangible aspects of operations.

Land, energy, and water are basic resources required for any supply chain activity. The required amount of these resources is a matter of technical requirements – for example, semiconductor production sites require huge water reservoirs. Access to such resources is considered one of the essential criteria for selecting the location of production facilities as strategic supply chain decisions.

Production managers are responsible for managing the available land, energy, and water resources at the operational level. Managing such resources at the factory level has indirect interaction with supply chain strategy but it directly impacts the supply chain structure. For example, limited land, energy, and water may encourage extending the supply tiers to find alternative sources for the products that cannot be produced in-house due to land, energy, and water limitations. Additionally, distributed and geographically dispersed facilities or relocation decisions may be triggered by resource limitations.

A holistic view of the long-term requirements, as well as the profile of available resources across the supply chain, are prerequisites for informed resource management decisions (Taherzadeh, 2021). At the factory level, the availability of land resources may influence inventory management decisions as well as the production level. Adaptive resource planning may be required to adjust to the changing operational conditions. In particular, dynamic adjustment of the available spaces is a relevant decision that can be considered to best manage such resources in volatile times.

The planning and control issues discussed up to this point of Sect. 3 are meant for routine operations – that is, when everything goes as planned. Disruptions, especially those impacting the factory level operations, change the situation, hence, require decisive actions and alternative solutions to mitigate the adverse supply chain effects as much as possible. Planning for disruption is discussed in the next subsection.

## 3.4 Planning for Disruption

Unexpected events that impact resources availability – availability of power, machines, material, and manpower – can interrupt the production processes at the factory level and can result in major supply chain disruptions. Planning for disruptions consists of preparing for unexpected situations, finding alternative solutions for maintaining the production facilities' operations, and having strategies for a quick recovery after a major disruptive event. Digitalization and SCI improve connectivity, transparency, and effective information flow between different departments within and outside of the factory, which enables a timely and well-informed course of managerial actions in times of disruption (Treber & Lanza, 2018). Training programs, which are discussed earlier in the chapter, and drills are some of the initiatives for labor-based disruption preparedness at the factory level.

Operationally, production processes can be impacted by disruptions in: (1) supply – material, parts, and components; (2) manpower, machines, energy, and water; and (3) demand. Supply and demand disruptions relate to supply chain management level activities. Supply chain decisions, such as location and volume of redundant inventory in the network can help alleviate the negative impact of material disruptions. For example, purchasing's time for finding alternative resources and addressing the shortage problem are additional activities.

At the factory level, a production manager could consider the severity of disruption and its root cause(s), which requires current knowledge on the state of the system at the time of disruption. The manager would need to decide to delay the operations, outsource them, or renegotiate the accepted orders for possible backlog or cancellation. Production rescheduling is a possible production management solution in response to production disruptions (Katragjini et al., 2013). Production management decisions, like rescheduling, have implications for supply chain performance (Rao & Ranga Janardhana, 2014). In addition, rescheduling the production operations is the most common way of minimizing the losses after disruptions (Paul et al., 2015). In either case, the company may have to employ additional machines and manpower or adjust the working hours of the existing ones – such as using additional shifts or overtime – to fulfill the backlogged demands. Such decisions should also be made in coordination with the supply chain partners to ensure a smooth flow of raw material and finished products.

Production managers may take advantage of alternative solutions – such as the application of new technologies – for producing the delayed parts or components in-house. For example, additive manufacturing can be used as an alternative production method in times of supply disruptions.

Possible changes in the production methods on the shop floor impact the supply chain structure. Taking the alternative manufacturing methods for producing parts or components as an example, the company may have to seek material suppliers or third-party 3D printing service providers, which can shorten or extend the partnerships, supply tiers, and alter the network configuration. This decision also has implications for supply chain performance in terms of cost, quality, speed, and flexibility. Dual-channel supply chain optimization models should be developed to account for the possible shift between the regular and alternate production approaches considering various disruption scenarios.

During market disruptions, the shop floor may not be required to operate at normal capacity due to the physical limitations in the factory and supply chain. Slowing down operations and reallocating resources in response to addressing demand disruptions are some of the possible production management solutions. These factory-level decisions should be made in coordination with downstream entities, in particular warehouses, distribution centers, and retail stores, to pursue optimum outcomes.

As another example, a disruption in outbound distribution operation due to accidents, vehicle breakdowns, and weather conditions may impact production operations. In this situation, integrated planning of production and distribution activities provides better outcomes than an isolated optimization approach (Li & Li, 2020). Production management decisions, such as production scheduling and line balancing on the shop floor, will interact with supply chain activities such as transportation modes, inventory, sourcing, and pricing policy decisions. Integrated optimization models may be helpful for well-informed decisions. Integrated optimization of the production and inventory variables considering the possible disruption risks in the production process (Malik & Sarkar, 2020) is a recent example.

Using redundant – excess – resources is a common strategy for dealing with disruptions caused by labor limitations and machine breakdown. From a planning perspective, employing additional manpower and machines reduces dependency on individual resources. The main tradeoff is between the costs of redundant resources and the ability of the system to remain operational in times of disruption.

Crucial resources and bottleneck operations should receive a higher priority for building redundancy. Identifying the cost break-even point of using redundant resources varies depending on the supply chain strategy. That is, a cost-effective supply chain may not use many redundant resources when compared to a responsive one. Cost-benefit analysis for deciding the use of redundant resources should consider a systemwide perspective. Decisions should not be only focused on the optimality of an individual production facility, or, more generally, a supply chain entity.

From a technical perspective, informed maintenance of machinery and equipment is necessary to prevent unplanned breakdowns. In the case of reactive maintenance, 3D printers can be used to facilitate repair and maintenance activities by producing machinery components and tooling equipment that may require weeks or months to be supplied in a regular situation. Energy source disruptions can have alternative solutions like the use of solar panels, which are becoming more viable and resilient options. The geographical characteristic of the production facility is an enabling factor for the selection of alternative energy sources.

Overall, different combinations of production management and logistics measures result in different outcomes when reacting to disruptions (Peukert et al., 2020). In this situation, a standalone planning approach may result in either infeasible or suboptimal solutions. Alternatively, possible disruptions in the system are usually reflected through parameter changes in the optimization models. In addition to stochastic optimization approaches and dynamic programming that can account for such features, applications of simulation-based optimization models help address the underlining uncertainties effectively, especially when planning for possible disruptions.

## 4 Concluding Remarks

SCI requires that possible interactions between individual units and their operations are taken into consideration for design and planning purposes; this integration will help achieve a global optimum when improving the operations. The integration between supply chain elements has seen developments in both academic literature and practice.

Production management topics including shop floor decisions and their interactions with the supply chain have received relatively less attention. To investigate the major links between the topics, design and development issues, including product design (what), material and technology selection (which), process design (how), and facility layout (where) are first studied. Planning and control issues, including production scheduling (when), quality management, resource management and supervision (who), and planning for possible disruptions are then considered.

The chapter discussed the interdependencies between the subject matter and the supply chain strategy, structure, and elaborated on the impact of the respective decisions on the supply chain performance. Each subsection concluded by providing insights into some of the latest technological and/or academic developments and suggestions for future works on the subject.

Overall, there are many opportunities for improving the supply chain performance beyond current norms by considering production management-related decisions. This includes joint optimization of production and supply chain variables as well as decision-making considering the factors integrating shop floor considerations. Given the tradeoff between the complexity of an optimization or management decision model and its practicability, the sort of integration should be determined considering the targeted competency and the core interactions. For example, integrating production scheduling and inventory management variables should be targeted when achieving a short product shelf-life is an optimization priority.

Broader supply chain perspectives such as end-of-life disassembly and reverse logistics variables should be optimized simultaneously when the supply chain emphasizes the use of recycled material and closed-loop operations. Operational mandates may impact the sort of integration, for instance, just-in-time production requires an advanced level of connectivity between the production and distribution operations. From a methodological perspective, simulation-based optimization frameworks should receive more attention in SCI. This is particularly relevant for integrating the micro and macro processes at the intersection of production management and SCI. Reducing modeling assumptions, generating more accurate model parameters, more realistic performance evaluation, and the effective inclusion of various uncertainty sources are some of the major advantages of simulation-based optimization methods.

Supply chain integration with production management will always be a prerequisite for broader strategic competitiveness.

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# Supply Chain "Flows" Management

Muhammad Hasan Ashraf and Mehmet G. Yalcin

## Contents



**Abstract**

This chapter provides an overview of the concept of Supply Chain Flows (SCF). While the normative literature in Supply Chain Management (SCM) emphasizes the importance of three primary flows – material, information, and finance – recent challenges, notably the COVID-19 pandemic, have highlighted the

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prominence of likely additional flows. This chapter delves into four such flows – human, knowledge, equipment, and technology – that significantly impact supply chain performance. This exploration prompts a reevaluation of traditional SCF scope. Theoretical approaches for effectively managing the interactions among SCF are also proposed. The chapter concludes by suggesting future directions in establishing a consensus-based SCF framework. Overall, this chapter provides a foundation for ongoing efforts to enhance SCF understanding and develop additional theoretical insights for SCM researchers and practitioners.

**Keywords**

Supply chain flows · Paradox theory · COVID-19

## 1 Introduction

The concept of flows was first introduced into the management domain by Forrester in 1958. He emphasized the importance of effectively managing five key flows – information, materials, money, manpower, and capital equipment – as they significantly impact an organization's performance. Supply chain management (SCM) is an interdisciplinary concept focusing on optimizing flows in most cases. Therefore, Forrester's initial conceptualization about flows for organizational success integrates with modern-day SCM (Mentzer et al., 2001).

Despite Forrester's conceptualization of five flows, SCM has traditionally focused on the flow of materials. As supply chains globalized, research on Supply Chain Flows (SCF) revealed many more flows as part of effective supply chain processes. Yet most SCM research focuses on three SCF – materials, finances, and information. Various other flows that play a significant role in effective supply chain performance have been overlooked. The limited acknowledgment of flows restricts SCM actors from thoroughly analyzing and integrating numerous crucial flows, thereby impeding the potential to expand the scope of SCF.

COVID-19 brought to the attention of practitioners and theorists the emergence of various lesser-acknowledged flows that became dominant or influential in SCM. For instance, the transportation sector encountered disruptions in human flows, struggling to retain essential workers such as drivers, sorters, pickers, material handlers, etc., mainly due to an upsurge in sickness cases. Similarly, the shipping industry witnessed a disruption in equipment flow, with firms facing challenges in securing empty containers due to extended transit times at ports. These examples underscore the importance of incorporating flows often overlooked in normative SCM literature into consideration, a point also emphasized in research and practitioner magazines and articles.

Most SCF research studies have centered on definitions and concepts from a functional viewpoint. They recommend implementing resources to improve specific flows in particular contexts but often overlook the simultaneous management aspect of all flows. Similarly, the current SCM frameworks present solutions on how to design and manage a particular SCF but do not address the theoretical foundations to manage the full spectrum of the flows (Ashraf, 2023). In most instances, SCM research perspectives are overly simplified and fail to align with real-world complexities (Carter et al., 2015). Consequently, SCM research has not adequately depicted how to efficiently manage the SCF. Given the extent of SCF disruptions during COVID-19, several researchers and practitioners have been calling for more advanced SCM knowledge – knowledge capable of addressing elaborate SCF interactions.

This chapter provides insights and initial steps to guide SCM scholars in building and extending their knowledge around various flows critical to ensuring effective and efficient supply chains. These flows, despite their significance, have been overlooked in normative literature. This chapter also provides potential SCM theories that can be utilized for effective SCF management. Theoretical underpinnings are necessary to manage the full spectrum of the SCF. For practitioners and learners, the content of this chapter can be used to recognize flows in their supply chains and provide guidance in selecting an appropriate theoretical lens to manage these flows efficiently.

## 2 Background

In 1985, the Council of Logistics Management (CLM) defined SCM (logistics) as "the process of planning, implementing and controlling the efficient flow and storage of raw materials, in-process inventory, finished goods, services, and related information from point of origin to point of consumption (including inbound, outbound, internal and external movements) for the purpose of conforming to customer requirements" (qtd. in Mentzer et al., 2001, p. 16). Flows are the core of SCM, and their significance is well acknowledged in the literature and the textbooks. For this reason, numerous researchers have defined SCM in terms of SCF. Table 1 provides an overview of a few such definitions.

In the early days of SCM, researchers primarily focused on the flow of materials as the most crucial aspect of the SCM. However, it wasn't until the late 1990s that they began to recognize the significant value of information in managing SCM processes. As a result, the boundaries of the SCF were expanded to encompass this new understanding. Despite this expansion, some researchers still emphasized the importance of material flow as the only integral flow needed to achieve desirable SCM performance. Nevertheless, with the advent of globalization, various forces emerged, such as economic factors (e.g., cost-cutting initiatives), political factors (e.g., war on terror), and technological advancements (e.g., automation) (Zhang et al., 2020). These factors compelled researchers to further extend the boundary of the SCF, leading them to include the flow of information and finances as a critical element on the list.

**Table 1** Definitions of SCM in terms of SCF in literature. (Source: Adapted from Mentzer et al., 2001 and updated for this chapter)

| Source | SCM Definition |
|---|---|
| Jones and Riley (1985) | "Supply chain management deals with the total **flow of materials** from suppliers through end users." |
| Stevens (1989) | "The objective of managing the supply chain is to synchronize the requirements of the customer with the **flow of materials** from suppliers in order to effect a balance between what are often seen as conflicting goals of high customer service, low inventory management, and low unit cost." |
| Mentzer et al. (2001) | "Supply chain is a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream **flows** of **products, services, finances, and/or information** from a source to a customer." (p. 4) |
| Anderson et al. (2007) | "The supply chain includes all the links involved in managing the **flow of products, services, and information** from their supplier's suppliers to their customer's customers." (p. 3) |
| Stock and Boyer (2009) | "The management of a network of relationships within a firm and between interdependent organizations and business units consisting of material suppliers, purchasing, production facilities, logistics, marketing, and related systems that facilitate the forward and reverse **flow** of **materials, services, finances and information** from the original producer to final customer with the benefits of adding value, maximizing profitability through efficiencies, and achieving customer satisfaction" (p. 706) |

The renewed understanding of SCF was confirmed by numerous industry initiatives as well. Walmart's downstream supply chain serves as a perfect example. The Arkansas-based retailer initially operated brick-and-mortar stores where customers would walk in to purchase everyday low-priced goods. The flow of materials was of immense significance for the retailer to ensure that customers found the desired goods on the shelves. However, with the advent of smart technology, such as smartphones, the flow of information became equally relevant. Customers began to prefer buying online or, at the very least, staying updated with the inventory in the store. This shift in consumer behavior gave rise to the phenomenon of e-commerce. Consequently, innovative payment methods became essential, making the flow of finances critical to the Walmart supply chain. Today, Walmart has successfully connected the supply and demand sides by integrating the flow of material, information, and finances. Several other firms, such as Amazon, eBay, United Airlines, McDonald's, and Coca-Cola, have also achieved efficient supply chains by effectively integrating these three flows.

During the mid-1990s, studies in SCM experienced a significant increase, and this trend has continued to grow up to the present day. A review conducted by Zhang et al. in 2020, focusing on five major Operations and SCM journals, found that a majority of papers published between 1997 and 2018 were centered around the flow of materials. Moreover, there was an increase in the number of papers addressing the flow of information and finances during this period. Table 2 provides an overview of some of the studies that highlight these flows in SCM literature.

**Table 2** Overview of SCF literature. (Source: Authors)

| Type of flow | Articles | Summary |
|---|---|---|
| Information | Pedroso and Nakano (2009) | Effective information sharing can be achieved by using information and communication technology-based tools (such as SAP, Oracle, Salesforce, etc.) which allow supply chain partners to get real-time information about the products. |
| | Sucky (2009) | When information does not flow promptly, it may lead to supply chain disturbances, resulting in sudden order quantity changes, overemphasized production lots, and excessive inventory. |
| | Cachon and Fisher (2000) | Supply chain costs are 2.2% lower on average for actors that share full information than the ones that work on traditional style and hold onto some information. |
| Material | Childerhouse and Towill (2003) | The route to achieving the goal of a fully integrated and effective supply chain is based on the principles of simplified material flow. |
| | Ashraf et al. (2022b) | Increasing the capacity to process high package volume in a third-party logistics hub might lead to a counterintuitive phenomenon called Braess Paradox. |
| | Grover and Ashraf (2023) | To achieve superior performance, autonomous and IoT-driven intralogistics systems are increasingly being deployed in warehouses to process the ever-increasing package (material flow) volume. |
| Finance | Stenzel (2003) | Introduce the term "logistics financing," where the logistics firms actively market the financial services in addition to logistics services to initiate another stream of competence. |
| | Steinmüller (2003) | Examine the financing and leasing of the logistics real estate (e.g., Penske rentals). |
| | Pfohl et al. (2003) | Locate the financial flow at the interface between logistics and finance and terms it a "financial supply chain." |

## 3 Impact of COVID-19 on SCF

COVID-19 was declared as a pandemic by the World Health Organization (WHO) in March of 2020. This prompted countries worldwide to take significant measures to comprehend and evaluate the pandemic's impact. The responses included widespread quarantines and lockdowns, which had a profound effect on supply chains, causing substantial disruptions. The virus originating in China caused a significant disruption in economic activity across various supply and demand channels.

In the U.S., the supply chain disruption had immediate and far-reaching consequences, particularly leading to a widespread shortage of crucial medical supplies like personal protective equipment (PPE). As a result, frontline health workers found themselves ill-equipped to properly care for Covid-19 patients. Similarly, hospitals faced difficulties in procuring lifesaving ventilator machines. Most of these machines were manufactured in foreign countries, leaving the U.S. healthcare sector dependent on already disrupted global supply chains. Federal and state governments had to collaborate with the private sector to ramp up domestic manufacturing and distribution of critical health-saving equipment to hospitals. However, producing these complex machines proved to be a challenge as they were composed of parts sourced from firms around the world.

The impact of the lack of PPEs and other safety equipment extended beyond the healthcare sector, affecting labor-intensive facilities like warehousing, manufacturing, and food processing plants. Employees in these industries faced the challenge of not having enough masks to protect themselves from contracting the virus, leading to the temporary closure of some facilities. In the commercial markets, demand vanished for some product categories, while others, such as toilet paper, furniture, food items, fitness equipment, and hand sanitizers, experienced a skyrocketing demand. Retailer inventory levels for these items reached near-record lows, exacerbated by the chaos in global shipping, which further fueled the ongoing disruption crisis. Additionally, the shortage of all-important semiconductor chips – vital components for electronics and automobiles – worsened the situation. Initially, the scarcity of chips resulted from plant closures during the first wave of COVID-19. Later, the plants faced challenges in meeting the surge in demand when global production resumed operations.

The disruption in material flow was directly correlated with the disrupted flow of information among supply chain partners, making it challenging for them to accurately communicate their demands to upstream providers. Additionally, the lack of visibility into the suppliers' network further exacerbated this issue. Most focal firms had no information regarding their suppliers' suppliers. Similarly, the disruption in financial flows also impacted the availability of material flow. For example, many fashion brands canceled their orders with suppliers due to perceived drops in demand, leading to delayed or withheld payments. This cascaded effect on deep-tier suppliers, most of which were small and medium enterprises, forcing some of them out of business. When the markets reopened, these suppliers had already closed down, significantly impacting production. Similar situations were experienced in other industry sectors, such as airlines, automotive, and the hospitality industry, where firms suspended or postponed payments to their suppliers.

COVID-19 exposed vulnerabilities in supply chains that significantly impacted the flow of goods, information, and finances. It became evident that these three flows were intertwined, and any disruptions in one flow affected the others. Table 3 illustrates the short-term and long-term impact of these three flows across five industry sectors – logistics, airlines, food, manufacturing, and healthcare.

While it is evident that the three most acknowledged flows in SCM experienced disruptions during COVID-19, the pandemic also brought about new threats that triggered interactions among several other flows. In this chapter, we identify and discuss four such flows that played a vital role in supply chain performance during COVID-19 – suggesting the need to reconsider the traditional boundaries of supply chain frameworks. The following sections delve into each flow in detail, providing

**Table 3** Short-term and long-term impact on SCF during COVID-19. (Source: Ashraf, 2023)

| Short Term Impact | Long Term Impact |
|---|---|
| *Information* | *Information* |
| **Logistics**: Distorted information from suppliers due to unexpected e-commerce boom (Sargent, 2020). | **Logistics**: Border restrictions and port delays would impact the real-time information sharing (Gui et al., 2022). |
| **Airline**: Lack of information collected by third-party booking sites impacted passenger tracing (Kitroeff & Silver-Greenberg, 2020). | **Airline**: Lack of information regarding customer behavior and preferences would impact pricing, and scheduling (Dichter & Riedel, 2021). |
| **Food**: Dramatic shift to online, digital food ordering (Aday & Aday, 2020). | **Food**: Restaurants to move for cloud kitchens and online-to-offline takeout (Aday & Aday, 2020). |
| **Health**: Overwhelmed by the information demands and the challenges encountered. No information regarding source of PPEs and other medical devices (WHO, 2020). | **Health**: AI Diagnostic equipment will enhance the ability of providers to do remote virtual care (Bestsennyy et al., 2021). |
| **Manufacturing**: Lack of information from overseas suppliers led to uncertainty (Yavar & Pratt, 2020). | **Manufacturing**: Unpredictable demand trends impact information for finished goods and inventory needs (Yavar & Pratt, 2020). |
| *Material* | *Material* |
| **Logistics**: Record volume causing backlog, hence delays in package delivery (Condon, 2020). | **Logistics**: People are embracing e-commerce; package volume is expected to grow; longer transit times due to port congestions (Bhattacharjee et al., 2021). |
| **Airline**: More than 20 airlines suspended operations by 100% in March 2020 (Statista, 2020) | **Airline**: Flight delays expected due to pilot shortage and retirements (Dolinger, 2022). |
| **Food**: Restaurant closure, plant shutdowns, dumped milk and euthanized livestock lead to food shortage. Further exacerbated by panic buying (Jeffery & Newburger, 2020). | **Food**: Less in-store dining will push food service toward smaller stores. Demand for organic items will increase. Logistical challenges may continue (Aday & Aday, 2020). |
| **Health**: Shortage of PPEs and other medical supplies. Patients unable to access care at the primary care and community care levels (WHO, 2020). | **Health**: More COVID-19 variants would lead to medical devices shortage, complemented by chip shortages and product recalls (Van Houten, 2022). |
| **Manufacturing**: Supply disruptions due to lockdowns in China. Service impacted due to delayed deliveries and cancelled orders (Yavar & Pratt, 2020). | **Manufacturing**: More delays expected due to n-tier suppliers' issues (Yavar & Pratt, 2020). |
| *Finance* | *Finance* |
| **Logistics**: Reduction in potential revenues due to lack of work force, delayed deliveries and cancelled orders (Bhattacharjee et al., 2021). | **Logistics**: Revenue to be impacted due to social distancing protocols, disinfecting of large facilities, delayed deliveries and high financial investments in automation (IFC, 2020). |
| **Airline**: Revenue fall by as much as $113B in 2020 due to lack of passenger traffic (IATA, 2020). | **Airline**: Bankruptcies or mergers and acquisitions among large airlines (OECD, 2020). |

(continued)

**Table 3** (continued)

| Short Term Impact | Long Term Impact |
|---|---|
| **Food**: Prices at supermarkets rose while manufacturers and grocery stores offered 28% fewer discounts than normal (Eliaz & Murphy, 2020). | **Food**: Change in eating habits and lower disposable incomes will impact the revenues of restaurant business (Eliaz & Murphy, 2020). |
| **Health**: Lower expenses and higher margins revenue associated to non-urgent admissions and surgeries evaporated (Lagasse, 2022). | **Health**: Due to telemedicine, lower non-urgent visits expected to the hospitals thereby, impacting the financial flows of the healthcare sector (Lagasse, 2022). |
| **Manufacturing**: Costs in selecting alternate suppliers were passed to consumers through higher prices (Yavar & Pratt, 2020). | **Manufacturing**: Offshoring versus Reshoring decisions to impact revenues (Kaplan, 2021). |

examples of how they were disrupted in various industry sectors during the pandemic.

## 4 Human Flows

Human flows are underrepresented in the supply chain research literature. One possible explanation for this is that supply chain scholars have not emphasized human resource development as a means to enhance supply chain performance (Gowen & Tallon, 2003). In a supply chain, every link requires human involvement to ensure successful operations, reduce uncertainty, and achieve organizational goals (Farndale et al., 2010). During COVID-19, human flow emerged as a critical factor affecting supply chain functioning. The reduction in labor availability spread through the paths of the supply chain network, significantly impacting the effectiveness and efficiency of the supply chains (Nagurney, 2021).

The logistics industry, for example, was one of the hardest hit by human flow disruptions (Ashraf et al., 2022a). Amazon's fulfillment centers, as well as UPS, FedEx, DHL, and the USPS's sorting hubs, faced challenges in hiring and retaining workers during the virus outbreak in their facilities. This challenging situation coincided with a surge in e-commerce volume, prompting these companies to suspend their guaranteed delivery/money-back services. Similarly, the airline industry faced pilot and ground staff shortages as they grappled with the increasing number of air travelers. In 2022, Southwest Airlines had to cut nearly 20,000 flights, and Delta canceled almost 100 daily flights during the summer due to staff shortages (Dolinger, 2022). In the agriculture sector, farm owners faced difficulties finding and retaining workers due to the delayed arrival of seasonal immigrant farm workers. As a result, they had to rely on alternative sources, such as high school students and laid-off workers, to work on farms (Weinraub & Ingwersen, 2020). The delay in summer harvesting led to a surge in wheat, soy, and corn prices. Meat and poultry processing facilities were also affected by human flow disruptions. A report presented to the House of Representatives revealed that in 2020, more than 86,000 meat and poultry workers tested positive for COVID-19, with over 400 deaths reported (Chadde, 2021). As a result, companies like Tyson Foods, JBS, Cargill, and National Beef had to suspend operations at several plants. In the healthcare sector, workforce shortage was already a challenge before COVID-19. The pandemic further exacerbated this issue due to extensive workforce burnout and many healthcare workers contracting the virus. The shortage of workers became even more critical during the surges of COVID-19 variants, such as Omicron and Delta.

In addition to the labor shortages caused by workers contracting the virus, another major human flow disruption emerged due to massive layoffs. Take the example of the U.S. manufacturing sector. About 1.4 million employees lost their jobs during the early days of COVID-19 (Wellener et al., 2021). General Motors had to lay off 6500 employees, while Tesla furloughed approximately half of its U.S. sales and delivery staff. According to a survey conducted by the National Association of Manufacturers (NAM), even as the industry rebounded in 2021, it was only able to fulfill 63% of the jobs lost during the pandemic, despite having a record number of job openings (Hennessey, 2022). Further, the survey respondents mentioned finding talented workers was 36% harder than pre-COVID-19. NAM also forecasted that by 2030, there could be a shortage of talented workforce leading to 2.1 million manufacturing jobs going unfilled. This shortage of workers will significantly impact the sector's supply chain and could cost the industry $1 trillion or more.

Like other flows, the disruptions in human flow during COVID-19 affected nearly every industry, resulting in an unprecedented global slowdown in production volumes and services.

## 5 Knowledge Flows

Knowledge is one of the most valuable assets for any firm (Yalcin et al., 2018). Knowledge flow is the transfer of knowledge between different entities or functions for "facilitating creation, access, and reuse of knowledge, typically by using advanced technology" (Laing et al., 2001, p. 430). Knowledge flow differs from information flow because "information flow focuses on what to do and where to get resources, while the knowledge flow focuses on how to do it" (Pudane, 2013, p. 2). Yet, most SCM research considers knowledge as part of the information flow. As a result, this perspective limits the effective analysis of various SCM issues related to the flow of knowledge.

Amidst the challenges of COVID-19, knowledge became a crucial resource for organizations dealing with uncertain circumstances. Authors such as Orlando, Tortora, Pezzi, and Bitbol-Saba (2021) argue that SCM scholars have not adequately studied the role of knowledge flow for firms and their supply chains. They suggest investing in knowledge flows could have enabled firms to respond effectively to unpredictable events, such as COVID-19. Similarly, Kassaneh, Bolisani, and Cegarra-Navarro (2021) propose that a greater focus on knowledge could have helped to reduce the knowledge gaps between supply chain partners, creating a "traceable and transparent environment" (p. 2).

Due to a lack of knowledge sharing with shippers, logistics firms like UPS, FedEx, and DHL faced challenges in arranging extra capacity to meet the sudden spike in package volume, resulting in delayed deliveries. On the downstream side, the absence of knowledge flow between sellers and consumers led to shortages of essential items due to panic buying. For example, there was a surge in consumers hoarding toilet paper, hand sanitizers, cleaning bleach, alcohol wipes, and utensils and placing numerous online orders for essentials due to their limited knowledge about the available stock levels. Similarly, well-known brands like Nike, Adidas, and J. Crew encountered difficulties in finding alternative suppliers since they lacked knowledge about their deep-tier suppliers, most of whom were located in developing countries such as Bangladesh, Vietnam, and Pakistan. In contrast, companies that had meticulously mapped their supply chains were better informed about their supply network and were able to identify suppliers, plants, and sites that were facing disruptions, enabling them to secure inventory and additional capacity from alternate sources (Choi et al., 2020).

Effective flow of knowledge among supply chain partners could have significantly alleviated the impacts of supply chain disruptions caused by COVID-19. According to a study by McKinsey and Company (2022), for firms to survive any pandemic-like disruptions in the future, they must "invest in foundational, end-to-end supply chain knowledge building, coupled with advanced functional, technical, and leadership training." To achieve this, the World Bank recommends that firms establish systematic learning platforms for stakeholders in their supply chains (Lutalo et al., 2022). These platforms could enable the exchange of experiences and insights – knowledge flow – aiding in the identification and resolution of any prevailing knowledge gaps. Establishing such systems to ensure knowledge transfer is crucial because relying on informal information collected through personal relationships is often "anecdotal" and based on sheer speculation (Choi et al., 2020). Apple, for instance, has recently partnered with Digital Public Square to create a mobile platform that facilitates the exchange of knowledge, including training modules, production status, employee health, and factory preparedness (Apple, 2021). The platform translates the information into the native languages of suppliers in Asia, making it easier for them to comprehend the content.

Modern-day supply chains are intricate, and COVID-19 has highlighted vulnerabilities within these interconnected networks. Recognizing the significance of knowledge flow can empower firms to discover solutions and mitigate challenges associated with processes within these complex networks, ultimately leading to improved supply chain performance.

## 6 Equipment Flows

Similar to the flow of humans and knowledge, the flow of equipment emerged as a critical flow during COVID-19. Equipment refers to any assets a firm utilizes, including transportation equipment like trucks, trailers, and containers, as well as industrial equipment such as forklifts, dollies, and conveyors. These assets are crucial in maintaining the smooth and efficient flow of materials within a supply chain. For companies such as UPS, FedEx, DHL, Walmart, Coca-Cola, and others, equipment flow holds significant importance. Therefore, investing in equipment flow might constitute one of the most substantial long-term capital investments for these firms.

A distinctive characteristic of equipment flows is the variations in their demand, which are directly influenced by changes in material flow or shifts in end-user expectations. These changes can significantly alter the flow of the equipment. For instance, when there is a surge in package volume during peak seasons, logistics companies like UPS etc., often opt to rent delivery vehicles from rental companies such as Penske, U-Haul, etc. This helps ensure the smooth continuity of equipment flow without any disruptions.

During COVID-19, the disruption in equipment flow became evident. To illustrate, The Washington Post reported a significant cause of disruptions to be the shortage of freight-handling equipment in ports (Lynch, 2021). Notably, the ports of Los Angeles and Long Beach experienced delays in container movement due to a shortage of trailer chassis. Similarly, a report by UNICEF (2021) highlighted a global shortage of shipping equipment as a primary factor behind disruptions in sea freight operations. Companies, particularly those that didn’t possess their transportation equipment, were affected by this situation. Acquiring containers became a challenge. In the food industry, small farm owners encountered difficulties obtaining containers and trucks to ensure the timely delivery of their produce to markets.

In addition to transportation equipment, there was a noticeable flow disruption of various equipment within the medical field. For instance, medical devices like blood collection tubes, which facilitate the movement of blood specimens, experienced shortages. These shortages led to disruptions in the blood supply chain, subsequently causing delays in obtaining COVID-19 test results. Consequently, the US Food and Drug Administration issued guidelines to healthcare providers, including laboratory operatives and phlebotomists, advising them to implement strategies for conserving collection tubes to reduce usage (USFDA, 2022). Likewise, in the UK, the National Health Service (NHS) temporarily halted blood testing for non-emergency illnesses (Kent, 2021). On the pharmaceutical side, vaccine production was affected by a shortage of crucial equipment like vials and disposable bioreactor bags, which were essential for transporting the vaccine (Bown, 2022). In the airline industry, infestations in mothballed aircrafts affected instrument accuracy, resulting in rejected takeoffs and in-flight turn-back events during their reintegration into service (Allianz, 2021).

The effective and efficient functioning of supply chains heavily relies on equipment flow. This flow typically necessitates coordination among various internal departments within a company, including purchasing, manufacturing, and planning. With the amplified volatility in supply chains, exacerbated by challenges brought about by COVID-19, the ability of firms to meet customer demands is closely linked to their adeptness in managing equipment flows.

## 7 Technology Flows

Like knowledge, technology flow has largely been examined within the context of information flows. However, it's important to recognize that these two types of flows are distinct. The information focuses on what to do and where to get resources, whereas technology enables coordination across departments, teams, and companies through a high integration amongst the key stakeholders in the network. Putnam and Evenson (1994) describe technology flow as the technological capability developed in one sector of the economy – or by one firm in the supply chain – spilling over to other sectors. The scope of technology flows may extend beyond organizational limits and include all the supply chain partners. For a focal firm to gain the most out of the technological flows, it must ensure that technological alignment is achieved among its supply chain partners.

During COVID-19, the fragmented technology landscape between the focal firms and their overseas partners was one of the major drivers for supply chain disruptions. A World Bank report highlighted that approximately 47% of companies within Bangladesh's manufacturing sector lacked the technological infrastructure to effectively monitor key performance indicators (Gu et al., 2021). This limited the focal firms' visibility into the manufacturers' operations. In another survey conducted by IBM, which involved over 3000 executives representing 22 different industries, the findings highlighted a clear imperative for improved technological alignment among the supply chain partners (Straight, 2020). Companies like Apple, for instance, encountered prolonged periods of reduced production due to insufficient technological integration among its supply chain partners in China.

Even locally, a noticeable disruption in technology flow emerged among supply chain partners. For example, many manufacturers and retailers had no coordination with their local customers, resulting in panic buying. Likewise, the absence of technological integration between logistics firms and vaccine producers posed substantial hurdles in vaccination deployment. The U.S. logistics sector was ill-equipped to handle such integration demands. As a result, healthcare providers and vaccination clinics lacked visibility into vaccine distribution operations.

Amid the repercussions of the COVID-19 disruptions, the technology flow stands out as one of the most influential factors in mitigating the impact on the supply chains. Virtually every industry sector is now channeling investments into enhancing technological flows within their supply chains. For example, Maersk has taken the initiative by implementing an Electronic Data Interchange platform (Maersk, 2021). This platform facilitates inventory optimization, automates financial transactions with suppliers, and enables real-time adjustments to cargo flow. Similarly, third-party logistics (3PL) companies are embracing cloud technologies to consolidate data from various internal and external sources. This consolidation provides heightened visibility for both suppliers and customers. In the healthcare sector, technology is being used to offer appointments and clinical checkups through telemedicine. Artificial intelligence-supported engines are being implemented to improve the healthcare supply chain by identifying high-risk regions and delivering personalized dosage recommendations (Mace, 2021).

Technology flows make the supply chains robust and immune to crisis. It can allow for integration in the key business processes, within and outside the supply network, thereby enabling firms to achieve profits by improving the quality of their product or service and minimizing coordination efforts and transaction risks. Technology is a vital SCF and should be considered by practitioners and scholars.

This is not a comprehensive list of flows; however, the above-mentioned flows should pave the way for SCM scholars and practitioners to explore and manage SCF that impact SCM.

Some might argue that the identified flows may not be suitable in the context of SCM since a flow must add value to the whole supply chain as it moves across various entities in a supply chain. Yet, a flow can be viewed within or between firms. Also, much depends on the type of industry and how it establishes the scope of its supply chain. For instance, consider a cosmetic manufacturing company like L'Oréal. Within its manufacturing facility, the company might employ intelligent robotic systems to perform tasks such as filling, screwing, and securely sealing makeup bottles. Subsequently, these bottles will be imprinted with production-specific laser codes and conveyed to an automated cartoning unit. The cartons will then be loaded onto GPS-equipped trucks managed by 3PLs such as UPS, FedEx, and DHL. Upon reaching the 3PL hub, the cartons will be offloaded and systematically processed using advanced conveyor systems, autonomous forklifts, automated sorters, and more, all to ensure their accurate placement onto the appropriate destination trucks. Once sorted, these cartons will be reloaded onto GPS-enabled delivery trucks, ready for their final journey to the end customer. This intricate scenario underscores the pervasive presence of technological flow throughout the supply chain. It is similar to how finance flows vary throughout the chain – an initial payment might convert from cash to a cheque to an online transaction as it moves through the supply chain. Therefore, SCF should be perceived not only from a macro supply chain perspective but also encompass the various flows intrinsic to internal business functions.

## 8 Managing Supply Chain Flows – Theories in Research

Supply chain management theory has been slow to change since Forrester highlighted the association between a firm's success and a company's functional interrelationships with related flows. However, what has changed is the context with the emergence of COVID-19, that has elevated the need to proactively manage these flows. It also required a shift from traditionally disjointed silos to more effective, integrated management of flows across the overall supply chain.

SCM scholars do now acknowledge integrated SCF to achieve more resilient and sustainable supply chain performance. Interestingly, there is no theoretical framework in the SCM literature that explains the effective management of all SCF. Current SCM frameworks present solutions on how to design and manage particular SCF but do not address the theoretical foundations to manage all the flows (Ashraf, 2023). Therefore, there is a need for SCM scholars to utilize a relevant theoretical underpinning to manage all the SCF. Within this section, several potential theories are presented, which can serve to assist both SCM scholars and practitioners in this matter.

### 8.1 Paradox Theory

COVID-19's immediate impact on SCF brought unprecedented "volatility, uncertainty, complexity and ambiguity" to supply chains (Golgeci et al., 2020, p. 129). In these situations, adhering to the usual course of business was not viable. Managers consistently found themselves grappling with tensions, specifically encountering situations where various options seemed to conflict with each other. This made the process of decision-making quite challenging. Table 4 highlights some of the tensions that surfaced across various industry sectors due to the impact of COVID-19 on SCF.

Such tensions are also called paradoxes in the management literature (Lewis, 2000). Paradoxes consist of "contradictory, yet interrelated elements – elements that seem logical in isolation, but absurd and irrational when appearing simultaneously" (Lewis, 2000, p. 760). The importance of paradoxes during the COVID-19 pandemic becomes evident when considering the usage of the term "paradox" by various media outlets to characterize the crisis. For instance, a New York Times article titled "Corona Virus and the Isolation Paradox" (Shihipar, 2020) exemplifies this phenomenon.

SCM researchers have mostly acknowledged the tradeoffs when addressing the tensions. However, Paradox theory can serve as the theoretical framework to make sense of the tensions that emerge when organizations undergo a major change, such as interactions in SCF due to disruptions (Zhang et al., 2021). It is a valuable theoretical lens since it guides researchers and managers in effectively managing the inherent tensions within the SCF. According to Lewis (2000), actors often simplify complex situations into polarized distinctions – such as focusing on certain flow(s) – when under pressure and narrow their choices to elements (flows in this case) most under their control. However, supply chains cannot perform without all the flows being managed simultaneously. A focus on only a few flows can be

**Table 4** Tensions emerging due to COVID-19. (Source: Authors)

| Tensions | Industry Context |
|---|---|
| Survival versus Sustainability | Manufacturing |
| Independence versus Dependence, Commonality versus Distinction | Management |
| Centralization versus Decentralization, Cooperation versus Competition, Authority versus Trust | Organizational decision making |
| Efficiency versus Resilience | Global value chains |
| Corporate interest versus Employee interests, Employment levels versus Downsizing, Financial interest versus Sustainability | Organizational human resources |
| Interaction versus Safety, Regular versus Critical customers, Responsiveness versus Driver shortage, Revenue versus Safety | Third-party logistics |

disadvantageous to the firm and can even be an obstruction to achieving long-term goals and viability.

## 9 Complimentary Theories to Explain SCF Interactions

Using complementary theories allows scholars to investigate the interactions of SCF that are not fully explained by other perspectives. Three theories – *contingency, institutional complexity*, and *complexity theories* – can address interactions between the SCF. In the following sub-sections, an overview of each theory is presented.

### 9.1 Complexity Theory

Complexity theory addresses several elements an organization must address simultaneously (Scott, 1992). Complexity theory suggests that "some systems with many interactions among highly differentiated parts can produce surprisingly simple, predictable behavior, while others generate behavior that is impossible to forecast, though they feature simple laws and few actors" (Anderson, 1999, p. 217).

Within the SCM context, complexity theory proposes that alterations in the supply chain network's structure will occur unpredictably (Zhang et al., 2021). It has been used to examine the persistent contradictions between short-term success and long-term survival in service innovation (Chae, 2012). Nilsson (2019) argues that complexity theory can be applied to study changes, interrelationships, and paradoxical tensions in supply chains. Therefore, complexity theory's capability to explain the simultaneous management of paradoxical elements can provide an alternate lens to investigate SCF management. It provides constructs such as co-evolution, emergence, patching, and self-organization that may be relevant in understanding the interactions in SCF.

### 9.2 Institutional Complexity Theory

Institutional complexity theory addresses tensions at the institutional and/or organizational levels. The theory depicts competing demands as originating from societal-level expectations. Institutional complexity is when firms "confront incompatible prescriptions from multiple logics" (Greenwood et al., 2011, p. 317).

Institutional logics offer fundamental sets of principles that guide understanding of tensions and appropriate behavior in social situations (Friedland & Alford, 1991). Actors adhere to these logics to attain approval and cultivate the necessary resources. For instance, in SCM, institutional complexity theory can assist in recognizing how social enterprises alter particular practices for social impact (Pullman et al., 2018). This occurs along a spectrum that ranges from purely commercial to purely social. Similarly, Sayed, Hendry, and Bell (2017) explore the influence of "institutional pressures, institutional logics and institutional complexity on Sustainable Supply

Chain Management practices across mixed public and private sector supply chains" (p. 542). Additionally, Baumann-Pauly, Scherer, and Palazzo (2016) explore how firms implement strategies and procedures to respond to contradictory institutional logics in their business environment.

Institutional complexity theory highlights the existence of various and potentially contradictory institutional logics – tensions. This theory offers an alternative perspective to understand how the tensions among SCF can be managed on an institutional level.

### 9.3 Contingency Theory

Contingency theory concludes that there is no universally optimal method for managing a corporation or making decisions, as distinct environments present varying demands (Fiedler, 2005). Managers must choose between competing demands based on internal and external environments. This perspective enables the generation of more advanced "if-then" insights, helping to identify the conditions under which firms can address diverse and conflicting demands (Qui et al., 2012). For instance, Lewis and Smith (2014) note that the "contingency approach to exploration and exploitation seeks to resolve the tension by determining when and where to focus on each strategy separately" (p.131).

Pina e Cunha, Fortes, Gomes, Rego, and Rodrigues (2019, p. 715) conducted research at the interface of contingency theory and paradox theory and determined that "a contingency theory of paradox may contribute to a more granular view of paradox in organizations." Within the context of SCM, Danese (2011) focuses in collaborative planning initiatives in supply networks. The author investigates the pertinent contingency factors influencing firms' selection of a specific collaborative planning initiative. Grötsch et al. (2013) investigated the factors that encourage the proactive adoption of supply chain risk management using the lens of contingency theory. Their study revealed that previous instances of supplier insolvencies influence organizations' vulnerability when engaging with those suppliers.

Overall, contingency theory can provide insights into managing tensions within SCF based on environmental change.

## 10 Moving Forward: Future Research and Current Practice

In this chapter, we highlighted the hesitancy amongst SCM researchers in expanding SCF definitions. The chapter provided an overview of various SCM definitions for SCF over the last few decades. The extent of confusion can be observed both in academia and practice amid the lack of a unified theory of SCM.

Previous SCM definitions do not do justice to various flows that are as impactful as the three most acknowledged flows – especially given recent COVID-19 evidence. Several flows that require attention by the research fraternity could be included within the boundaries of the SCF. Future researchers can broaden their research horizon and identify more flows vital to supply chain performance

**Table 5** Limitations of proposed theories. (Source: Authors)

| Theory | Assumptions | Conflict with SCF |
|---|---|---|
| Paradox Theory | Two elements existing in relation to one another<br>Tensions persist over time | SCF are more than two elements.<br>Tensions between SCF may or may not persist over time.<br>Intensity of tensions might change over time. |
| Contingency Theory | Tensions to be solved discretely | Flows are integrated and must be managed simultaneously. |
| Institutional complexity theory | Tensions emanating from societal-level expectations | Tensions in SCF are inherent that may emerge through an act of the firm (such as implementing new technology) or through environmental change (such as COVID-19). |
| Complexity Theory | Self-organizing systems with little to no direct control<br>Chaos is a necessary condition | Firms can manage the interactions between flows with predictable outcomes.<br>Chaos is not a necessary condition. |

(i.e., resilience, sustainability, etc.). Some possible flows to look into are *value flows, ownership flows, resource flows,* and *risk flows.*

To investigate such flows, there needs to be awareness of what qualifies as SCF. SCM literature does neither clearly define the SCF concept nor discuss the attributes required to be qualified as an SCF. Therefore, the absence of a SCF definition has made it difficult to develop the concept and build a consistent stream of research, and standard practice, in this domain. Without adopting a grounded definition or a framework, confusion will continue to hamper the studies related to SCF and consequently impact the development of SCM research.

For practitioners, the absence of a SCF framework will make it more challenging to effectively identify the critical flows in their supply chains and adopt processes to manage them. Hence, a consensus definition of SCF is greatly needed to advance the field. Therefore, we suggest that future researchers should undertake studies aimed at its development.

Theoretically, a robust SCF theory can only be developed when its valid constructs are established (Stock and Boyer, 2009). Though we proposed four theories that could explain the management of SCF through their interactions, each theory has its limitations that may not fully explain the underlying characteristics of SCF. Table 5 presents some of the limitations of each theory that may not fit well with the SCF dynamics. Therefore, we suggest future researchers develop theories that consider all the aspects of SCF and provide insightful guidance in managing them.

## 11 Conclusion

Motivated by the discussions surrounding the failure of SCM research to respond to disruptions in SCF during COVID-19, this chapter is written to present a basis for debate and development around the extant concept of SCF by attempting to consolidate learning, identify possible gaps, and thereby present possible future directions for development. The nature of research in SCM and, more specifically, what would constitute the domain of SCF, and whether Paradox Theory can provide a critical lens to manage the interactions in SCF, especially amid instances that are unexpected. In doing so, this chapter also provides information on potentially using complementary theoretical approaches to investigate interactions within SCF. Limitations of each theory are presented along with future research suggestions, such as investment in establishing a consensus definition and developing a theoretical framework for SCF so that the research in this domain remains consistent and focused.

The purpose of this chapter is not to undermine the importance of material, financial, and information flows within SCM. Rather, it aims to take an initial step toward enhancing the SCF understanding. It encourages scholars and practitioners not to disregard flows that might hold significance on par with the three most acknowledged flows. This chapter provides a foundation to develop additional theoretical insights for SCM researchers.

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# Agile Supply Chain Management

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## Contents



**Abstract**

Creating agile supply chains is of utmost importance to stay competitive. However, making supply chain operations agile or transforming networks towards an agile form is often challenging for most organizations. This chapter focuses on the agility concept in supply chains. The chapter overviews agile supply chain studies focused on developing models or frameworks for supply chain agility. A comprehensive collection of studies is summarized along with discussing the components of previously developed models or frameworks. The chapter further presents a section about the implementation of supply chain agility in different industries. Manufacturing, automotive, and construction industry examples are discussed. After discussing agility in different industries, the chapter provides emergent concerns and outstanding research areas to direct potential researchers and industry practitioners in terms of assessing supply chain agility. Main research areas on supply chain agility were demonstrated as the integration of

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supply chain agility with organizational operations, barriers to supply chain agility implementation, and the relation between supply chain agility and performance. To complement, managerial implications are summarized.

**Keywords**

Agility · Agile supply chain · Supply chain management

## 1 Introduction

The main motivation behind agility is increasing change facing organizations and supply chains. Globalization, advancements in technology, accumulation of knowledge, customer requirements, competitiveness, uncertainty, and complexity have all increased (Najrani, 2016). In these circumstances, change becomes inevitable. Hence, agility is one of the essential requirements that an organization needs to continue as an operable entity.

There are many examples of leading companies that lost their competitive advantage and failed because of their inability to adapt to changing environments or customer requirements (Najrani, 2016). Hence, agility is essential for survival. To gain and maintain a competitive advantage, supply chains rather than individual organizations have become the unit of competition (Christopher & Peck, 2004; Van Hoek et al., 2001). In that way, supply chain agility became a crucial (Swafford et al., 2006).

This chapter introduces the concept of agile supply chain management. Firstly, the supply chain is defined and the importance of supply networks for individual companies is discussed. Supply chain management is specified, and several strategies are presented based on the previously established studies. Secondly, agility is discussed based on the review of agility definitions and the historical background of agility. The level of agility is also examined. Building on the concepts of supply chain management and agility, agile supply chains are discussed based on the need for agile supply chains and existing definitions. Then, the concept of supply chain agility and other related concepts such as leanness, flexibility, adaptability, and resilience are reviewed and compared. The following section presents a collection of supply chain agility models and frameworks that have been developed so far. Then, examples of empirical studies from different industries are provided. The existing concerns in the prevalent literature are discussed, and future directions are suggested. Managerial implications considering the supply chain agility domain are disclosed. Finally, the summary and conclusions of the chapter are listed.

## 2 Supply Chain Management

Supply chains are networks of companies that are taking part through upstream and downstream linkages from design to delivery of products (Yusuf et al., 2004). It includes all parties extending from suppliers of suppliers to end customers

(Whitten et al., 2012). The supply chain is not a linear chain but a complex network that includes more than two organizations that embody indirect relations and link various organizations, industries, and economies (Christopher & Peck, 2004). It aims to produce value for customers using products and services (Iskanius, 2006).

Organizations should not consider their operations in isolation from the other supply chain parties (Naylor et al., 1999). They need links that support them to become successful (Christopher & Peck, 2004). Developing and maintaining the core competencies to meet the objectives is mostly problematic for individual companies. Hence, they are forced to cooperate and collaborate (Yusuf et al., 2004). The notion of being increasingly dependent on suppliers raised awareness of the need for the management of the whole supply chain from end to end. The dominant means of competitive advantage became supply chains rather than individual companies (Ismail & Sharifi, 2006; Van Hoek et al., 2001).

Supply chain management facilitates the integration of supply chain parties to satisfy the end-customer demand (Agarwal et al., 2007). It is one of the main domains that help companies to achieve a competitive advantage (Lee, 2002). Supply chain management provides a different approach from traditional command and control. Some supply chains are more command and control depending on the industry and conditions. It aims for mass customization rather than mass production and marketing, and also focuses on processes rather than functional, geographical, and product departments (Van Hoek et al., 2001).

Management of the supply chain is complicated and challenging, because of increasing product variety, shortening the life cycle of products, development in technology, globalization, competition, and increasing customer requirements (Christopher, 2000; Lee, 2002). Supply chains in numerous industries are faced with the problem of excessive products or scarcity of products due to difficulties in the prediction of demand (Fisher, 1997). Hence, supply chain management strategy should be determined according to the characteristics of the demand and supply (Lee, 2002).

The foundation of supply chain management is considered to be laid by Forrester (1958) that investigated and modeled the dynamics of demand and supply rates and presented an approach for supply chain management. Being one of the influential studies, Fisher (1997) suggested a framework for supply chain strategies based on the demand characteristics of products. Products can be categorized as functional and innovative. Functional products have stable and expected demand, long product life cycles, and low-profit margins. On the other hand, innovative products have variable and unpredictable demand, shorter life cycles, and higher profit margins. Fisher (1997) considered two types of supply chain processes. Efficient supply chains aim to meet foreseen demand by focusing on cost. Responsive supply chains intend to respond to unforeseen demand and focus on speed and flexibility. According to characteristics of product demand and supply chains, Fisher (1997) proposed that functional products necessitate efficient supply chains, while innovative products require responsive supply chains.

By developing Fisher's framework, Lee (2002) proposed the "uncertainty framework" to determine the supply chain strategy according to uncertainties in demand and supply of products. Differently from Fisher (1997), Lee (2002) categorized the uncertainty of supply as low (stable) and high (evolving). A stable supply process has an established foundation, lower complexity, higher automation, reliable lead time, constant and higher yields, more reliable suppliers, and long-term agreements. In contrast, evolving supply has developed and advancing processes that may cause limitations in capacity and experience. With these complexities, there is more vulnerability to breakdowns, more changes in processes, changing lead time, lower and unstable yields, and less reliable suppliers (Lee, 2002). To increase the performance of the supply chain, uncertainties in demand and supply should be minimized. In some cases, despite the stability of demand from customers, the upstream supply chain may perceive irregular demand patterns. This situation is called the "bullwhip effect" which is the increase of variability throughout upstream of the supply chain (Lee, 2002). As the number of parties in the supply chain increases, the forecasts become more error-prone (Prater et al., 2001). Information sharing, synchronized planning, collaboration, and coordination are significant methods to reduce demand and supply uncertainties (Lee, 2002).

Lee (2002) provided a framework including two dimensions of uncertainties in demand and supply to determine appropriate supply chain strategies. Low uncertainty in demand and supply requires an efficient supply chain in which competitive advantage is gained through efficiency. Industries such as basic apparel and oil and gas can be considered in this category. Functional products that have low uncertainty in demand and evolving supply that have high uncertainty in supply necessitate risk-hedging in supply chains. Hydroelectric power is an example of this category. When the products are innovative with high uncertainty in demand and supply is stable with low uncertainty in supply, companies need to devise responsive supply chains. For instance, the fashion apparel industry is in this category. On the other hand, if both demand and supply uncertainty is high, companies with innovative products and evolving supply should consider an agile supply chain as a strategy. Telecom and high-end computers industry are in this group.

Agility becomes more crucial as demand and supply become more variable and faster in most industries. The effect of natural disasters, crises, pandemics, and other macroenvironmental issues on supply chains escalates this variability given that most supply chains are global. Even though efficiency is required, efficient supply chains are incapable of responding to unpredictable demand and supply changes, as a result, fail to gain a competitive advantage. Some reasons cause supply chain breakdown. Transfer of products in large quantities is useful for cost-efficiency; however, it restricts reacting to the customer demand in a timely fashion. On the other hand, low demand causes excessive inventory, which may result in discounted prices and increased costs while reducing profit along with lowering the value of the product. Lacking buffer stock and the pressure of speed make the supply chain prone to producing defective products (Lee, 2004).

## 3 Agility

Agility is a broad, multidimensional, and complex concept including various aspects of an organization's (Li et al., 2008; Swafford et al., 2006). To make supply chain agility understandable, we first discuss agility definitions. In several studies across different disciplines, agility is defined using varying perspectives as can be seen in Table 1. Given definitions are not attempted to be comprehensive, but representative of significant studies. A review of agility definitions gives the insight to understand underlying foundations and common elements of agility.

**Table 1** Definitions of agility

| | |
|---|---|
| (Iacocca Institute, 1991) | "[. . .] a manufacturing system with extraordinary capabilities (internal capabilities: hard and soft technologies, human resources, educated management, information) to meet the rapidly changing needs of the marketplace (speed, flexibility, customers, competitors, suppliers, infrastructure, responsiveness)." |
| (Goldman et al., 1995) | "[. . .] the ability to thrive in a competitive environment of continuous and unanticipated change and to respond quickly to rapidly changing, fragmenting global markets that are served by networked competitors with routine access to a worldwide production system and are driven by demand for high-quality, high-performance, low-cost, customer-configured products and services." |
| (Yusuf et al., 1999, p. 37) | "[. . .] the successful exploration of competitive bases (speed, flexibility, innovation proactivity, quality and profitability) through the integration of reconfigurable resources and best practices in a knowledge-rich environment to provide customer-driven products and services in a fast changing market environment." |
| (Sharifi & Zhang, 1999, p. 496) | "[. . .] is the ability to cope with unexpected changes, to survive unprecedented threats of business environment, and to take advantage of changes as opportunities." |
| (Jin-Hai et al., 2003, p. 7) | "[. . .] the strategic process of responding to the competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets. It takes multiple winners (manufacturers, suppliers and customers) as an objective, integration (of resources, methods, technologies, departments) as the means, with IT as an essential condition and core competence as the key." |
| (Sambamurthy et al., 2003, p. 245) | "[. . .] the ability to detect opportunities for innovation and seize those competitive market opportunities by assembling requisite assets, knowledge, and relationships with speed and surprise. Agility encompasses the exploration and exploitation of opportunities for market arbitrage." |
| (Overby et al., 2005, p. 296) | "[. . .] the ability of firms to sense environmental change and respond appropriately." |
| (Ganguly et al., 2009, p. 414) | "[. . .] the ability of an organization to rapidly and efficiently response to any proactive/reactive changes in the technology/industry without compromising with the cost and the quality of the product/service that it is catering." |

(continued)

**Table 1** (continued)

| | |
|---|---|
| (Charbonnier-voirin, 2011, p. 123) | "[. . .] a response capability which is intentionally sought out and developed by the organization in order to enable it to act efficiently in a changing environment characterized in particular by complexity, turbulence, and uncertainty." |
| (Lu & Ramamurthy, 2011, p. 933) | "[. . .] a firm-wide capability to deal with changes that often arise unexpectedly in business environments via rapid and innovative responses that exploit changes as opportunities to grow and prosper." |
| (Rimienė, 2011, p. 895) | "[. . .] an ability of a company in a changing market environment profitably exploit market opportunities, quickly and flexibly respond to customers' needs, and qualitatively, suffering minimum cost, satisfy them by using innovative solutions and partnership cooperation." |
| (Singh et al., 2013, p. 10) | "[. . .] the ability of a firm to sense and respond to the environment by intentionally changing (1) magnitude of variety and/or (2) the rate at which it generates this variety relative to its competitors." |
| (Teece et al., 2016, p. 17) | "[. . .] the capacity of an organization to efficiently and effectively redeploy/redirect its resources to value creating and value protecting (and capturing) higher-yield activities as internal and external circumstances warrant" |
| (Walter, 2021, p. 37) | "[. . .] a learned, permanently-available dynamic capability that can be performed to a necessary degree in a quick and efficient fashion, and whenever needed in order to increase business performance in a volatile market environment." |

Almost all definitions consider agility as dependent on environmental change (Singh et al., 2013). The environment is characterized as volatile, turbulent, uncertain, complex, and competitive, which also encompasses continuous and unpredictable external and internal changes, proactive/reactive changes, and threats and opportunities. The most prominent facets in the definitions are sensing the environment and responding to changes. Further, speed is highlighted as an essential element in most of the definitions. Flexibility is also mentioned as an element of agility. Objectives of agility are highlighted as cost, quality, performance, and customer orientation. Some benefits of agility are mentioned such as surviving, gaining competitive advantage, and increasing and maintaining performance. Jin-Hai et al. (2003) stated principle elements of agility definitions as a response to change and uncertainty, building core competencies, supplying highly customized products, synthesizing diverse technologies, and intra-enterprise and inter-enterprise integration. Iskanius (2006) listed the most cited agility attributes such as cost-effectiveness, flexibility, customer responsiveness, speed, reconfigurability, and technology innovation. The main dimensions of agility were implied as cooperation, enriching customer, handling change and uncertainty, and leveraging the impact of people and information by Meade and Sarkis (1999).

Agility is not a new concept. The usage of the term dates back to the late twentieth century (Singh et al., 2013). It has been studied in different fields such as economics, operations research management, manufacturing, strategic management, software engineering, and information technology/information systems (Seethamraju, 2006).

In the software development context, agility drew attention with the introduction of the *Agile Manifesto* proposed by 17 software developers. The Agile Software Development Alliance specified important values and principles in the *Agile Manifesto*. They revealed better ways of software development by valuing: "(1) individuals and interactions over processes and tools, (2) working software over comprehensive documentation, (3) customer collaboration over contract negotiation, and (4) responding to change over following a planned development" (Beck et al., 2001).

Agility is often considered interchangeable with the terms of flexibility, adaptability, and resilience (Li et al., 2008). This shows the overlapping nature of these concepts (Bernardes & Hanna, 2009). Agility involves elements of flexibility and adaptability, which are prior concepts. Even though these concepts have similar elements, they are conceptualized differently in terms of some aspects. Flexibility is the "ability of a system to change status within an existing configuration (of pre-established parameters)" (Bernardes & Hanna, 2009, p. 41). Flexibility helps to minimize environmental uncertainty by acting as a buffer to stabilize the processes. Alternatively, agility helps to take advantage of uncertainties by enabling competitive actions with the help of the reconfiguration (Bernardes & Hanna, 2009). Another significant difference is the management of change. Flexibility deals with predictable change; however, agility faces unpredictable changes (Iskanius, 2006). Flexibility is achieved with pre-established parameters, while agility involves flexibility by including the ability to respond to changes in which the conditions are not established a priori (Bernardes & Hanna, 2009). Another distinguishing point is that flexibility does not have a time element. Agility embeds speed response as an important capability on the contrary to flexibility (Ganguly et al., 2009).

In the context of the manufacturing industry, agility was popularized by the Agile Manufacturing Enterprise Forum by a group of researchers from the Iacocca Institute at Lehigh University in 1991 (Bal et al., 1999; Ganguly et al., 2009; Horney, 2013; Yusuf et al., 1999). The report provided the viewpoint of representatives from industry, government, and academia and presented a new manufacturing system (Iacocca Institute, 1991). This study became a center of interest in manufacturing studies (Sharifi & Zhang, 1999). The group proposed that organizations need to adapt to the dynamic environment and changing requirements like speed, flexibility, and response-ability (Seethamraju, 2006). The report included agile manufacturing organizations, their elements, and operational mechanisms (Yusuf et al., 1999). The Iacocca Institute (1991) further specified some recommendations for the industry to become agile. Another influential study was a book called *Agile Competitors and Virtual Organizations* by Goldman et al. (1995) that drew attention to agility. They emphasized agile capabilities which are enriching the customer, mastering the change, leveraging resources, and cooperation (Bal et al., 1999). However, it was criticized by some researchers that the concept was not founded on management theory (Li et al., 2008; Yusuf et al., 1999).

Early studies mostly focused on agility as a general concept or in the context of the manufacturing industry (Van Hoek et al., 2001). In earlier studies, agility was mostly studied at the organizational level as a whole (Sharifi & Zhang, 1999; Yusuf et al., 1999).

Additionally, another stream of agility research focuses on agile project management and other areas such as workforce agility, human resource agility, information systems/technology agility, business process agility, and operational agility (Seethamraju, 2006; Walter, 2021).

Some studies specified levels of agility. Jin-Hai et al. (2003) and Yusuf et al. (1999) proposed elemental, micro-, and macrolevels. The elemental level is related to individual resources (people, management, and equipment) and functions; the microlevel refers to the organizational level where the key resource is the competence of the organization, and the macrolevel focuses on inter-organizational relations where core competencies of different organizations are utilized (Jin-Hai et al., 2003; Yusuf et al., 1999).

Likewise, van Oosterhout et al. (2005) considered agility at two levels: the enterprise level (similar to the organizational level) and the business network level (similar to the inter-organizational level). Eltawy and Gallear (2017) mentioned agility within three levels: manufacturing, organization, and supply chain. An alternative view has some studies stating that agility consists of operational agility, partnering agility, and customer agility dimensions (Sambamurthy et al., 2003).

As can be seen, there is a variation in the emergence and agility definition. These are presented to provide a broad overview. We now provide some agility definitions within the supply chain context.

## 3.1 Supply Chain Agility

In the past, time, cost, and quality criteria were satisfactory for achieving success (Seethamraju, 2006). However, in current conditions, most organizations are challenged with the dynamics of operations (Ismail & Sharifi, 2006), variety of products (Verma et al., 2012), the short life cycle of products (Christopher, 2000; Rimienė, 2011; Verma et al., 2012; Yusuf et al., 2004), long supply chains (Christopher & Peck, 2004), and unpredictable demand and unreliable supply (Rimienė, 2011).

Several factors such as globalization, customer expectations, emerging markets, and advances in technology lead to strong competition (Carvalho et al., 2012; Christopher, 2000; Ismail & Sharifi, 2006; Rimienė, 2011; Verma et al., 2012; Walter, 2021; Yusuf et al., 2004). Further, other unexpected events are likely to occur such as crises, pandemics, or macroenvironmental issues. The recent COVID-19 pandemic caused disruption in supply chains, material scarcity, variability in demand, and, as a result, unstable prices. All this results in a highly volatile, turbulent, dynamic, and complex environment with an increasing rate of change and uncertainties (Christopher, 2000; Christopher & Peck, 2004; Ismail & Sharifi, 2006; Prater et al., 2001; Verma et al., 2012). These factors further create pressure on time, cost, quality, and performance (Verma et al., 2012). Considering these pressures, companies struggle to integrate and manage upstream and downstream supply chain (Yusuf et al., 2004).

With an unstable, changing, and transforming environment, agility is essential. Responding to changing conditions is mainly influenced by the capabilities of supply chain partners (Power et al., 2001). Since supply chains rather than individual organizations have become the unit of competition (Christopher & Peck, 2004; Van Hoek et al., 2001), supply chain agility became a crucial component for gaining and maintaining competitive advantage (Bal et al., 1999; Lee, 2004; Li et al., 2008; Swafford et al., 2006). Parallel developments in agility and supply chain management resulted in the foundation of the agile supply chain concept (Ismail & Sharifi, 2006). Supply chain agility was introduced in the late 1990s (Bal et al., 1999; Naylor et al., 1999). It was defined by several researchers and some of the definitions are presented in Table 2. Together with being like agility definitions, they refer to the

**Table 2** Definitions of supply chain agility

| | |
|---|---|
| (Bal et al., 1999, p. 75) | "[. . .] the basis for achieving competitive advantage in changing market conditions." |
| (Naylor et al., 1999, p. 108) | "[. . .] using market knowledge and a virtual corporation to exploit profitable opportunities in a volatile market place." |
| (Christopher, 2000, p. 38) | "[. . .] the ability of an organization to respond rapidly to changes in demand, both in terms of volume and variety." |
| (Christopher & Towill, 2001, p. 236) | "[. . .] is a business-wide capability that embraces organizational structures, information systems, logistics processes and in particular, mindsets." |
| (Prater et al., 2001, p. 824) | "[. . .] the degree to which a firm's supply chain is agile is determined by how its physical components (i.e. sourcing, manufacturing and delivery) are configured to incorporate speed and flexibility." |
| (Christopher & Peck, 2004, p. 10) | "[. . .] the ability to respond rapidly to unpredictable changes in demand or supply." |
| (Lee, 2004, p. 1) | "[. . .] respond to short-term changes in demand or supply quickly." |
| (Lin, Chiu, & Tseng, 2006, p. 287) | "[. . .] structure under the goals of satisfying customers and employees within which every organization can design its own business strategies, organization, processes and information systems." |
| (Swafford et al., 2006, p. 172) | "[. . .] the supply chain's capability to adapt or respond in a speedy manner to a changing marketplace environment." |
| (Li et al., 2008, p. 421) | "The result of integrating an alertness to changes (opportunities/ challenges), both internal and environmental, with a capability to use resources in responding (proactively/reactively) to such changes, all in a timely, and flexible manner." |
| (Braunscheidel & Suresh, 2009, p. 126) | "[. . .] the capability of the firm, internally, and in conjunction with its key suppliers and customers, to adapt or respond in a speedy manner to a changing marketplace, contributing to agility of the extended supply chain." |
| (Ngai et al., 2011, p. 233) | "[. . .] the capability of supply chain functions to provide a strategic advantage by converting unexpected market uncertainties and potential and actual disruptions into competitive opportunities through assembling requisite assets, knowledge, and relationships with speed and surprise." |
| (Shashi et al., 2020, p. 324) | "[. . .] a critical strategy for companies to manage supply network, and develop flexible capabilities to meet rapidly changing customer demands." |

level of supply chains and/or networks. Considering these definitions, agile supply chain management helps to generate the ability to respond appropriately to unexpected changes in a volatile and turbulent environment (Carvalho et al., 2012).

## 3.2 Supply Chain Agility and Related Concepts

Several concepts are highly related to the agility (Overby et al., 2005). Some terms have various meanings from different perspectives, while some terms have similar meanings based on the context (Horney, 2013). This creates inconsistencies in the usage of the terms (Li et al., 2008). Understanding the similarities and differences of these concepts with agility can clarify the meaning and implementation (Walter, 2021).

The relationship between lean and agility has been discussed in various studies, which resulted in different perspectives. Some studies argue that leanness precedes agility, and agility is founded in the lean manufacturing (Van Hoek et al., 2001). On the contrary, some studies claim that agility involves a leanness (Iskanius, 2006; Sarkis, 2001). In some studies, they were considered as mutually supporting and complementary approaches (Naylor et al., 1999; Yusuf et al., 1999). Apart from these, some researchers propose combining lean and agile paradigms and benefitting from this synergy (Christopher & Towill, 2001; Naylor et al., 1999).

Lean can be considered as doing more and maximizing value using fewer resources and minimizing waste (Sarkis, 2001). Agility can be considered as the ability to perceive internal and external changes and respond properly. Both lean and agility have similar approaches to some concepts; however, their competitive objectives are in different fields (Walter, 2021). Both paradigms focus on customer requirements and integration of the supply chain (Naylor et al., 1999). Both approaches consider time compression as a significant element; however, their main motivation is slightly different. In lean, eliminating nonvalue adding activities is a primary concern, and these activities are compressed. On the other hand, agility focuses on increasing responsiveness while compressing material and information flows. In lean, the primary goal is to minimize waste. Agility also adopts this concept, however, to the extent that its ability to respond to changes is not prevented (Ganguly et al., 2009).

Rapid configuration is desirable for lean; however, it is not as crucial as for agile. Cost, lead time, quality, and service are important metrics for both methodologies (Naylor et al., 1999). The essential difference between lean and agile is market conditions. Lean is more applicable in more stable and predictable environments, whereas in volatile and changing environments, agility is necessary (Ganguly et al., 2009; Naylor et al., 1999). Agility provides robustness and flexibility in contrast with stability in leanness. While agility focuses on competitiveness and taking advantage of future market opportunities, lean does not focus on these fields (Walter, 2021). Besides, the way of planning and controlling work is different. Lean utilizes a pull system; however, in the agile approach, planning is carried out to respond quickly focusing on the customer demand (Eltawy & Gallear, 2017).

Several researchers discussed using the combination of lean and agile together as a hybrid strategy (Iskanius, 2006). Naylor et al. (1999) proposed the integration of lean and agile concepts as a supply chain strategy which is called leagility. They discussed the decoupling point, which acts as a buffer and separates the part of the supply chain with variable demand from the part with smaller variety. Upstream from the decoupling point has smoother demand with less variety; hence, the lean concept is applicable. Downstream from the decoupling point has a highly variable demand and higher product variety; therefore, the agile concept is appropriate.

Christopher and Towill (2001) also studied lean and agile integration and suggested the following approaches: decoupling point, Pareto curve, and separation of base and surge demands. The Pareto curve approach can be used for lean and agile integration. For instance, considering that 20% of products have more predictable and stable demand, lean is suitable. The other part of the production, that is, 80%, which is less predictable and unstable, necessitates agility. Another approach is the separation of base and surge demands. Base demand can be predicted based on past data and lean is more suitable, while surge demand cannot be predicted and agile is applicable.

Agility is considered an extension of flexibility in several studies (Iskanius, 2006). Based on capability and competency relation, Swafford et al. (2006) examined supply chain agility as an externally focused capability and considered flexibility as an internally focused competency. In other terms, supply chain agility is rather considered a concept derived from the flexibilities in the supply chain processes. Hence, flexibility is viewed as an antecedent of agility. Similarly, it is considered one of the main prerequisites of agility in many studies (Bernardes & Hanna, 2009; Swafford et al., 2006). Another common approach is to examine flexibility as a characteristic of the agility (Christopher & Towill, 2001; Sarkis, 2001; Zhang & Sharifi, 2000). Other studies conceptualize agility and flexibility as distinct but related concepts (Swafford et al., 2006).

Adaptability is “the ability to change from one state to another state in a timely and cost-effective manner” (Swafford et al., 2006). An adaptable supply chain aims to adjust and modify the supply chain to meet the changes (Lee, 2004). The Triple-A supply chain approach conceptualized agility and adaptability as highly related concepts to achieving competitiveness (Lee, 2004). Adaptability is considered to be needed for the flexibility (Iskanius, 2006; Swafford et al., 2006). Even though there are different views on these concepts, flexibility, adaptability, and agility originated as a solution to deal with uncertain and unpredictable environments. As the most developed concept, agility can be considered to involve flexibility and adaptability (Bernardes & Hanna, 2009).

Responsiveness is the tendency to change states in response to altering stimuli (Bernardes & Hanna, 2009). Responsiveness can be considered a component of agility. For example, Van Hoek et al. (2001) stated that agility requires both responsiveness and flexibility. On the other hand, Qrunfleh and Tarafdar (2013) found that an agile supply chain leads to responsiveness, while lean does not. Postponement strategy was found to mediate the relation between agile supply chain and responsiveness. Strategic supplier partnership acted as a mediator in the relation of lean supply chain and responsiveness.

Resilience is "the ability of a system to return to its original state or move to a new, more desirable state after being disturbed" (Christopher & Peck, 2004). Supply chain resilience aims to prevent the undesirable states, which lead to failure by dealing with unpredicted disturbances (Carvalho et al., 2012). Both agility and resilience concepts have the same global aim to increase the performance and competitiveness of the supply chain. They both try to improve quality, enhance customer service, reduce lead time, develop collaborative relations, and work with flexible suppliers. However, their priorities are different. Agility is highly focused on responding to customer requirements, while resilience prioritizes flexibility and redundancy (Carvalho et al., 2012).

Even though agility and resilience definitions have many similarities in terms of responding to internal or external stimuli, their main difference is the stimuli type. In resilience, the organization is faced with an issue or disruption that should be responded to sustain the output capability and survive. In agility, the organization is faced with changes that can be threats but also can be exploited as opportunities. This implies that resilience is a reactive approach, on the other hand, agility provides a proactive approach. Christopher and Peck (2004) proposed that agility is an antecedent to resilience. Carvalho et al. (2012) studied the integration of agile and resilient strategies through the lens of supply chain management.

### 3.3 Supply Chain Agility Models and Frameworks

Christopher (2000) developed one of the earlier and more comprehensive conceptual frameworks explaining the characteristics of the agile supply chain, which are market/customer sensitivity, virtual integration, process integration, and network integration. He proposed a four-dimensional framework, which has been highly cited in many research studies (Iskanius, 2006). These four dimensions are market and customer sensitivity, virtual integration, process integration, and network integration.

*Market and customer sensitivity* indicates the ability to understand and react to real demand and customer requirements. *Virtual integration* pertains to the use of information and knowledge throughout the supply chain both upstream and downstream. *Process integration* relates to the management of uncertainties affecting the supply chain with the help of collaborative and cooperative working. *Network integration specifies* close, collaborative, and fluid associations with suppliers and customers in the supply chain (Christopher, 2000; Van Hoek et al., 2001). This framework assumes that supply chain parties have open relations, information sharing, and technology use (Iskanius, 2006). This framework provides an external, multiorganization focus. Processes and structures to establish an agile supply chain were highlighted across companies, but not within the companies (Gligor, 2014). The framework presented in the study of Van Hoek et al. (2001) was very similar to this framework. Further, Christopher et al. (2004) utilized and developed this framework.

Swafford et al. (2006) adopted a process-based view of supply chains including three main processes: procurement, manufacturing, and distribution. This model conforms with source, make, and delivery processes. On the contrary to Christopher (2000) and Van Hoek et al. (2001), Swafford et al. (2006) suggested a framework that has an internal and single-organization focus (Gligor, 2014). This framework has some limitations in terms of lacking elements such as process integration according to Gligor (2014).

Li et al. (2008) suggested that the main dimensions of supply chain agility are alertness to changes and response capability. They recommended that the degree of agility be measured on timeliness and flexibility. They modeled supply chain agility at episodic, operational, and strategic design levels from the perspective of work design. At the episodic level, work episodes are performed by using existing or obtained resources. The operational design focuses on adjusting available work episodes or involving new work episodes. The strategic level is involved in modifying existing operational systems or building new systems. The three levels are aligned and assumed to be positively associated. This study makes an effort to combine the elements: across organization practices from Christopher's (2000) framework and within organization practices from Swafford et al.'s (2006) framework (Gligor, 2014).

Gligor (2014) suggested a conceptual framework considering the importance of demand and supply management, and flexibility in demand and supply processes to achieve supply chain agility. Unlike studies focusing on supply only, they emphasized both demand and supply management and their integration. They also stated that organization-level strategies should be aligned with supply chain orientation.

The *Triple-A* supply chain framework was utilized by several studies. Lee (2004) introduced that top-performing supply chains have three distinct characteristics as agility, adaptability, and alignment, which were called *Triple-A* supply chains. Agility is responding to unforeseen changes in demand or supply. Lee (2004) explained some rules to create agile supply chains: continuous information and data sharing with supply chain partners, establishing collaborative relations with partners, postponement of some parts of production until customer demand is clarified, keeping inventory of some materials leading to bottlenecks, and having reliable logistics system and experienced human resources.

Adaptability is adjusting the supply chain to conform to the changes. Some necessary actions for adaptability were stated as following economic trends and changes, forecasting end consumer expectations, developing alternative supply chain partners, and considering supply chain implications at the design stage. Alignment is the arrangement of conditions to align supply chain parties towards the same goal. The ways of establishing alignment were identified as the exchange of data with supply chain partners, clear identification of roles and liabilities of supply chain partners to prevent conflict, sharing risks, costs, and savings, and giving incentives and initiatives to improve performance (Lee, 2004).

Whitten et al. (2012) evaluated the Triple-A supply chain-supply chain performance relationship through a Structural Equation Modelling (SEM) methodology. They found a significant and positive relationship that supports Lee's (2004) proposal. Dubey et al. (2018) investigated supply chain agility, adaptability, and alignment and their relationship with some antecedents to them in the auto components industry. They tested hypotheses using multiple regression analysis. They demonstrated that supply chain visibility has a positive effect on supply chain agility, adaptability, and alignment. Top management commitment was found to act as a moderator in this relationship.

Several studies conceptualized supply chain agility by considering agility drivers, capabilities, and enablers. Change is the main driver of agility. Agility drivers specify the changes, agility capabilities are essential to respond to these changes, while agility enablers help to achieve capabilities.

Prater et al. (2001) revealed the relation between external vulnerability and supply chain agility, and as a result, proposed the supply chain exposure concept. They defined supply chain agility as flexibility and speed in sourcing, manufacturing, and delivery. Weaknesses make the supply chain vulnerable internally and externally. External vulnerability is caused by complexity and uncertainty. According to the case studies they conducted, it was revealed that exposure affects supply chain agility. Christopher and Towill (2001) proposed an integrated model for the agile supply chain that explains the enabling concepts within three levels. The first level showed principles that support the agile supply chain, which is postponement and rapid replenishment. The second level specified plans that should be applied to accomplish key principles. Lean production, flexible response, and quick response were proposed to achieve postponement; agile supply, organizational agility, and demand-driven supply chain were presented to achieve rapid replenishment. In the third level, actions for realizing these plans were demonstrated.

Yusuf et al. (2004) analyzed supply chain agility based on two dimensions – range of integration (from messaging to use of the Internet) and reach of information (from personal to global). They developed a conceptual model evaluating the capability of an agile supply chain. Supply chain practices indicate the type of relationship with supply chain parties, which can be categorized as traditional, lean, and agile supply chains. This model proposed that supply chain practices impact competitive objectives, change drivers, and performance. Others identified success factors critical for agile supply chain management (Power et al., 2001). Variables were grouped as participative management, computer-based technology, technology use, resource management, continuous improvement, relationship with suppliers, and just-in-time method.

A group of researchers further focused on developing agile supply chain frameworks or models to discuss the aspects of supply chain agility. For example, Ismail and Sharifi (2006) proposed a framework revealing an approach to achieving an agile supply chain. They suggested integrating two complementary concepts: design of the supply chain and design for the supply chain. In the framework, they also presented factors that affect the supply chain strategy. These factors were grouped as being related to market and business environment, product, organization, and supply chain. Lin, Chiu, and Chu (2006) developed a conceptual model based on previous studies. The model consisted of agility drivers, agility capabilities, and agility enablers. Agility enablers were considered as collaborative relations, process integration, information integration, and customer sensitivity, similar to Christopher's (2000) study. Agile capabilities are specified as responsiveness, competency, flexibility, and speed. Jain et al. (2008) presented a framework integrating several approaches. They included external vulnerability, agility drivers, agility capabilities, agility pillars, and agility enablers on a comprehensive framework by considering the supply chain agility of organizations that appear both internally and externally. However, it was unclear whether the level at which enablers are realized was supply chain or organization level according to Gligor (2014).

In a considerable portion of studies, the impact of virtual teaming and collaborative technologies on the supply chain systems was emphasized. Among these, Bal et al. (1999) investigated the implementation of virtual teaming in supply chain agility. To eliminate uncertainty in the supply chain, information on value and demand should be conveyed upstream, and information on cost and supply should be transferred downstream. Bal et al. (1999) further explain the relationship between data, information, knowledge, and expertise. Data given in a relevant context generates information that helps to gain knowledge, then competent application of knowledge produces expertise. Turbulence is considered within design, volume, mix, schedule, and process categories. To avoid turbulence, concurrent engineering and late configuration can be used; however, they have some limitations since they provide design solutions and are not efficient in other types of turbulence. Keeping stocks is another alternative; however, it is risky, especially for products with short life cycles (Bal et al., 1999). The flow of information can be improved with the help of communication technologies.

Several studies investigated the relationships between supply chain agility and its antecedents or outcomes. Agarwal et al. (2007) developed a model including supply chain variables including market sensitiveness, speed of delivery, the accuracy of data, new product launching, centralized and collaborative planning, process integration, use of information technology, reduction of lead time, improvement of service level, cost minimization, customer satisfaction, quality enhancement, uncertainty reduction, developing trust, and eliminating resistance to change. An Interpretive Structural Model (ISM) allowed them to investigate the relations among these multiple antecedent variables.

Organizational factors are also important in terms of supply chain agility. Therefore, some studies focused on these dynamics between organizations and supply chains. For instance, Braunscheidel and Suresh (2009) revealed the relation between organizational orientation, organizational practices, and supply chain agility. Organizational orientation was conceptualized to be composed of market orientation and learning orientation. Organizational practices were internal and external integration practices and external flexibility. They conducted an SEM analysis. The study revealed that market orientation has a significant effect on all organizational practices. Learning orientation was found to affect internal integration only. Organizational practices were found to impact supply chain agility positively and significantly.

There is further evidence regarding the relationship between infrastructure and supply chain agility. In this respect, Al-Shboul (2017) examined the relationship between infrastructure framework and supply chain agility, indicating all installations such as roads, railways, airports, etc., that are required to provide a flow of products and services. They employed SEM using data collected from developing countries. It was found that the infrastructure framework does not significantly affect supply chain agility. However, delivery dependability and time to market were found to act as mediators in this relationship. In another study, Mandal (2019) studied the relationship between supply chain agility and big data analytics management that covers processing data and drawing inferences. Big data analytics planning, coordination, and control were found to have a positive and significant effect on supply chain agility. This leads to the conclusion that firms dealing with big data have to develop ways for supply chain agility.

Many studies examined the effect of supply chain agility on performance. Building on the resource-based view, Ngai et al. (2011) developed a model to explain the role of supply chain agility on firm performance. They argued that organizations should have some competencies to achieve supply chain agility. These competencies were information technology competence that includes information technology integration and flexibility, operational competence that covers supply chain integration, flexibility, and learning orientation, and management competence that encompasses top management and employee competence. They conducted multiple case studies and evaluated the relations qualitatively. The positive relation between competencies and supply chain agility was supported. Al-Shboul (2017) and Ngai et al. (2011) also inferred that supply chain agility has a positive impact on firm performance.

## 3.4 Implementation of Supply Chain Agility Across Industries

Supply chain agility is of utmost importance in terms of fast responding to the changes in turbulent markets by taking the advantage of benefits and avoiding threats (Dubey et al., 2018; Li et al., 2008). Despite the common benefits, different industries have varying agile operations and take advantage of supply chain agility in different ways.

Supply chain agility is most utilized in the manufacturing industry. Supply chain agility helps manufacturing organizations to revise their prices, specs, quantity, and quality requirements as well as delivery times (Lin, Chiu, & Chu, 2006). Multiple enablers were identified for manufacturing organizations that included practices, methods, tools, and techniques. People and organizational issues were found to be the most important practices for manufacturers (Zhang & Sharifi, 2000). The study further implied that Internet, mass-customization, and virtual organizations are less employed practices by most manufacturing organizations surveyed. This leads to the fact that manufacturing organizations are more concentrated on people and organizational issues when creating agile supply chains.

In another study, Narasimhan and Das (1999) stated that the ability to manufacture and respond to change stems from appropriate selection, development, and integration of suppliers. According to the study of Power et al. (2001), the more agile manufacturing companies are more customer-focus and practice both soft and hard methodologies to meet customer expectations. Moreover, more agile companies were reported to be more active in terms of integrating suppliers in the processes to reach higher levels of customer satisfaction and use technology to promote productivity, new product development, and customer satisfaction. Many mature industries such as manufacturing and steel supply face similar challenges in terms of agility (Iskanius, 2006). In meeting these similar challenges, supply chains must be designed to be sensitive, virtual, and network-based in terms of communication and have process integration to be truly agile.

Agile transformation is a serious concern also for the automotive industry. Baramichai et al. (2006) assessed agile supply chain transformation in a corporation producing automobile parts. After careful consideration of corporation-specific practices, they concluded that the corporation had to reduce the time for supplier selection, find ways to best integrate them into the supply chain, and consider the use of more computer-based systems for order allocation and scheduling to have agility improvement. Vinodh et al. (2013) conducted a case study with an automotive component manufacturing organization to study agile supply chain performance. They proposed a set of attributes to improve supply chain performance such as material planning, adoption of time compression technologies, elimination of paperwork by IT, streamlining of the process, and coordination and cooperation. Similarly, Bal et al. (1999) investigated a major automotive manufacturer to assess agility in the supply chain. They revealed that virtual teaming is critical for the success of supply chain agility, where collaborative supply chain partners are integrated into the processes regardless of their geographic location.

Further, supply chain agility was studied in the electronics industry. Tse et al. (2016) provided a conceptual framework and collected empirical data from electronics companies. They implied that supply chain agility components should be applied together to achieve the best benefits.

Fashion, apparel, and textiles industries require an agile supply chain due to their nature of short life cycle, low predictability, high volatility, and changing customer demand (Christopher et al., 2004). Christopher et al. (2004) implied that critical lead times of fashion supply chains are time-to-market, time-to-serve, and time-to-react.

Even though the discrete manufacturing industry has been widely analyzed in terms of agility, studies in process manufacturing are a limited. The food industry mostly includes products with low shelf-life, which requires a quick response to changing customer demand. Khalili-Damghani et al. (2011) provided a conceptual model for supply chain agility including agility capabilities and enablers in the food industry. Then, they collected empirical data from diary industry companies and measured the effectiveness of agile supply chains.

The pharmaceutical industry is another one that requires agile supply chains. It is a significant industry for health and medicine; hence, it needs to provide drugs continuously with minimum delay and error (Mehralian et al., 2015). Agile supply factors in the pharmaceutical industry include delivery speed, cost reduction, quality, market research, flexibility, and use of information technology tools, which are amongst the highest-ranked priorities in terms of affecting agile supply chains (Mehralian et al., 2015).

Oil and gas industries are characterized by small- and medium-sized companies. Companies in this industry started outsourcing rather than keeping all capacity, which made supply chain integration more important. Complexity and uncertainty are inherent in the oil and gas industries. Piya et al. (2020) studied several factors affecting agility in the oil and gas industries. They came up with a comprehensive list including strategic alignment, top management commitment and support, internal collaborations within the organization, external collaboration among supply chain partners, integration of information systems technology, and applying advanced and new technology.

Along with these industries, others also investigated agile supply chains, even though, to a limited extent. The construction industry – which relates to several other industries – has significant uncertainty and volatility in the supply of materials. It is a complex and risky industry including multiple stakeholders and complex relations (Oyegoke et al., 2008). Thipparat (2010) evaluated the agility of the construction supply chain by using agility capabilities flexibility, responsiveness and quickness, competency, and cost as measurement criteria, in levels of sourcing, construction, and delivery. Then the model was applied to companies as case studies and validated. Poloie et al. (2012) examined the agility of the supply chain in mass construction. They determined criteria for agility: technology, quality, partnership, market, information technology, financial, government, and society. According to empirical data collected, they utilized the interpretive structural model (ISM). They deduced that "government" is the key criterion for agility.

However, all criteria should be at an ideal level to achieve supply chain agility. Markets were viewed as critical based on Poloie et al. (2012) criteria with "information technology" as the least important criterion in construction industry agile supply chains. Oyegoke et al. (2008) studied supply chain management from the perspective of agile specialists. Findings showed that the agile approach helped to reduce cost and time, decrease the uncertainty, and mitigate communication problems.

## 4 Emergent Concerns, Outstanding Research, and Future Directions

The supply chain agility domain includes many studies. Yet, it still has the potential for further investigation. A majority of studies focused on definitions and conceptual models using qualitative approaches (AlKahtani et al., 2019). Several measurement criteria and agility index scales were developed in a relatively limited number of studies. An ambiguity of concepts exists across studies. For example, some studies use agility capabilities for agility assessment – others also include agility enablers. There are no generally accepted agile supply chain measurement criteria. There is a lack of studies on the effectiveness and applicability of the assessment methods (AlKahtani et al., 2019). Empirical studies have utilized varying conceptual models across different industries. In some studies, supply chain agility was integrated with other concepts especially with lean. These studies aimed to provide better ways of supply chain management by combining different perspectives. The main areas observed in supply chain agility are presented along with relevant references in Table 3.

**Table 3** Summary of the research areas of supply chain agility

| Research area | Example studies | Research directions |
|---|---|---|
| Conceptual models of supply chain agility | (Christopher, 2000; Jain et al., 2008; Lee, 2004; Lin, Chiu, & Chu, 2006; Mehralian et al., 2015; Swafford et al., 2006) | Existing studies investigated supply chain agility from various perspectives. Dimensions of supply chain agility were considered in some studies. Process-based view and dynamic capability view were taken into account by some researchers. Several studies investigated supply chain agility based on different levels such as operational, organizational, strategic, and supply chain levels. However, a comprehensive conceptual model is still needed. |
| Empirical studies of supply chain agility | (Baramichai et al., 2006; Christopher et al., 2004; Iskanius, 2006; Khalili-Damghani et al., 2011; Tse et al., 2016; Vinodh et al., 2013; Zhang & Sharifi, 2000) | Manufacturing, automotive, and textile industries mostly adopted supply chain agility. Case study, interview, and questionnaire survey methodologies were mostly employed in empirical studies. |
| Measurement and assessment of supply chain agility | (Agarwal et al., 2007; AlKahtani et al., 2019; Baramichai et al., 2006; Jain et al., 2008; Lin, Chiu, & Chu, 2006; Sarkis, 2001; Vinodh et al., 2013) | Most utilized methodologies for measurement of supply chain agility were fuzzy logic, statistical analysis, analytical hierarchy process, and quality function deployment. |
| Integration of supply chain agility with related concepts | (Gunawardhana et al., 2014; Naylor et al., 1999; Qrunfleh & Tarafdar, 2013) | Agility was combined with various related concepts, for example, leanness, flexibility, resilience, green, and sustainability. It was expected to achieve competitive advantage and better performance with the integration of different management methods. |
| Enablers of supply chain agility | (AlKahtani et al., 2019; Braunscheidel & Suresh, 2009; Lin, Chiu, & Chu, 2006; Mandal, 2019; Ngai et al., 2011; Swafford et al., 2006; Tse et al., 2016; Vinodh et al., 2013; Yusuf et al., 2004) | Most commonly mentioned enablers were: Flexibility, supply chain integration, use of information technology, coordination and cooperation, transparent information sharing, flattened organizational structure, and learning organization. |

(continued)

**Table 3** (continued)

| Research area | Example studies | Research directions |
|---|---|---|
| Barriers to supply chain agility | (Shashi et al., 2020; Zhukov et al., 2019) | Most mentioned barriers were unavailability of appropriate technology, poor partnership formation, lack of top management support, and lack of human resources. |
| Relationship between supply chain agility and performance | (Al-Shboul, 2017; Ngai et al., 2011; Tse et al., 2016; Vinodh et al., 2013; Whitten et al., 2012) | Most of the studies found that supply chain agility has a positive impact on firm performance, business performance, and marketing performance. |

Investigation of the existing studies revealed some research gaps in the area. The existing studies have a narrow view mostly focusing on manufacturing. In-depth studies for the implementation of supply chain agility are needed in most industries. Because of globalization, competition, and rapid customer change, every industry is increasingly faced with changes and more vulnerable to them, which requires supply chain agility.

The literature lacks a detailed, comprehensive, and guided study. Further, the level of investigation is also important. A comprehensive model should be able to integrate supply chain, organization, and team levels. Longitudinal studies are also lacking, most of the empirical studies examine only a cross-section over time. Studying over a period could be beneficial to investigate practices deeply and draw inferences thoroughly.

## 5 Managerial Implications

This chapter summarizes the implications of the agile supply chain and provides practical examples regarding the use of agile practices. In this respect, the chapter presents a comprehensive approach to implementing an agile supply chain in terms of including supply chain partners most effectively. Organizations might benefit from the conclusions provided in this study to set up collaborative structures – across and within stakeholder groups – to enhance the agility of supply chains and develop early action towards changes to overcome supply chain challenges.

Organizations might further benefit from the strategies provided in this study to foster the use of technology in the supply chain, enhance the process and network integration, and educate management by increasing responsiveness towards changes. A critical implication is the multiple solutions, antecedents, and outcomes. Organizations will need to be able to evaluate and implement these various elements for agile supply chains. It is unlikely that one organization or even a whole supply chain can implement all these dimensions in one pass; many times, the outcomes will not meet expectations. But at what point will investment in agility in supply chains no longer be economically or operationally feasible. These complexities need to be managed carefully, and it is not clear that one project or programmatic management approach can guarantee success.

## 6 Summary and Conclusions

Agile supply chains are important in terms of creating an environment ready to handle change. Therefore, organizations must take action towards creating agile teams, integrative processes, and a strengthened network chain. However, there is a growing interest in researching the agility of supply chains and ways to improve the effectiveness of those. Therefore, this chapter focuses on the agility of supply chains by providing the comprehensive definitions of "agility" and its meaning for the supply chains.

Previous studies are investigated in terms of the models and developed for supply chain agility. Cases are provided from different industries to assess supply chain agility. The assessment of supply chain agility indicated that there are challenges with creating agile supply chains in terms of process and network integration as well as handling changes. Therefore, it is recommended that organizations set up effective working teams with the agility concepts and tools to best manage projects and sustain continuous improvement.

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# Agility in the Supply Chain

Nallan C. Suresh

## Contents



**Abstract**

Today's marketplace is characterized by intense competitive pressures as well as high levels of turbulence and uncertainty. Organizations require agility in their supply chains to better manage disruption risks, ensure uninterrupted service, and provide superior value to customers. A systematic cultivation of agility is required in all segments of the supply chain, with the ability to anticipate as well as respond rapidly, in a coordinated fashion, to supply and operational disruptions. Supply chain agility is thus of value for both risk mitigation and response. This chapter provides an updated perspective on agility, based on a summary of research conducted to date, along with current and emerging managerial and research concerns. Major gaps in the literature and shortfalls in practice are summarized, along with critical needs in both research and practice domains. The research literature on agility is covered under the categories of: (1) Supply chain disruption risk management; (2) Conceptualization and evolving

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definitions of agility; (3) Antecedents, drivers, and impacts of supply chain agility; (3) Current managerial concerns regarding the vulnerabilities of supply chains and major gaps in the literature; (4) Emergent concerns regarding both research and managerial practices on agility; and (5) Managerial implications and specific actions that may be pursued to enhance agility, followed by the conclusions. It is hoped that the material presented promotes convergence of research and managerial practices aimed at enhancing the robustness of global supply chains amidst increasing turbulence and volatility.

**Keywords**

Supply chain · Agility · Flexibility · Resilience · Disruption · Risk management · Mitigation · Response

## 1 Introduction

Organizations are increasingly subject to many types of disruptions, with little or no predictability. In recent years, in addition to increasing levels of competition, greater product variety and customization, shorter product life cycles, increasing customer demands, pressures to reduce cost and improve quality, businesses have also had to deal with growing levels of turbulence and unpredictability.

Global supply chains have been exposed to a wide range of catastrophes in recent years, such as earthquakes, tsunamis, hurricanes, volcano eruptions and, as experienced still, pandemics like Covid-19. These seem to occur with increasing frequency and impact. The disruptions due to the recent Covid-19 pandemic have also proved to be different to the catastrophic events of the past two or three decades, serving to expose some fundamental inadequacies in supply chain networks. The term *common cause failure* is often used in these contexts to describe a situation where a global system failure is caused by a single event with tightly coupled system components. Common cause failures, also referred to as command mode failures, are dependent on multiple failures that can be traced to one common cause (Hagen, 1980). They are often viewed as one-in-a-billion, "black swan" events. There is now a growing recognition that organizations require a proactive approach, equipped with a structured decision process to protect themselves against disruptive events.

Given an increasingly turbulent and unpredictable environment, it has been stressed that organizations must consciously develop agility in the entire supply chain to provide superior value as well as manage disruption risks and ensure uninterrupted service to customers (Christopher & Towill, 2001; Zhang et al., 2003; Chopra & Sodhi, 2004; Kleindorfer & Saad, 2005; Swafford et al., 2006). The systematic cultivation of agility in the supply chain, adopting measures to counter various types of disruption is subject to increasing attention among both researchers and practitioners. The management of disruption risks is now recognized to be an integral part of managing supply chains. It involves both: (a) *Mitigation*: actions aimed at reducing the probability of occurrence of a disruption and

(b) *Response and recovery*: measures aimed at reducing the impact of the disruption once it occurs, ensuring fast recovery back to normal modes of operation.

As we emerge from the Covid-19 pandemic, major economies of the world have witnessed an increase in consumer demand for a wide range of products, presenting favorable demand conditions that should work towards a fast economic recovery. Yet, we have been faced with major supply-side constraints that have stifled economic recovery, besides contributing to inflation. There has been a noticeable shortage in critical components like semiconductors, which has curtailed production in automotive and other industries, congestions in the US west coast ports, disruptions in major export hubs and ports in Asia, container shortages, truck driver shortages, and disruptions in the labor market due to new, post-Covid expectations regarding work-life balance and ensuing shortage of labor across industries. The need for supply chain agility based on more diversified and disruption-free supply networks has been palpably felt by many nations.

In this chapter, we present an updated perspective based on a summary of research conducted to date on supply chain agility, along with current managerial practices. We also highlight major gaps or shortfalls in practice and summarize critical needs in both research and practice domains with a view to enhancing the agility and robustness of global supply chains amidst greater turbulence and volatility.

This chapter is organized as follows. In Sect. 2, we summarize the research literature on agility under four subcategories. In Sect. 3 regarding agility, we discuss issues of importance to practitioners. This section is followed by Sect. 4 wherein we discuss major gaps in the literature as well as future research issues and evolving managerial practices. Section 5 is the next section, which outlines specific courses of action for managers for the systematic cultivation of agility. Section 6 ends the chapter by summarizing various issues covered in the chapter.

## 2 Background: Literature Review

This section provides a summary of the research literature under four subcategories: (1) Supply chain disruption risk management; (2) Evolving definitions and conceptualization of agility; (3) Flexibility, agility, and resilience; and (4) Antecedents, drivers, and impacts of supply chain agility, with a view to exploring, in subsequent sections, the managerial actions needed to cultivate and enhance agility within organizations and supply chains.

### 2.1 Supply Chain Disruption Risk Management

The management of supply chain disruption risk has received widespread attention among researchers over the last two decades, and many types of risk faced by supply chains have been identified in all areas of supply chain activity. Figure 1 shows the basic functional domains in supply chain management. The top level involves

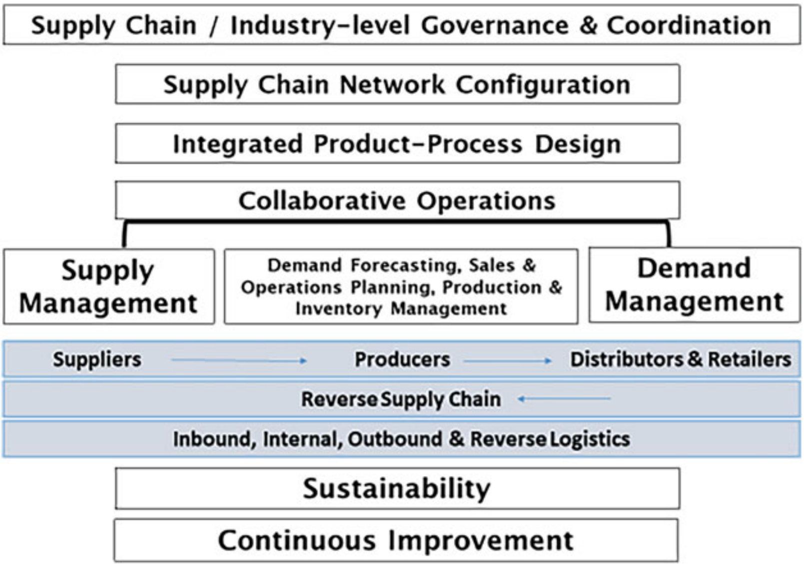


**Fig. 1** Supply chain functions

coordination among firms in a supply chain, typically via a steering committee which connects supplier firms, manufactures, distributors, and retailers. However, supply chains often tend to operate as supply chain networks, instead of linear chains, and the level of coordination among supply chain firms is often limited to a collection of individual relationships among supplier firms, manufacturers, distributors, and retailers. In addition, industry-level coordination tends to be quite inadequate, and supply chains are highly divided, as pointed out in a *Wall Street Journal* article by Smith (2020).

The next level involves supply chain network configuration decisions, often undertaken by the major manufacturers and retailers in the chain. The interorganizational development of new products and processes may be placed at the next level. For the development of new products, many firms have gone through the transition from sequential development to a process based on inter-functional integration via *concurrent engineering* over the last two or three decades. In the supply chain phase, this *inter-functional integration* has given way to an *interorganizational product and process development*, with greater involvement of suppliers and distributors in the design process via *interorganizational concurrent engineering* teams.

The fourth level involves collaborative planning and control of supply chain operations, linking supply management, production and inventory management, and demand management that are required to operate the physical supply chain, which is shown below this level. Reverse supply chain processes are seen below this, as an integral part of the physical supply chain, geared towards sustainability and circular

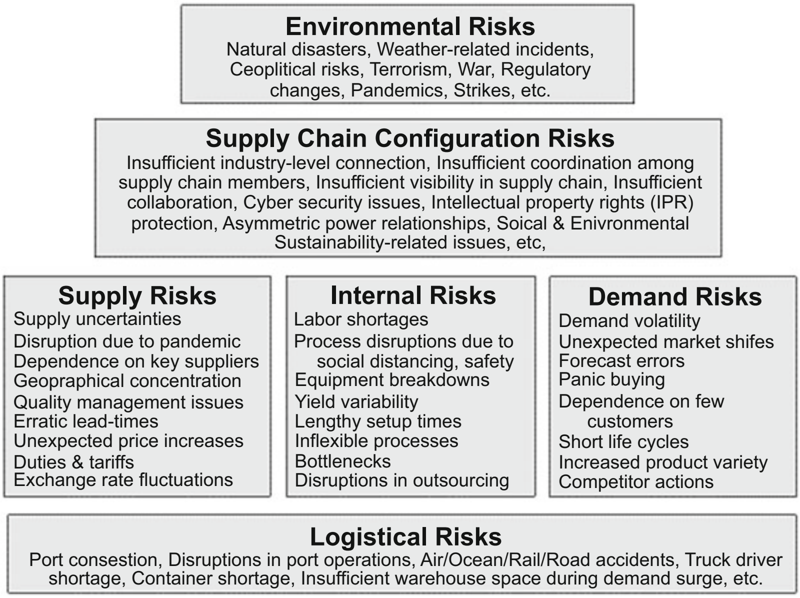


**Fig. 2** Types of disruption risks in supply chains

economy objectives. Logistics functions ensure the forward and backward flow (transportation) and storage (warehousing) of goods and services in the supply chain. Logistics activities can be categorized as inbound (procurement), internal, outbound (distribution), and reverse logistics. Sustainability goals and efforts are shown at the next level. Finally, continuous improvement efforts based on six sigma and lean-six sigma for disseminating and implementing operational performance and quality improvements appear at the bottom of Fig. 1.

Many types of risks exist in various segments of supply chain operations. These risks can be categorized as shown in Fig. 2. The supply chain, overall, is subject to, first, environmental risks which include natural disasters, weather-related incidents, geopolitical risks, terrorism, war, regulatory risks, and pandemics. At the supply chain configuration level, operational and financial risks stemming from insufficient coordination, insufficient industry-level connections, insufficient visibility in the supply chains upstream and downstream, cybersecurity vulnerabilities, weak links in the information network, and sustainability-related issues such as the presence of high carbon footprint areas in the supply chain.

In addition to the above, numerous sources of supply-side risks exist on the inbound side, stemming from supply-side uncertainties, overdependence on key suppliers, geographical concentration of supply sources, unexpected changes in duties and tariffs, exchange rate fluctuations, and other supply-related issues such as poor performance on cost, quality, delivery, flexibility, and service ("CQDFS") dimensions on the part of suppliers. Likewise, numerous sources of variability and uncertainty exist internally.

Demand-side uncertainties include unexpected market shifts, demand volatilities, and panic buying on the part consumers, as experienced by grocery supply chains during the recent Covid-19 years. As on the supply side, overdependence on key customers and geographical concentration of customers may also occur on the demand side. Finally logistical risks, shown at the bottom of Fig. 2, include the numerous sources of risk in warehousing, transportation, and other segments of international and domestic logistics, such as the recent port congestions in the US west coast ports, disruptions to export port operations in China and other Asian countries due to Covid-19, nonavailability of containers, shortage of truck drivers, customs clearance delays, to name a few.

Given the wide array of risks that global supply chains are exposed to, researchers have attempted to identify the risks comprehensively and suggested various tactics for mitigation and response. Researchers have also been developing systematic frameworks for risk management procedures (e.g., Zsidisin et al., 2005; Suresh et al., 2020) which companies can adopt to address the risks of disruption.

Table 1 summarizes recent studies that have addressed the topic of supply chain disruption risk management. Chopra & Sodhi (2004) classified supply chain risks into the risk of disruptions, delays, information systems failures, demand forecast errors, loss of intellectual property (IPR), procurement-side risks, accounts receivable risk, inventories, and capacity. These risks are summarized in Table 2. The drivers of these risks and mitigation strategies to address them have also been listed in Table 2, such as the selective provision of reserve capacity in critical areas of the supply chain, inventory buffers, multiple sourcing, provision of flexibility, and pooling of demand. Kleindorfer & Saad (2005) categorized these risks into two types: (1) risks related to supply and demand coordination and uncertainty and (2) disruption risks that are caused by such events as natural disasters, terrorism, and labor strikes. They developed a conceptual framework consisting of ten principles for supply chain risk assessment and mitigation. Tomlin (2006) makes the distinction between mitigation tactics (which are taken in advance of a disruption) and contingency tactics (response tactics which are adopted only if a disruption occurs). The adoption of volume flexibility, for instance, is viewed as a mitigation tactic that provides for the possibility of rerouting supplies after a disruption has occurred or has become imminent. The cultivation of flexibility, agility, and responsiveness has been frequently mentioned in this emerging stream of literature as a key component in the management of disruption risks. The three terms have been mentioned somewhat interchangeably. Along these lines, there have been many prescriptive articles that have identified different types of risks and different types of actions to both anticipate such risks (mitigation) and different ways by which firms can recover quickly from such disruptions if and when they occur (responsiveness).

Numerous tools and techniques for risk management, such as failure mode and effects analysis (FMEA), cause and effect (Ishikawa) charts, and Bayesian approaches, have been developed. These are applied for analyzing the causes, their possible consequence, impact analyses, and corresponding mitigation and recovery tactics. For brevity, these tools and techniques are not described here.

**Table 1** Representative studies on supply chain disruption risk management

| | |
|---|---|
| Chopra & Sodhi (2004) | Classified risks into disruptions, delays, information systems failures, demand forecast errors, loss of intellectual property, procurement risks, accounts receivable risk, inventories, and capacity. Mitigation strategies such as reserve capacity, inventory, multiple sourcing, flexibility, and pooling of demand are prescribed |
| Hallikas et al. (2004) | Outlines the general structure of the risk management process and presents methods for risk management in a complex network environment |
| Zsidisin et al. (2005) | Case study findings on business continuity planning by firms to manage risk |
| Kleindorfer & Saad (2005) | Categorized risks into two types: (1) risks related to supply and demand coordination and uncertainty and (2) disruption risks caused by such events as natural disasters, terrorism, and labor strikes. Developed a conceptual framework consisting of 10 principles for supply chain risk assessment and mitigation |
| Tang (2006) | Various mitigation strategies are presented to enable a supply chain to manage the inherent fluctuations efficiently and make a supply chain more resilient in the face of major disruptions. Reviews quantitative models for managing supply chain risks, highlighting gaps between theory and practice, to motivate researchers |
| Tomlin (2006) | Distinguished between mitigation tactics (taken in advance of a disruption) and contingency tactics (adopted only if a disruption occurs) |
| Craighead et al. (2007) | Employed a multi-method empirical research and presented six propositions relating severity of disruptions to (1) design characteristics of density, complexity, and node criticality and (2) mitigation capabilities of recovery and warning. Questioned the wisdom of practices such as supply base reduction, global sourcing, and sourcing from supply clusters |
| Knemeyer et al. (2009) | Develops a process to proactively plan for catastrophic risk events. It builds on a risk analysis framework used by the insurance industry to quantify risks |
| Ho et al. (2015) | Provides a comprehensive literature review on supply chain risk management |
| Suresh et al. (2020) | Business continuity management as a framework for agility and supply chain risk management, based on the structure provided by ISO 22301 standards |

## 2.2 Agility: Evolving Definitions and Conceptualization

Over the years, a growing body of research, seeking to identify the defining aspects of agility, has generated valuable insights into the elements underpinning agility and, consequently, has led to an ongoing reevaluation of the definition of supply chain agility. Table 3 provides a summary of evolving definitions of agility among representative research studies, along with key elements of agility identified in the literature.

Early definitions of agility (e.g., Fliedner & Vokurka 1997, Mason-Jones et al., 2000) emphasized the importance of *sensing market opportunities* and quick understanding of customer requirements as being integral to agility, in addition to responsiveness to customer requirements. For instance, Fliedner & Vokurka (1997) defined

**Table 2** Supply chain risk categories, drivers, and mitigation tactics (From Chopra & Sodhi, 2004)

| Risk categories and drivers of risk | | Mitigation tactics |
|---|---|---|
| Disruptions | Natural disaster, labor dispute, supplier bankruptcy, war, terrorism dependency on a single source of supply | • Increase capacity<br>• Acquire redundant suppliers<br>• Increase responsiveness<br>• Increase inventory<br>• Increase flexibility<br>• Pool or aggregate demand<br>• Increase capability |
| Delays | High capacity utilization at supply source, inflexibility of supply source, poor quality or yield at supply source, increased border crossings/changes in transportation modes | |
| Systems | Information infrastructure breakdown, system integration, networking, and e-commerce systems | |
| Forecast | Inaccurate demand forecasts<br>Bullwhip effect: Information distortion due to sales promotions, incentives, lack of supply-chain visibility and consumer hoarding | |
| IPR | Vertical integration of supply chain, global outsourcing, and markets | |
| Procurement | Exchange rate risk, percentage of a key component or raw material procured from a single source, industry-wide capacity utilization, long-term versus short-term contract | |
| Receivables | Number of customers, financial strength of customers | |
| Inventory | Rate of product obsolescence, inventory holding cost, product value, demand and supply uncertainty | |
| Capacity | Cost of capacity, capacity flexibility | |

agility to be "the ability to offer low-cost, high quality products with short lead times, varying volumes to provide enhanced value to customers through customization, utilizing: (1) enriching the customer (quick understanding of customer requirements and providing them); (2) cooperating internally and externally to enhance competitiveness; (3) organizing to master change and uncertainty; and (4) leveraging people (training and empowerment) and information." However, in later years, definitions of agility tended to focus somewhat more on the responsiveness dimension.

Swafford et al. (2006) defined supply chain agility as the capability to adapt or react to marketplace changes, or seize/exploit opportunities with speed and quickness. Fliedner & Vokurka (1997) contended that firms can no longer gain competitive advantage by positioning themselves at a particular point on the *product-process matrix*. Instead, due to the presence of dynamic markets, shorter product life cycles, and a faster pace of innovation, firms will need to become agile and simultaneously deliver on the basis of cost, quality, dependability, and flexibility. Naylor et al. (1999) advanced the notion that both lean and agile paradigms need to be adopted (as "leagility") in supply chains, separated by the decoupling point between push and pull systems.

Mason-Jones et al. (2000) asserted that organizations first need to identify and understand the requirements of the marketplace before embarking on reengineering programs. Christopher & Towill (2001) presented conceptual arguments to define agility as a business-wide capability that embraces organizational structures, information systems, and mindsets along with four characteristics vital to an agile supply chain: market sensitivity, information-based (vs. inventory-based) posture,

**Table 3** Evolving definitions and conceptualization of agility

| Study | Definition and elements of agility (E) or independent variables (IVs) in study |
|---|---|
| Fliedner & Vokurka (1997) | Ability to offer low-cost, high quality products with short lead times, varying volumes to provide enhanced value to customers through customization.<br>E: (1) enriching customer (quick understanding of customer requirements and providing them); (2) cooperating internally and externally to enhance competitiveness; (3) organizing to master change and uncertainty (concurrent engineering, cross-functional teams, etc.); (4) leveraging people (training and empowerment) and information |
| Naylor et al. (1999); Mason-Jones et al. (2000) | Using market knowledge and virtual networks to exploit opportunities in volatile markets, with correct decoupling of push and pull<br>E: Use of market knowledge, virtual corporation/integrated supply chain, lead time compression, rapid reconfiguration, and robustness |
| Overby et al. (2006) | Ability of the firm to *sense* environmental change and *respond* readily<br>E: Sensing and responding abilities. Sensing involves sensing of competitors' actions, consumer preference changes, economic shifts, regulatory/legal changes, and technological advancements. IT (knowledge vs. process-oriented IT) enables both sensing and responding, mediated by digital options. IT may also hinder agility. The degree of alignment between sensing and responding is posited to impact enterprise agility |
| Swafford et al. (2006) | Capability to adapt or react to marketplace changes, or seize/exploit opportunities with speed and quickness; agility is an externally focused *capability*, while flexibilities are internally focused *competences*<br>E: Reduced manufacturing, development, and delivery cycle time; increased frequency of new product introductions; increased customization; adjust delivery capacity/capability; improved customer service and delivery reliability; responsiveness to changing market needs; reduced setup/changeover time; ramp-up time for new products; increased capacity |
| Swafford et al. (2008) | Supply chain agility represents speed of firm's supply chain functions to adapt to changes<br>IVs: Information technology integration and supply chain flexibility |
| Braunscheidel & Suresh (2009) | Firm's supply chain agility (FSCA): Capability of the firm, internally, and in conjunction with key suppliers and distributors, to adapt or respond (mitigation and response) in a speedy manner to changing markets, contributing to agility of supply chain |
| Vickery et al. (2010) | Responsiveness to needs and wants of customers<br>IVs: SC IT, and SC organizational initiatives |
| Roberts & Grover (2012) | Degree to which a firm is able to sense and respond quickly to customer-based opportunities for innovation and competitive action. Firm performance is higher when sensing and responding are aligned; and when sensing and responding are both high than when both low |
| Gligor et al. (2015) | A firm's ability to quickly adjust tactics and operations within the supply chain to respond or adapt to changes, opportunities, or threats in its environment<br>E: Agility has five dimensions: Alertness, accessibility, decisiveness, swiftness, and flexibility<br>Supply chain agility dimensions can be categorized into *cognitive and physical* |

(continued)

**Table 3** (continued)

| Study | Definition and elements of agility (E) or independent variables (IVs) in study |
|---|---|
| Eckstein et al. (2015) | Ability to sense short-term changes (demand fluctuations, supply disruptions, suppliers' delivery times) and to rapidly and flexibly respond to changes in the existing supply chain. Adaptability is long-term agility with the ability to reconfigure supply chains |

becoming a fully linked network, and collaboration among partners. Agarwal et al. (2006) sought to demonstrate that supply chain performance is improved if it is able to respond quickly to changing customer demand, while reducing costs. They found that supply chain agility depends on customer satisfaction, quality and cost improvements, delivery speed, new product introduction, and service level improvement. Narasimhan et al. (2006), in distinguishing between agility and leanness, defined agility as the ability to efficiently change operating states in response to uncertain and changing market conditions. This definition clearly has a response, as opposed to mitigation orientation.

In subsequent years, both *sensing and responding* capabilities came to be emphasized as essential elements of agility (e.g., Overby et al., 2006; Roberts & Grover, 2012). These later studies have argued that, in addition to being responsive, supply chains should also be alert and sensitive to market changes, requiring an explicitly defined set of routines, referred to as sensing capability. The notion of sensing has been emphasized in strategy literature as the role of market knowledge and capabilities that enable a firm to stay "ahead of the market and succeed" in fast-changing markets (Zaheer & Zaheer, 1997; Swafford et al., 2008). Gligor et al. (2013) modelled supply chain agility as a second-order construct consisting of five elements: alertness, accessibility, decisiveness, swiftness, and flexibility. These five elements were found to be operable as constituent dimensions of agility. The five dimensions were not found to be distinct dimensions of agility. Gligor et al. (2015) identified five dimensions of agility: alertness, accessibility of relevant data, decisiveness, swiftness, and flexibility.

Swafford et al. (2006) made theoretical arguments that agility is an externally facing *capability*, drawing from many types of flexibility that are internal *competences*. They found that an organization's supply chain agility is directly influenced by the degree of flexibility in manufacturing and procurement/sourcing and is indirectly influenced by distribution/logistics.

Supply chain agility was defined in terms of a *firm's* supply chain agility (FSCA) (Braunscheidel & Suresh (2009)). It is the capability of a firm, internally, and in conjunction with key suppliers and distributors, to adapt or respond in a speedy manner to changing markets, contributing to agility of supply chain. FSCA was again seen as a capability, drawn from flexibility competences to provide both mitigation and response characteristics to the supply chain.

In the work of Eckstein et al. (2015), a distinction was made between agility and *adaptability*. Supply chain agility was again seen to consist of sensing and responding dimensions. However, *agility* was viewed as a short-term capability, while adaptability was defined as a long-term capability of being able to reconfigure the supply chain in response to longer-term changes.

Based on these updated perspectives, a firm's supply chain agility may perhaps be defined as the capability, both internally and in conjunction with its supply and distribution partners, to both sense and respond in a speedy and cost-effective manner to marketplace and environmental changes in the short and long term, with the ability to reconfigure and adapt the supply network.

## 2.3 Flexibility, Agility, and Resilience

Prior to the notion of supply chain agility, many types of flexibility were identified with the advent of flexible manufacturing systems (FMSs) in the 1980s. Starting with the early work of Slack (1983), many taxonomies of flexibility were developed. Slack (1987) defined flexibility as the range of states a system can adopt, along with the ease, time, and cost with which changes can be made within the capability envelope. Based on this essential notion, many other types of flexibility were identified: machine, labor, product, mix, process, routing, and volume flexibilities, to name a few. An evolution of the notion of flexibility can be found in the works of Gerwin (1993), Slack (1987), Sethi & Sethi (1990), Gupta (1993), Upton (1997), Koste & Malhotra (1999), Vokurka & O'Leary-Kelly (2000), D'Souza & Williams (2000), and Zhang et al. (2003).

With the subsequent focus on agility, flexibility came to be differentiated with agility. Based on the *competence-capability paradigm* in strategy literature, Swafford et al. (2006) argued that flexibilities are internally oriented *competences*, while agility is an external-facing *capability* of an organization. Thus, supply chain agility came to be regarded as an externally focused capability that is derived from the many flexibilities in supply chain processes, which in turn were viewed as internally focused competencies. Based on these arguments, agility and flexibility were deemed to be distinct, yet related concepts, with flexibility being an antecedent of agility (Swafford et al., 2006).

Flexibilities themselves have been categorized as internal- and external-facing flexibilities based on the competence-capability relationship (Zhang et al., 2003). Flexibilities were established to be important antecedents of agility, but other initiatives like supply chain integration with suppliers and distributors were also seen to be antecedents of agility (Braunscheidel & Suresh, 2009). The systematic cultivation of supply chain agility has come to be viewed as an essential means for coping with the increasingly volatile conditions faced by businesses.

In addition to flexibility and agility, a third, parallel stream of literature has been aimed at augmenting supply chain *resilience*. Resilience has been defined as the capacity of an enterprise to survive, adapt, and grow in the face of turbulent change (Fiksel, 2006). Resilience involves improving the adaptability of global supply chains, collaborating with stakeholders, and leveraging information technology to assure continuity, even in the face of catastrophic disruptions. Resilience goes beyond risk mitigation, enabling a business to gain competitive advantage by learning how to deal with disruptions more effectively than its competitors, and possibly shifting to a new equilibrium (Fiksel et al., 2015) (Table 4).

The concept of resilience has a distinct orientation towards *fast recovery from disruptions*. Several antecedents for supply chain resilience have been identified, which include firm-level resilience, risk management infrastructure, and resource reconfiguration capability. Compared to agility – which may be seen as a means to an end – resilience may be argued to represent the end goal itself (Suresh et al., 2020). It has been recognized within this literature that a lack of a unified definition of resilience has contributed to ambiguity of the concept of resilience relating to supply chain disruptions (Bhamra et al., 2011; Ambulkar et al., 2015).

**Table 4** Definitions and representative studies in flexibility, agility, and resilience

| Flexibility | |
|---|---|
| Representative definitions | Slack (1987): Range of states a system can adopt, along with the ease, time, and cost with which changes can be made within the capability envelope<br>Upton (1997): The ability to change or react with little penalty in time, effort, cost, or performance |
| Representative studies | Slack (1987); Gerwin (1993); Gupta (1993); Sethi & Sethi (1990); Upton (1997); Koste & Malhotra (1999); Vokurka & O'Leary-Kelly (2000); D'Souza & Williams (2000); Zhang et al. (2003) |
| **Agility** | |
| Representative definitions | Swafford et al. (2006): Capability to adapt or react to changes, or seize/exploit opportunities with speed and quickness; agility is an externally focused capability, while flexibilities are internally focused competences<br>Braunscheidel & Suresh (2009): The capability of the firm, internally, and in conjunction with key suppliers and distributors, to adapt or respond (mitigation and response) in a speedy manner to changing markets, contributing to the agility of supply chain.<br>Gligor et al. (2015): A firm's ability to quickly adjust tactics and operations within the supply chain to respond or adapt to changes, opportunities, or threats in its environment |
| Representative studies | Representative studies on agility provided in Tables 3 and 5 |
| **Resilience** | |
| Representative definitions | Rice & Caniato (2003): The ability to respond to disruptions and restore normal operations<br>Fiksel et al. (2015): The capacity for an enterprise to survive, adapt, and grow in the face of turbulent change<br>Blackhurst et al. (2011): A firm's ability to recover from supply chain disruptions quickly<br>Pettit et al. (2019): The capability to anticipate and overcome supply chain disruptions |
| Representative studies | Rice & and Caniato (2003); Hamel & Valikangas (2003); Sheffi & Rice (2005); Bhamra et al. (2011); Blackhurst et al. (2011); Pettit et al. (2019); Ambulkar et al. (2015); Fiksel et al. (2015) |

It has been pointed out that in today's global business environment, supply chains have increased in both length and complexity. This increase in length and complexity, coupled with a focus on improving efficiency, such as lean manufacturing practices, may lead to higher levels of supply chain risk where the likelihood of a disruption severely impacting supply chain performance increases. Resilient supply chains have been touted as a means to reduce the likelihood and severity of supply chain disruptions. However, there is little empirical evidence relative to the factors that contribute to or detract from supply resiliency (Blackhurst et al., 2011).

There has been clearly an overlap between the notions of supply chain agility and supply chain resilience. Gligor et al. (2019) have identified the unique themes in both streams of research as well as the overlapping elements. First, they identifies six major dimensions that capture agility: ability to quickly change direction, speed/accelerate operations, scan the environment/anticipate, empower the customer/customize, adjust tactics and operations (flexibility), and integrate processes within and across firms. Similarly, six dimensions were uncovered for resilience: the ability to resist/survive disruptions, avoid shocks altogether, recover/return to original form following disruption, speed/accelerate operations, adjust tactics and operations (flexibility), and scan the environment/anticipate. Agility and resilience were found to share three common dimensions: the ability to adjust tactics and operations (flexibility), speed/accelerate operations, and scan the environment/anticipate. Thus, while the distinction between flexibility and agility has become clear, thanks to works such as Swafford et al. (2006), the concepts of agility and resilience are yet to be clearly differentiated.

## 2.4 Antecedents, Drivers, and Impacts of Agility

Besides research on conceptualization of agility, as seen above, a significant amount of research has been conducted on two other key agility aspects: (1) antecedents or drivers of agility and (2) impact of supply chain agility on operational and financial performance. A few studies have investigated both antecedents and performance outcomes. Table 5 summarizes representative studies on both themes, summarizing the independent variables (IVs), dependent variables (DVs), and key findings of each study, which may be of interest to researchers.

However, in this section, a slightly practitioner-oriented summary is presented, in order to indicate the sets of practices that may be utilized by executives to cultivate agility in their firms and supply chains, and the sets of practices that may lead to tangible performance outcomes. We categorize these antecedents and drivers broadly under the following categories: (1) internal integration; (2) external integration with suppliers and customers; (3) flexibility; (4) sensing capabilities; (5) lean management practices; (6) information and communication technologies; and (6) cultural antecedents.

**Table 5** Representative studies: antecedents of agility and agility-performance relationship

| Study | Independent and dependent variables (IVs and DVs) and findings |
|---|---|
| Swafford et al. (2006) | IV: Procurement, manufacturing, and distribution flexibilities. DV: Supply chain agility<br>Procurement and manufacturing flexibility impact SC agility significantly, but not distribution flexibility, which correlated with procurement and manufacturing flexibility |
| Braunscheidel & Suresh (2009) | IV: Market and learning orientation => [internal and external integration, external flexibility (mix and volume] => DV: firm's supply chain agility (FSCA)<br>Market orientation impacts internal and external integration, and external flexibility; learning orientation impacts only internal integration; internal integration impacts external integration; internal and external integration, and external flexibility impact FSCA |
| Chiang et al. (2012) | IV: Strategic sourcing => firm's strategic flexibility (FSF); both => FSCA. Mediation effects of FSF. DV: FSCA<br>Strategic sourcing and flexibility impacts FSCA significantly. Strategic flexibility partially mediates impact of strategic sourcing on FSCA |
| Gligor et al. (2016) | IV: Environmental uncertainty => [market orientation, SC orientation] => DV. Market orientation => SC orientation. DV: FSCA<br>All hypothesized effects supported, except environmental uncertainty to SC orientation. |
| Swafford et al. (2008) | IT integration => [SC flexibility => SC agility] => DV. DV: Competitive business performance<br>IT impacts flexibility directly, but not agility; flexibility impacts agility; flexibility mediates impact of IT integration on SC agility; agility impacts business performance; agility mediates flexibility => performance |
| Roberts & Grover (2012) | Sensing and responding: Matching and mediation => DV. DV: Firm performance<br>Firm performance is higher when sensing and responding are aligned; and when sensing and responding are both high than when both low. The responding capability mediates the sensing capability on the firm's performance |
| Gligor et al. (2015) | FSCA => [customer effectiveness, cost efficiency], moderated by environmental munificence, dynamism, and complexity. And, FSCA => DV; DV: Financial performance<br>FSCA impacts customer effectiveness and cost efficiency, but not financial performance. Customer effectiveness and cost efficiency mediate FSCA => financial performance. All moderation effects supported, except munificence on FSCA => cost efficiency |
| Eckstein et al. (2015) | [SC agility, adaptability] => DVs. Moderated by product complexity. SC agility mediates adaptability => DVs. DV: Cost and operational performance<br>SC adaptability and agility both affect cost and operational performance significantly. Agility mediates adaptability => [cost and operational performance]. Moderation of product complexity partially supported |

(continued)

**Table 5** (continued)

| Study | Independent and dependent variables (IVs and DVs) and findings |
|---|---|
| Tarafdar & Qrunfleh (2017) | IV: Agile supply chain strategy (ASC); DV: Supply chain performance, mediated by supply chain practices; moderating effect of IS capability for agility on this mediated relationship was also tested<br>Strategic supplier partnership and postponement found to mediate [ASC => supply chain performance]. Higher the IS capability for agility, stronger the mediations of strategic supplier partnership, customer relationship and postponement on [ASC => supply chain performance] |

## Internal Integration

Internal integration refers to cross-functional integration, representing practices that allow organizational functions to coordinate and cooperate with one another (Braunscheidel & Suresh, 2009). Internal integration involves the use of cross-functional teams, internal communication regarding goals and priorities, openness and teamwork, and the use of formal and informal meetings. Internal integration has been studied extensively in past research on supply chain performance. Several studies have suggested that internal integration is also a necessary first step before integrating externally with suppliers and customers (e.g., Vickery et al., 2003).

There is now a vast amount of research literature on the impacts of both internal and external integration measures on operational and financial performance. Useful summaries of this extensive body of literature are found in works such as Mackelprang et al. (2014). However, there have been far fewer studies on the impact of internal and external integration on supply chain *agility*, as opposed to *operational and financial performance*. We focus here on the impacts of supply chain integration on agility.

## External Integration with Suppliers and Customers

A second important supply chain initiative, external integration, represents activities and practices that coordinate the flow of information and goods with upstream and downstream members of the supply chain (Braunscheidel et al., 2010). Strong external integration enables a coordinated preparation for contingencies as well as a coordinated response on the part of the supply chain members to act in times of disruption.

There has been a significant amount of research on integration with customers and suppliers and its impact on supply chain performance, but not enough on agility. A study of German multinational firms by Blome et al. (2013) concluded that there is a direct relationship between supply-side and demand-side competences with supply chain agility.

Braunscheidel & Suresh (2009), employing a second-order construct of external integration, identified a pathway from external integration to supply chain agility. Thus, there is strong evidence that internal and external integration enable the supply chain to act in a coordinated fashion to address both mitigation and response aspects of supply chains, and hence contribute to agility.

### Flexibility

Flexibilities may be classified as internal flexibilities (deemed as competences in the work of Swafford et al., 2006) and external flexibilities, which, like agility, may be viewed as capabilities. Zhang et al. (2003) classify flexibilities thus as internal and external flexibilities within a competence-capability framework.

The two outward-facing flexibilities of mix and volume flexibility have been shown to be direct antecedents of agility in Braunscheidel & Suresh (2009). Mix flexibility is the ability of the organization to produce different combinations of products economically and effectively, given a certain capacity (Zhang et al., 2003). Mix flexibility is measured as the ability to produce a wide variety of products and different product types without major changeovers, or different products in the same plant with speed and quick changeovers. Volume flexibility is defined as the ability of an organization to operate at various levels of output without compromising the performance of the system with respect to cost, quality, or service (Zhang et al., 2003). It enables the firm to operate profitably at different levels of production and to change production quantities easily, swiftly, and cost effectively.

Thus, given a wide range of different flexibilities – such as machine, labor, process, routing, mix, and volume flexibilities – achieving the right mix and balance of these types of flexibilities within organizations is recognized to be a foundational requirement for agility in the supply chain.

### Sensing Capability

Sensing capability refers to the ability to detect or sense opportunities and threats. Sensing involves the systematic acquisition of information about buyers and competitors in target markets, and disseminating the information throughout a business and its partners. Sensing pertains to activities such as gathering market intelligence, monitoring government relations, legal, research and development (R&D), and information technologies (IT).

Many studies have emphasized the role of market knowledge and capabilities that enable firms to stay "ahead of the market and succeed" in fast-changing markets (Zaheer & Zaheer, 1997; Swafford et al., 2006). Naylor et al. (1999) argued that market knowledge helps firms to figure out proper supply chain strategies to pursue by exploiting profitable opportunities in a volatile market place. Sensing enables an organization to anticipate as well as react more quickly and effectively to marketplace volatility and other uncertainties. Firms that are more market-sensitive are also better able to synchronize supply with demand and are able to achieve higher customer service levels. A greater level of sensing also enables a firm to produce more innovative products that are better aligned with customer needs (Overby et al., 2006).

### Lean Management Practices

Lean management practices, as articulated in the seminal work of Womack et al. (1990), have been widely adopted in practice. Lean is associated with the elimination of waste from all processes within a firm and in the extended supply chain. Lean supply chains often operate with tightly coupled systems with very little slack. This goal may come at the expense of agility, rendering supply chains more vulnerable to disruptions. It has been pointed out that in today's global business environments, supply chains have increased in both length and complexity. This situation, coupled with a singular focus on improving efficiency using lean manufacturing practices, may lead to higher levels of supply chain risk where the likelihood of a disruption severely impacting supply chain performance increases (Blackhurst et al., 2011).

However, it may be noted that the bundle of practices associated with lean also includes action steps such as reduction in setup times, faster changeovers, labor flexibility and cross-trained workforce, and dynamic scheduling – each may contribute to agility in other ways. It is perhaps an injudicious and across-the-board pursuit of waste elimination through inventory reduction, limited reserve capacities, and other types of waste elimination that has contributed to the current rethink of lean practices amidst global supply disruptions.

### Information Systems and Technologies

The important role of information and communication technologies (ICT) in supply chain planning and operations is well recognized, and many important research studies have investigated the impacts of IT on supply chain performance. Focusing on agility, however, important studies in the information systems (IS) literature addressing supply chain agility include the works of Chakravarty et al. (2013), Liu et al. (2013), Lu & Ramamurthy (2011), Qrunfleh & Tarafdar (2013), Tarafdar & Qrunfleh (2017), and Vickery et al. (2010).

Information and communications systems form the glue that holds supply chains together. They contribute both towards sensing capability – for the acquisition of business intelligence information – and rapid dissemination of the information throughout the supply chain. They also contribute to fast response and recovery capabilities in the event of a disruption. Thus, the important role of ICT for both mitigation and response is clear. In addition, information systems and technologies are utilized both at strategic and tactical levels, and for both *exploitative* and *exploratory* functions. During exploitation, firms use their existing knowledge to enhance organizational efficiency. On the other hand, during exploration, firms search for new knowledge, develop new products and services for emerging customers and markets, and enhance their innovation performance (Benner & Tushman, 2003).

Works such as Tarafdar & Qrunfleh (2017) have investigated the complementary roles of supply chain practices and information systems capabilities for realizing supply chain agility. Vickery et al. (2010) have investigated two competing models wherein IT and supply chain organizational initiatives may have separate or complementary effects on supply chain performance, with supply chain agility acting as a moderator. The model with the complementary effects was seen to fit the results better. Liu et al. (2013) categorized agility into two types: *market-capitalizing agility* and *operational adjustment agility*, and demonstrated the positive impacts of IT on organizational agility. The IS literature has made important contributions towards a better understanding of agility. A better integration of IS literature and operations management (OM) literature devoted to agility appears to be in order.

### Cultural Antecedents

There has been very little investigation on organizational culture pertaining to supply chain performance and agility. In the work of Braunscheidel & Suresh (2009), the impact of two organizational culture variables, *market orientation* and *learning orientation*, were shown to be indirect antecedents of agility. Supply chain efforts clearly involve major cultural changes such as the establishment of trust, a shift from adversarial relationships to collaboration, and partnership among buyers and sellers in the supply chain. It was found that market orientation has a significant influence on both internal integration and external integration with key customers and key suppliers, and a moderate influence on external flexibility. Learning orientation was seen to strongly influence internal integration, which in turn was seen to significantly affect supply chain agility.

In Braunscheidel et al. (2010), the competing values framework (CVF) of Quinn & Rohrbaugh (1983) was utilized to test whether the four organizational culture types of *adhocracy, clan, hierarchy, and market* are related to supply chain internal and external integration practices, and their effects on delivery performance. It was found that a firm's clan cultural score had no effect on any of the integration practices. However, a firm's adhocracy score strongly affected external integration practices, while the firm's market characteristics had a mild influence on these same practices. Finally, the hierarchy score was found to strongly influence both internal and external integration practices, but in a negative way. Thus, firms exhibiting a strong hierarchical culture tended to have lower external integration. Overall, more research on organizational culture aspects on supply chain performance and agility would be fruitful.

## 3 Current Concerns

From a practitioner standpoint, some major concerns facing global supply chains include the following.

***Increasing unpredictability and a seeming inability to anticipate the next disruptive event***. Supply chain disruptions appear to be occurring more frequently, with increasing impact and unpredictability, ushering us into an *era of unknown unknowns*. This new era clearly calls for superior environmental scanning to anticipate possible climate change events, geopolitical changes, unforeseen changes in economic and global trade issues, acts of nature like earthquakes, tsunamis, volcano eruptions, or asteroid hits, and human-induced incidents like war and terrorism. But, despite the sophistication of the scanning methods used, some events may simply not be predictable. Businesses have to face that reality and plan for contingencies on that basis. No matter what the next disruptive event turns out to be, it will involve supply disruption *in one or more arcs in the network*, *one or more nodes being incapacitated*, a combination of both, or the entire network being incapacitated. Contingency planning based on risk and impact assessments on that basis, along the lines of FMEA and various other tools is warranted.

***Need for structured processes for risk management***. Numerous tools and techniques for risk management, such as FMEA, Ishikawa charts, and Bayesian approaches, have been developed. These are being applied for analyzing the causes, their possible consequences, impact analysis, and corresponding mitigation and recovery tactics. But, despite the availability of numerous tools and techniques for risk management, it is clear that organizations and supply chains are striving for a more structured approach to risk management. Business continuity management (BCM) (Zsidisin et al., 2005) and ISO 22301 of the International Organizations for Standardization (ISO) have served to provide such structured methodologies.

***Need for greater coordination at supply chain and industry levels***. This need has been particularly evident lately. For instance, when consumers could not venture out to eat at restaurants during the Covid-19 disruption, the demand for food products reduced in restaurant channels, giving way to higher demand in grocery supply chains. However, this shift of products across the channels could not be easily effected, due to insufficient coordination at the industry level, contractual rigidities, different packaging requirements, safety standards, etc. (Smith, 2020). Likewise, there is a pronounced need for greater coordination and governance of firms at the supply chain level.

***Need for diversifying global supply networks***. It is also realized that the pursuit of cost efficiencies has led to greater reliance on production in low-cost regions and, in addition, production consolidations in these regions to realize economies of scale. This consolidation has resulted in a concentration of production in low-cost countries and an overreliance on a limited set of suppliers. The recent shortages in semiconductors have been attributed to one large firm in Taiwan, namely TSMC, dominating the supply source, for instance.

***Need for balancing leanness with agility***. There is a growing sense that the pursuit of leanness, eliminating all types of waste, such as excess inventory and capacity wastage, has also rendered globally extended supply chains more vulnerable to disruptions. The disruptions in grocery and food supply chains during Covid-19 have tended to make this clear (Gasparro et al., 2020).

Many of these concerns came to the fore recently in the food supply chain and grocery industry, and the supply of medical devices. In the case of grocery chains, demand volatility, caused by panic buying and hoarding on the part of consumers, led to unexpected shortages of items such as sanitizing wipes and toilet tissues. The industry was caught by surprise, even though grocery chains have been making impressive advances in supply chain management over the years, offering a plentiful and affordable supply of a wide variety of products to consumers. However, the industry has become too lean in recent years, operating with low inventory levels, sacrificing agility and resilience (Gasparro et al., 2020).

Grocery chains found that the lessons learned from the past, the era of hurricanes, were ineffective in handling pandemic situations, which have proved to be different. In the case of hurricanes, demand surge for products can be met by shipments from other, unaffected regions. But in a pandemic, there is a demand surge across the nation, or even globally, limiting shipments from other regions. Pandemics impose constraints on the supply side as well, by having to ensure safer working conditions and social distancing, thereby reducing the ability to scale up production quickly.

The grocery chain industry has also revealed a distinct lack of coordinated response within supply chains. Such supply chain-wide organization, leadership, and coordination through steering committees at supply chain or industry levels. Other factors, such as contractual rigidities in supply chains, have contributed to the inability to redistribute supplies from restaurant channels, which experienced a downturn in demand, towards consumer channels, which faced demand surges (Smith, 2020).

Likewise, the absence of risk management procedures across the supply chain has also been evident. A systematic examination of risk, impact assessments, and contingency actions in all stages of the supply chain is warranted. The vulnerabilities in the upstream, supply network become evident in the case of supply chains for medical devices. Medical devices like ventilators, masks, and personal protection equipment (PPE) rely on a globally dispersed supply chain, originating from global regions which have themselves been affected by the virus, thereby limiting supplies. The risks emanating from overreliance on a limited number of suppliers or distributors, excessive concentration of suppliers, distributors, and other entities in distant geographical regions, etc., can be avoided by systematically examining the risks in all segments of supply and distribution.

## 4 Emergent Concerns: Research Gaps and Future Directions

On the research front, many useful contributions have been made over the years to enhance our understanding of the issues pertaining to agility. Many types of supply chain risks have been identified, numerous tools and techniques have been developed to mitigate risks and enable fast recovery after disruptions, and structured frameworks have been developed for practitioner use (e.g., Ho et al., 2015). However, there are some major gaps in the research literature, and some of these are identified below as emergent concerns, along with suggestions to narrow the gaps between research and practice.

***Dominance of cross-sectional research.*** In the research methodologies employed so far, cross-sectional survey research has tended to dominate, coupled with case study research. The limitations of cross-sectional research are well known: the results pertain to one moment in time; cross-sectional studies often rely on responses elicited from a single, key respondent within an organization; they are based on subjective assessments, with limited validation with objective data; the risk of common method bias; and the responses being limited to one firm within the supply chain.

Causal effects pertaining to agility initiatives and their antecedents may be better captured in longitudinal studies. The use of longitudinal assessments poses some challenges, and secondary data may be hard to obtain for agility and related constructs. However, there has been research employing announcements of supply chain glitches and disruptions, and the impact on financial performance has been assessed through event-study methodology (e.g., Hendricks & Singhal, 2012).

Case studies may also perhaps be employed to discern longitudinal and causal effects, and there is definitely a need to supplement current investigations with more structured, case-study investigations in this field. The extent of case study investigations on flexibility, agility, and resilience is undoubtedly limited, compared to the extent of case study usage in the sustainability field, for instance. Thus, there is a need for broadening the methodological base for empirical research in this area.

***Research silos.*** Research on supply chain agility and research on resilience have proceeded somewhat independently, and there is a clear need to reconcile, and perhaps unify both streams under a common theme. Agility research has been an outgrowth of research on flexibility, whereas research on resilience appears unconnected to flexibility literature. Studies on resilience also have a distinct orientation towards response and recovery from catastrophic disruptions. Gligor et al. (2019) have attempted to reconcile both streams of literature and have identified common themes, as mentioned earlier. However, more studies are warranted for this effort. Likewise, there is a noticeable gap between OM and IS literatures on agility, and this is another area requiring some integration.

***Need for empirical research on supply chain governance and industry-level coordination.*** Though a voluminous body of empirical research has emerged on supply chain integration and coordination, there is a significant gap in our knowledge on how firms in a supply chain are actually coordinating with each other. The advent of Covid-19 disruptions has served to identify such a lack of coordination, both among firms in a supply chain and among supply chains within a given industry (Smith, 2020).

Though the use of steering committees has been advocated by academic researchers, it is not clear to what extent firms actually use steering committees to coordinate activities in supply chains. There is also insufficient research on the organizational aspects of collaboration initiatives such as vendor-managed inventory (VMI) and collaborative planning, forecasting, and replenishment (CPFR) systems, and to what extent they may contribute to agility and resilience. The fact that real-world supply chains operate more as supply networks, than as linear chains, perhaps accounts for the insufficient amount of higher-level coordination.

***Need for research on the use of risk management techniques.*** It is also not clear to what extent firms and supply chains actually utilize the numerous risk management tools that have been developed. Though the use of stress tests and simulations has been advocated for resilience preparation, for instance, it is not clear to what extent supply chains actually use them. More research is also needed on the extent of use of structured risk management approaches like business continuity management (BCM) and implementation of standards such as ISO 22301 (Suresh et al., 2020).

***Gaps in the literature.*** Despite the proliferation of studies on supply agility, there are also some noticeable gaps. These include the dearth of studies on organizational culture and behavioral antecedents of agility. There is also a need for more studies on the use of technologies such as the internet of things (IoT) and blockchains and their impacts on the agility of a supply chain. In the event of a disruption in the food and agribusiness supply chains, it is known that blockchains enable fast traceability of the source of contamination or defects and facilitate fast remedies. Such technologies enable both mitigation and response efforts. Industries also lack guidance currently on how to design and effect the tradeoffs between leanness and agility in various parts of the supply chain. There is also an insufficient base of quantitative modeling on agility, despite a profusion of risk analysis models.

In addition, there is also a need for more contingency research on the impacts of agility in specific situations such as specific national cultures and countries or specific industries. Past research has employed cross-sectional surveys covering a wide range of industries, and it would be of interest if these generally established research results hold in specific industries and contingent contexts. The studies of Blome et al. (2013: Germany), Yang (2014: China), Fayezi et al. (2015: Australia), Dubey et al. (2018: Indian automotive industry), Yusuf et al. (2014: oil & gas industry), and Jahed et al. (2021: Bangladesh fast fashion apparel industry) may be included under this category of research on contingent effects. More such studies are warranted.

## 5 Managerial Implications

We next summarize the managerial implications as a broad set of actions needed on the part of supply chain executives to ensure agility in all segments of supply chain activity, generally in the order shown in Figs. 1 and 2.

***Environmental and Supply Chain Configuration-Level Initiatives.*** Consistent with supply chain management principles developed over the last two decades, firms are expected to actively share information with upstream and downstream partners, maintain visibility of demand forecasts, inventory information, production plans, etc., with suppliers and distributors.

A high-level steering committee, consisting of senior executives of upstream and downstream partner firms, may be created first to provide governance and overall direction to supply chain coordination and improvement efforts. Supply chain-level coordination procedures, such as the ones advocated by Lambert et al. (1998), are particularly useful at this level. The supply chain steering committee may consist of key members who are the major value-adding firms in the chain. This high-level committee systematically examines the supply chain flows to identify points of vulnerability in terms of supply and distribution. At this level, environmental scanning to anticipate potential disruptions may be undertaken to mitigate environmental risks. In addition, network decisions, such as avoiding excessive concentration of production in the hands of one or a few suppliers and avoiding excessive geographical concentration of supply sources, may be addressed.

A map of the supply chain should be examined carefully to identify redundancies in capacity and inventory buffers at critical positions to prevent possible disruptions. Sources of uncertainty must be examined systematically in all segments of the supply chain and their root causes must be addressed for mitigation, prior to developing contingency plans to react after disruptions occur. A useful tool to identify potential risks and estimate the probability of occurrence and their consequences is a supply chain vulnerability map or a subjective risk map. By employing inter-functional and interorganizational teams, a comprehensive vulnerability map can be constructed. This enables the supply chain to not only identify potential risks but also enables the preparation of contingency plans that can be implemented in advance of a disruption.

The identification of potential risks enables the prioritization of risks, the identification of controllable and noncontrollable risks, and the ability to assess the cost of mitigating risk exposure with the benefits of reduced risk exposure (Van Mieghem, 2012). The supply chain map can also be utilized to identify high-impact areas to implement supply chain improvements or identify high carbon footprint areas, as examples.

Supply chain optimization and initiatives such as form postponement (delayed differentiation) and logistics postponement have been advocated for ensuring agility and fast response to changing customer demands. Postponement strategies, by virtue of delaying product differentiation as close to the customer as possible, help reduce the supply-demand mismatch that many global supply chains have to cope with. Under normal circumstances, postponement improves the capability to manage supply, while during a disruption event, it enables a firm to change the configuration of different products quickly (Tang, 2006).

Systematic sharing of information, as part of initiatives such as vendor-managed inventory (VMI), collaborative planning, forecasting and replenishment (CPFR) systems, etc., also involves sharing of demand forecasts and operating plans with other supply chain partners, and they contribute to mitigation as well as coordinated response on the part of the supply chain members. In many situations, the integration and synchronization of planning and execution of production plans via VMI, CPFR, or similar initiatives can minimize and/or eliminate disruptions caused by demand-supply mismatches.

***Internal Integration.*** Managerial actions pertaining to internal (inter-functional) integration may lead to a connected and more coordinated response to marketplace changes and disruptions. Internal integration has often been mentioned as a necessary first step in supply chain integration process (Vickery et al., 2003). Vickery et al. (2003), in a study of the automotive supply industry, found that there is a positive, causal relationship between integrative information technologies and supply chain integration, comprising both horizontal integration (within a firm) and vertical integration (with suppliers and customers).

Firms with high levels of internal integration have cross-functional teams that include members of operations, marketing, procurement and logistics, and other functions. In addition to being knowledgeable about real and potential risks, functions must coordinate with one another to ensure a smooth flow of products to their customers in normal times as well as when disruptions occur. Thus internal integration is beneficial during normal operations as well as when disruptive events occur.

***External Integration with Upstream Suppliers.*** In order to ensure a connected response on the part of suppliers, to potential and actual supply chain disruption, many supply-side integration measures can be undertaken. These are normally the same set of measures needed to ensure better supply network performance: frequent sharing of information with suppliers, greater transparency, sharing of inventory information, providing frequent, constructive feedback on quality and delivery performance, striving to establish long-term relationships with suppliers, working with suppliers to seamlessly integrate interfirm processes, joint development of new products/services, and joint operational planning. One of the potential benefits of providing quality improvement feedback and integration of interfirm processes is the identification and elimination of problems before they arise. Elimination of potential problems through process improvement is better than mitigating the impact of these problems (Van Mieghem, 2012).

It is also critical to have an extended view of the supply network and business intelligence pertaining to the upstream supply network. Many major supply disruptions and adverse incidents of safety or unfair labor practices have occurred due to suppliers who are two or three tiers upstream, and downstream firms do not have a sufficiently deep understanding of upstream supplier activities.

***External Integration with Downstream Customers.*** As for integration with upstream partners, integration with downstream partners also involves information sharing, and frequent inputs on demand trends and marketplace changes from downstream partners. A well-developed sensing mechanism, geared towards eliciting early market signals, serves to prepare upstream partners to anticipate and be prepared for changes. These measures also include the conventional demand-side integration tactics such as feedback elicited from customers on quality and delivery performance, frequent gathering of market signals, downstream partners being actively involved in new product development process, frequent sharing of demand information from customers, sharing of production plans and inventory levels with downstream partners, joint production planning with downstream partners as important elements in logistics planning, and information integration with downstream organizations.

***Cultivation of Flexibility.*** Many types of flexibility have been identified – such as machine, labor, process, routing, volume, and mix flexibilities – and they have been shown to be critical, competence elements of agility. Some of these are externally focused, like mix and volume flexibilities, and they affect agility performance of a firm and supply chain directly. These flexibilities involve capabilities such as the ability to operate efficiently at different levels of output, ability to operate profitably at different production volumes, ability to quickly change production quantities, and volumes of a process, the ability to produce a wide variety of products, and the ability to produce different product types with little or no changeover. Many of these flexibilities are created during the implementation of lean manufacturing systems. The bundle of lean practices includes reduction of setup times, single-minute exchange of dies (SMED), cross-training of the workforce, and designing versatile tools for a wider range of parts and machine operations.

In this context, even though lean manufacturing involves the cultivation of many flexibilities that contribute to agility, it also involves the systematic elimination of waste, especially reduction in inventory buffers, demand-driven (pull) systems, and tightly coupled systems that have rendered global supply chains more vulnerable to disruptions. Thus, going forward, lean implementation has to be judiciously pursued, without compromising resilience.

***Organizational Culture and People***. Finally, it is also important to address organizational cultures and individual behavioral attributes that are conducive to agile supply chains. Cultural traits such as market orientation and learning orientation have been shown to be indirect antecedents to agility (Braunscheidel & Suresh, 2009).

Firms with a high market orientation closely monitor the needs of customers and pay close attention to the competitive landscape in terms of the strengths and weaknesses of current and potential competitors. They provide strong sensing capabilities so that organizations can be alert and they swiftly seize opportunities which arise.

Likewise, a firm's learning orientation has a direct effect on internal integration, so that firms learn to work more effectively in a cross-functional manner. Another key advantage of possessing a learning orientation is the ability for organizations to learn from disruption events. Organizational culture types such as adhocracy – as opposed to clan and hierarchy – are desirable firm characteristics in terms of being agile. Firms that possess the attributes of an adhocracy culture may be better suited to sense and recover from disruption situations.

When highly uncertain, low probability events occur, employees may need to operate *on the fly* with real-time information of the particulars of the event. Such situations require employees to take some risks as they try to respond to disruption in real time. If an organization is highly structured, with too many formal rules, first responders to the disruption may defer to higher levels for guidance on to how to handle the disruption, thereby losing valuable time. Thus, many managerial implications of value can be drawn from the set of antecedents mentioned earlier in Sect. 2.4.

## 6 Conclusions

In this chapter, the critical issue of agility in the supply chain was addressed by summarizing the research literature along with managerial practices required for the systematic cultivation of agility in the supply chain. This chapter has attempted to provide an updated perspective on agility, synthesizing agility-related research from both operations management and information systems literature. Current and emerging managerial concerns were also addressed, along with major gaps in the literature and shortfalls in practices.

The topic of supply chain agility was directed towards a risk management initiative that enables a firm to anticipate as well as respond rapidly to marketplace changes and disruptions in the supply chain. Disruptions may have numerous impacts on supply chain performance. The scope and magnitude of the consequences of these disruptions require intra- and inter-functional, as well as interorganizational coordination and communication.

This chapter has provided an updated perspective of an emerging body of literature devoted to supply chain agility. Based on our own research stream on this topic, a set of supply chain initiatives were discussed as antecedents for the cultivation of agility. These included internal and external integration measures, cultivation of external flexibility, and lean practices. Following this, more fundamental, cultural antecedents towards the cultivation of agility were mentioned, which included the constructs of organizational culture type, market orientation, and learning orientation.

Since the validity of these models has been established through empirical research, these findings can be translated into a set of managerial practices for the cultivation of agility. Based on these practices, a systematic cultivation of agility in all segments of the supply chain is required, from both mitigation and response perspectives. Tactical issues coupled with the agility to reconfigure the supply chain (adaptability) are both important as business conditions become more volatile and unpredictable. Much work still remains to be completed on supply chain agility, and it is hoped that this chapter provides a broader and deeper understanding of agility in the supply chain.

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# Lean Supply Chain 5.0 Management (LSCM 5.0): Lean and Value Reconceptualized

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## Contents



**Abstract**

Lean supply chain management (LSCM) has long been an approach to increase firm competitiveness. However, with rapidly changing, competitive markets, there is no guarantee on whether previously defined LSCM principles are enough to overcome today's challenges. The cyber-physical systems introduced by industry 4.0 have already transformed into talks of industry 5.0 with a focus on human centricity, sustainability, and resilience. In this chapter, we define LSCM through an industry 5.0 context via a two-dimensional matrix incorporating core values of industry 5.0 with LSCM pillars including stakeholder management, technologies, just-in-time (JIT) production, logistics management, and continuous improvement. Using this matrix, 15 lean supply chain management 5.0 (LSCM 5.0) principles and practices are defined in this chapter. We assert that a narrow focus on value in LSCM ought to be adjusted to reflect the broader nature

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of value as it is defined through the emerging industry 5.0 context. In an industry 5.0 environment, all stakeholders such as workers, managers, shareholders, and customers should be considered in decisions and valued. In addition, a broader perspective of valuation through waste reduction ought to be reconsidered through a more inclusive stakeholder approach.

**Keywords**

Lean supply chain · Lean principles · Lean practices · Supply chain 5.0 · Industry 5.0 · Lean industry 5.0

## 1 Introduction

It is arguable that in the past couple of years, supply chain as a field has seen an abundance of change in networks, practices, and processes more so than in the past couple of decades. Catalyzed by a global pandemic, causing massive shortages in material and human resources, risk management, regionalization, and agility were pushed to the top priority for most organizations across industries. Rapid adjustments forced by uncontrollable external events brought forth a renewed dedication toward lean practices for those companies who devote themselves to the lean philosophy, while at the same time led others to question these age-old practices.

The foundation of lean emerged in Japan during the 1950s when manufacturing companies were seeking to make the most use of confined resources (Schniederjans et al., 2018). It started in the automotive sector (Sinha & Matharu, 2019) and is now applied to both manufacturing and nonmanufacturing organizations alike (Samuel et al., 2015).

Lean management (LM) is a management system with the goal of waste reduction by simultaneously decreasing or minimizing internal and external variability (Núñez-Merino et al., 2020). Adopting LM and applying it to supply chain management (SCM) is considered as an approach to maintain company competitiveness by increasing organizational output given a respective level of input (Jasti & Kodali, 2015). LM has been linked to various operationalization of performance improvement – inventory-level reduction, customer satisfaction, and profitability (Kadarova & Demecko, 2016). In SCM, LM has been applied to almost all areas and is especially prevalent in studies focusing on product procurement, service level (Moyano-Fuentes et al., 2019), and systematic reduction of variability sources in supply network design (Núñez-Merino et al., 2020).

In a panel hosted by Decision Sciences Institute, Professors Tyson Browning, Richard Schonberger, Urban Wemmerlov, and Rachna Shah discussed the future of lean (Browning et al. 2021). They reiterated a need for a review of how LM ought to be framed. Previous research elucidates this notion suggesting a lack of agreement on defining lean. Specifically, value through lean can be defined in multiple ways, across different times and people (Samuel et al., 2015).

Schniederjans et al. (2018) define lean through four main principles: waste elimination, quality improvement, product flow maximization, and cost reduction. According to Cusumano et al. (2021), lean is defined as a way of thinking to create needed value with fewer resources and less waste. In another study, Samuel et al. (2015) define lean as an operations paradigm with the goal of variability reduction and time compression to improve flow. Tortorella et al. (2018) define lean through an aim to reduce waste, decrease variability, enhance operational performance, and add value to customers.

Shifting to lean with a focus on supply chains we arrive at lean supply chain management (LSCM). LSCM is defined through the mutual interaction between LM and supply chains (Moyano-Fuentes et al., 2019) but it is mostly defined as omitting any activity in supply chains which have no added value to customers (Jasti & Kodali, 2015). This definition – as well as others – take on a customer-centric approach to value creation in organizations.

Other LSCM definition examples include Núñez-Merino et al. (2020) who define interorganizational processes optimization from the end customer's point of view as the goal of applying lean principles into supply chains. Womack and Jones' (1997) five-stage process of lean thinking involves value being defined by customers in terms of their needs and expectations. However, some research has broadened this scope to include other concepts of LSCM value.

There have been suggestions that the goal of LSCM as customer satisfaction can be increased through a broader stakeholder approach by inefficiency reduction, establishing strong relationships with suppliers, and creating a balance between demand and capacity (Moyano-Fuentes et al., 2019).

When considering previous LSCM research, it can be concluded that the common element of the lean definition is to create a value stream with the final customer in mind. Hence, a customer-centric view of value has been considered and is often the focus in LSCM literature (Browning & de Treville, 2021). This customer-centric approach results from the critical role of customers in supply chains since the customer is the ultimate judge of supply chain performance (Jeong & Hong, 2007). However, with new and emerging concepts in automation, technology, and growing concerns in sustainability (from both social and environmental contexts), LSCM and its concept of value is adjusting due to questions of its legitimacy.

Industry 5.0 is defined through a shift from a technology-centric approach to a human and society-driven movement (Xu et al., 2021). Previous industrial revolutions mostly focused on the separation of manual labor with automated labor (Demir et al., 2019). Concerns of job displacement and ideation inefficiencies through highly automated tasks have since spurred the underpinning of collaborative efforts between human and machine.

Industry 5.0 complements the fourth industrial revolution (industry 4.0) – whose focus was primarily on automation integration and intelligent systems – by adding sustainability, resilience, and human centricity concerns. The rapid push toward automation has forced us to question the sustainability of the consistent change toward machinery versus manual labor. Additionally, supply chain scholars and practitioners are now rethinking traditional models for supply networks into new versions of digital capability models for supply networks (ASCM, 2022) in order to enhance performance via automation. Coupled with global pandemics that catalyze these changes, scholars and practitioners are rethinking fundamental concepts in value as they relate to LSCM. From a resilience perspective, LSCM was once primarily defined through the optimization of inventory levels. Yet in an environment wrought with global issues and crises, how can lean be leveraged and integrated within the boundaries of ever-evolving industrial changes?

This chapter identifies various lean principles and practices, their implementation, and applicability to the emerging industry 5.0 context. Industry 5.0 core values are reviewed to examine if defined lean principles and practices are aligned or redefined. To achieve the proposed objectives, this chapter first identifies LSCM history and definitions. This section is followed by an explanation of the revolution of industry 4.0 into industry 5.0. Next, the approach to redefining lean supply chain management 5.0 (LSCM 5.0) principles and practices is presented. Additionally, we provide both managerial and research implications in regard to calls for actions in: (1) stakeholder management, (2) implementation and adoption of technologies, (3) JIT production, (4) logistics management, and (5) continuous improvement as well as future research questions for empirical work in these areas. Finally, this is followed by a summary and conclusion and the last section includes future direction.

## 2 Background

### 2.1 Lean Supply Chain Management (LSCM)

With globalization, companies have encountered the demand for higher quality products, at lower prices (Prado-Prado et al., 2020), and shorter lead times (Tortorella et al., 2017). To survive within increasingly globalized markets, companies compete through supply networks as competition will inevitably surpass geographic boundaries (Moyano-Fuentes et al., 2019).

Applying lean principles and practices to SCM can provide the needed global competitiveness that organizations seek. The concept of LSCM was first introduced by Womack and Jones in 1994 (Jasti & Kodali, 2015) and remains active in research. The number of LSCM articles between 1996 and 2018 have grown significantly (Garcia-Buendia et al., 2021) – this growth in studies continues.

LSCM can be further defined as “a set of organizations directly linked by upstream and downstream flows of products, services, information and funds that collaboratively work to reduce cost and waste by efficiently pulling what is needed to meet the needs of individual customers” (Vitasek et al., 2005).

LSCM has been adopted from lean manufacturing and extended, which is not a simple process due to many reasons. It is easier to determine and quantify waste in manufacturing in comparison to supply chains since the manufacturing processes are managed by top management while collaboration from suppliers to customers is needed for supply chains (Tortorella et al., 2018). Since the main cause of waste in SCM systems is information (Jasti & Kodali, 2015), LSCM allows a clear flow of products and information among supply chain partners without waste (Nimeh et al., 2018).

Through LSCM, organizations can establish closer relationships with their main suppliers (Jasti & Kodali, 2015) and build and manage long-term relationships with customers. This situation results in achieving the long-held goal of LSCM focusing on customer satisfaction (Kumar Singh & Modgil, 2020). Hence, lean implementation in supply chains provides integrity among suppliers and customers – an important factor to boost organizational competitiveness (Tortorella et al., 2018). LSCM moves away from defining short-term profit goals and negotiating strongly with suppliers and customers to building and maintaining long-term trusting relationships with partners with a focus on waste reduction along supply chains (Tortorella et al., 2018).

Lean is governed by principles that include legal aspects and ideal situations (Kumar Singh & Modgil, 2020). These can be conceptualized in varied ways. For example, Nimeh et al. (2018) define LSCM practices as just-in-time (JIT) systems, the flow of information, supplier relationships, customer relationships, and waste reduction. In another study, Moyano-Fuentes et al. (2019) determine LSCM practices mostly focus on suppliers and chain agents. In terms of suppliers, LSCM practices are defined by having a limited number of suppliers, selecting and evaluating suppliers based on their added value, defining supplier development programs, and involving suppliers in the product design.

Considering chain agents, building trustable relationships, sharing information, and frequently exchanging feedback with them to solve problems through collaboration are LSCM practices. The conceptual complexity of LSCM has been core to the scholarly debate. For example, Jasti and Kodali (2015) investigate 30 LSCM frameworks to find out the standard elements referring to lean production procedures, techniques, practices, and tools which are adopted by organizations to implement in supply chains. A total of 129 LSCM elements are recognized in their study – a characteristics of the many dimensions and complexity of LSCM. In another study, 27 main practices adopted in LSCM are identified and the relationships among them are investigated furthering the complexity of LSCM (Tortorella et al., 2018).

Although LSCM can increase responsiveness to demand variations, reduce operating costs (Jasti & Kodali, 2015), eliminate waste, improve quality (Garcia-Buendia et al., 2021), minimize the production lead time, increase competitiveness and success, improve performance outcomes (Nimeh et al., 2018), and enhance flexibility and efficiency (Moyano-Fuentes et al., 2019), the complexity of lean continues to pervade its orientation surrounding value for an organization. This predicament is only propagated through emerging industrial changes. Successful implementation of lean principles and practices largely depends on varied technology, as well as organizational and environmental factors (Tornatzky et al., 1990), showing that not all organizations have to accept a defined set of principles and practices (Tortorella et al., 2018) but yet an ever-fluid orientation.

## 3 On the Route to Industry 5.0

In an evolving world, industry is always seeking to increase production and manufacture objects more efficiently and effectively using new machinery, technology, energy sources, or a mixture of them. Historically, to address this concern, three industrial revolutions are already behind us, while the fourth is being experienced. The onset of the first industrial revolution (industry 1.0) took place in the late eighteenth century over the mechanization and use of steam power (Vinitha et al., 2020). The late nineteenth century marked the start of the second industrial revolution (industry 2.0) focusing on manufacturing mass production (Vinitha et al., 2020). The development of machines running on electrical energy distinguished the second industrial revolution from the previous one. In the age of the third industrial revolution (industry 3.0), which began in the 1970s in the twentieth century, industries entered automation through electronics and computer-controlled devices (Vinitha et al., 2020).

On the back of the first three industrial revolutions the fourth industrial revolution was first publicly announced at the Hannover Fair in 2011 by a working group from a project in the high-tech strategy of the German government (Xu et al., 2021). Industry 4.0 is defined as "a group of rapid transformations in the design, manufacture, operation, and service of manufacturing systems and products" (Davies, 2015).

Although industry 4.0 originated in Germany, it was widely adopted by other industrialized or industrializing regions such as the European Union, China, and India (Gilchrist, 2016). Different terms have also defined it including smart factories, smart industry, and advanced manufacturing (Davies, 2015). Industry 4.0 is considered a technology-driven revolution that results in higher efficiency and productivity (Xu et al., 2021), better quality, increased speed, and mass customization (Davies, 2015).

The concept of industry 4.0 centers around the use of technologies – for example, artificial intelligence, cloud computing, and sensors – to enact greater automated and integrated efficiency (Demir et al., 2019). While currently in the midst of industry 4.0, practitioners and academics are seeking to fill the problems associated with rapid pushes toward automation including the disintegrating use of human capital (Frederico, 2021). Threats involving job displacement, ideation, and creativity reduction continue to pervade the current industry 4.0 environment.

In addition to the social concerns, environmental concerns are another reason researchers and practitioners are continually adjusting and looking for new opportunities. Sarkis et al. (2020) points to the various paradoxes emerging among industry 4.0 – via the Internet of Things, blockchain, and quantum computing – and green supply chains including the promise for efficiencies enhancing greater unit usage over time.

Industry 5.0 utilizes the efficiencies of industry 4.0 but does so through a human-centric approach concentrating on resilience, sustainability, purpose, values, ethics, diversity, and the circular economy. Industry 5.0 is a more stakeholder-centric approach to industry 4.0's focus on automation for the purpose of creating value.

Similar to the concept of lean, academics and practitioners are questioning how value is conceptualized from both an industrial revolution and philosophical context.

From an industry 4.0 context, lean has been conceptualized and reconceptualized through a more efficiency-driven focus. Supply chains for decades have experienced challenges related to accuracy, integrity, and timely information flow. Lean concepts have only become more important in the current global crises and the crisis impacts on supply networks. There is no argument that industry 4.0 technologies, with the ability to use intelligent processes, collect and analyze autonomous data, and provide interaction between suppliers and customers (Rosin et al., 2020), can help networks integrate information and physical flows to supply chain processes (Núñez-Merino et al., 2020). In this regard, many researchers have considered lean thinking as a foundation for industry 4.0 and industry 4.0 as an enabler of lean effectiveness (Rosin et al., 2020).

However, with a focus on automation, and with either a narrow or contingent scope of value defined by scholars and practitioners, societal obligations – including economic, social, and environmental dimensions – are at risk. As a response, in January 2021, the European Commission formally released the document titled "*Industry 5.0: Towards a Sustainable, Human-centric, and Resilient European Industry*" (Xu et al., 2021).

This document details industry 5.0 as a systematic approach to integrating social and environmental concerns while focusing on human resources at the center of the production process, with an effort to reconcile the automation paradoxes presented by industry 4.0 (Nahavandi, 2019). Industry 5.0 provides a symbiosis of humans and machines in the workplace leading to effective collaboration between automation and human resources, with a goal of imposing waste and cost reduction through more efficient production processes (Nahavandi, 2019).

If we continue toward the path of globalization, a sole focus on profit maximization and process efficiency through automation may not equate to long-run optimal value for organizations. Instead a focus on prosperity through social, environmental, and economical considerations and a balance among all three (Yun et al., 2019) ought to be considered from a broader stakeholder perspective (Breque et al., 2015).

Industry 5.0 goes beyond profits and focuses on three main elements: human centricity, sustainability, and resilience (Breque et al., 2015). The human-centric approach considers humans as the main focus of the production process and aligns technologies with human needs and expectations (Breque et al., 2015). In this approach, workers are valued as investments not cost and technology is in the service of humans and societies (Xu et al., 2021).

Using new technologies should guarantee no violations of human resource rights, privacy, and dignity (Breque et al., 2015). New technologies should support worker well-being. The second industry 5.0 core value is sustainability which means to reduce energy consumption and greenhouse emissions and not to threaten future generational resources to address today's needs. Resilience which is the last core value of industry 5.0 refers to having a high level of robustness in production systems to be able to act efficiently and effectively against disruptions and natural crises (Breque et al., 2015).

LSCM plays a critical role in society by providing and exchanging goods and services between businesses and consumers in the most efficient way possible. Industry 5.0 can be leveraged to create value given its ability to connect highly automated and intelligent digital ecosystems with human resources. However, a clearer understanding of industry 5.0 as well as its associations with value as defined by LSCM is necessary to understand how a more human-centric approach to the automation focus of industry 4.0 can be realized (Frederico, 2021).

## 4 Difference Among SCM, LSCM, and LSCM 5.0

To better illustrate the difference between SCM, LSCM, and LSCM 5.0, we adopt comparisons proposed by Martínez-Jurado and Moyano-Fuentes (2014), and Myerson (2012) focused on the differences between SCM and LSCM. Then, we add LSCM 5.0 to their comparison as presented in Table 1.

LSCM 5.0 takes a middle approach to the inventory management problem identifying the paradox among high levels of inventory while maintaining optimal levels for purposes of building resiliency in supply (Fig. 1).

## 5 Emergent Concerns, Outstanding Research, and Future Directions

### 5.1 A Conceptualization of LSCM Through Industry 5.0: A Two-Dimensional Matrix

So far, different views on LSCM have been developed which have resulted in a wide variety of LSCM principles that may at times conflict (Jasti & Kodali, 2015). Further, there is no guarantee if the defined LSCM principles and practices are still robust enough to help firms to gain competitive advantage now and into the future. The conceptualization of industry 5.0 provides an opportunity for researchers and practitioners to revisit the lens of lean methods, principles, practices, and solutions and redefine them in a more applicable way to current issues.

We leverage the understanding of LSCM 5.0 further by enacting a two-dimensional matrix (Fig. 2) combining LSCM pillars with industry 5.0 core values to conceptualize an understanding of the evolution of LSCM through industry 5.0 concepts. Using this matrix, 15 LSCM principles and practices in the industry 5.0 environment are defined (Table 2).

The rows of the matrix show LSCM pillars including stakeholder management, technologies, JIT production, logistics management, and continuous improvement. To define the LSCM pillars, this chapter relies on the extensive literature review paper conducted by Jasti and Kodali (2015). According to their research, related LSCM principles and practices in terms of goals and target groups are classified into different groups named LSCM pillars.

**Table 1** Comparison among SCM, LSCM, and LSCM 5.0

| Characteristics | SCM | LSCM | LSCM 5.0 |
|---|---|---|---|
| Relationship patterns | Sporadic relationships | Trust-based collaborative relationships | Trust- and resilient-based collaborative relationships |
| Time horizon | Short term | Long term | Long term for strategic partners and short term for nonstrategic partners |
| Supply chain structure | Large-scale vertical integration | Low vertical integration | Collaboration |
| Suppliers | Multiple supply sources | Single or dual supply sources | Different groups of suppliers with different levels of importance |
| Supplier selection criteria | Mainly price-based criteria | Multifaceted criteria such as supplier capability and on prior relationship | Multifaceted criteria focusing on sustainability and agility in response |
| Technical support | Nonexistent focus or with limited scope | Supplier development programs | Stakeholder development programs |
| Communication and information sharing | Nonexistent or infrequent information sharing, limited feedback transfer | Frequent information sharing with open-door policies, frequent feedback transfer | Frequent information-sharing mechanism resistant to data distortion and tampering |
| Delivery practices | Not very frequent | Very frequent | Very frequent only for high-priority products/services |
| Quality | Less strict inspection process | Strict process inspection process | Strict process inspection process focusing on sustainability aspect |
| Risk and benefit approach | Low levels of shared risk and benefits | High levels of shared risk and benefits | High levels of shared risk and benefits |
| Order quantities | Large lots | Small lots | Medium lots |
| Inventory level | Large | Small | Medium |
| Value focus | Nonexistent focus or with limited scope | Waste reduction | Value maximization |
| Flexibility | Low | High | High |
| Demand | Push system | Pull system | Push-pull system |
| Trust | Limited | Extensive | Extensive |

Adapted from: Martínez-Jurado & Moyano-Fuentes, 2014; Myerson, 2012

Since LSCM 5.0 exceeds only focusing on customers and values a wide variety of stakeholders, the first LSCM pillar of the matrix is devoted to stakeholder management including customer management, human resource management, supplier management, and shareholder management. Considering the intersection of this pillar with industry 5.0 core values, six LSCM 5.0 principles and practices are introduced including seeking a strategic stakeholder value focus, seeking leadership, seeking lean supporting teams, seeking sustainable partner selection, seeking to have a small

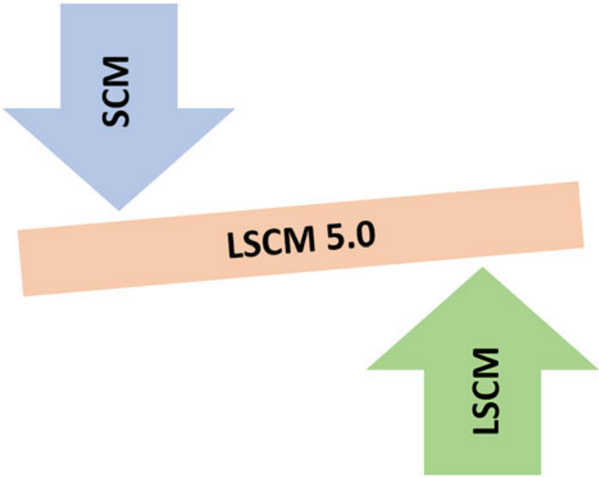


**Fig. 1** LSCM 5.0

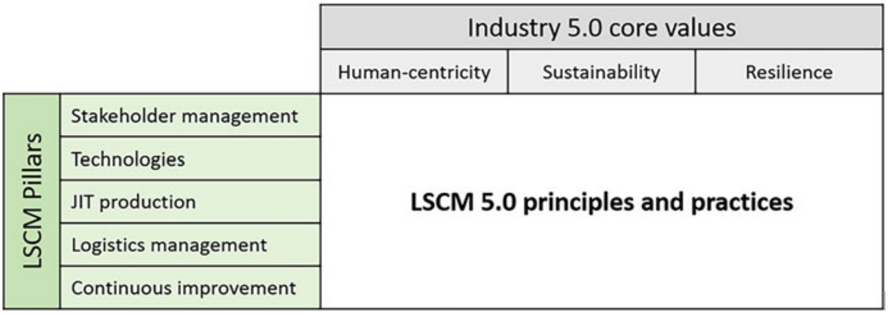


**Fig. 2** Two-dimensional matrix to define LSCM 5.0

number of reliable suppliers, and seeking to build and maintain ethical and trust-based alliances with partners.

Bridging aspects from industry 4.0 within an emerging industry 5.0 context, we identify the second LSCM pillar: technologies. To define LSCM principles and practices aiming to advance industry 5.0 core values, particularly sustainability and resiliency, there is a need to focus on industry 4.0 technologies such as blockchain, cloud computing, Internet of Things (IoT), etc. In addition, to leverage the human-centric aspect of industry 5.0, collaborative robot technologies (cobots) which put machines very close to human life is required. The concept of cobots means working intelligently by employing disruptive technologies hand in hand with employees to improve productivity, minimize waste, and achieve sustainable goals (Frederico, 2021).

Lean development resulted in emerging a set of waste removal guidelines named Just in Time (JIT) principles. The concept behind the term JIT is to effectively and

**Table 2** LSCM conceptualized through industry 5.0 (principles and practices)

| | Industry 5.0 core values | | |
|---|---|---|---|
| LSCM pillar | Human centricity | Sustainability | Resilience |
| Stakeholder management | Seek a strategic stakeholder value focus: In industry 5.0 environment, which is a full integration of human and intelligent systems, firms should shift from customer-centric value to stakeholder-centric value which is itself a step forward to increase customer satisfaction. Nowadays, customers seek products marked by human care and design, they are also willing to even pay more for these products. In an industry 5.0 environment, workers are as important as customers and their health, welfare, job security, and job satisfaction are firms' concerns. Other stakeholders such as shareholders, suppliers, etc. play critical roles in the success of firms. Hence, firms should go beyond the customer-centric value and create a balance of value for all their stakeholders. Value is not only about value-adding actions, and it constitutes the interactions of those actions as well (Browning & de Treville, 2021), focusing on stakeholders help organizations to better manage the whole value stream<br>Seek leadership | Seek sustainable partner selection: There is an increasing demand for sustainable products and services from customers and stakeholders. To meet this expectation, firms' strategic partners should adopt the sustainability concept and apply it to their products/services. Since logistics services can significantly affect the green and sustainable supply chain, evaluation and selection of third-party logistics providers from a sustainability perspective are vital (Raut et al., 2018). In addition to third-party logistics providers, suppliers also significantly affect the success or failure of supply chains and play a critical role in producing/offering sustainable products/services. Environmental, economic, and social factors in suppliers' selection should be considered not to produce waste (Hoseini et al., 2020) | Seek to have a small number of reliable suppliers (Schniederjans et al., 2018; Jasti & Kodali, 2015): Having a limited number of reliable suppliers reduces administrative costs and increases response speed due to the familiarity between the firm and its suppliers as a result of frequent contacts between them (Schniederjans et al., 2018). On the other hand, a limited number of suppliers may decrease supply chain resiliency since any failure to deliver products from suppliers to the firm may create critical problems for customers. To meet resiliency, different levels of suppliers should be defined. During a shift in demands period, short-term contracts with noncritical suppliers should be considered to keep the system responsive (Schniederjans et al., 2018)<br>Seek to build and maintain ethical and trust-based alliances with partners (Schniederjans et al., 2018): To achieve this principle, there are two approaches. First, to create and maintain |

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**Table 2** (continued)

| LSCM pillar | Industry 5.0 core values | | |
|---|---|---|---|
| | Human centricity | Sustainability | Resilience |
| | (Schniederjans et al., 2018; Jasti & Kodali, 2015):<br>For LSCM, high-level management support as a driving force is necessary. Successful leaders can provide accurate and sufficient information which avoids wasteful decisions (Schniederjans et al., 2018)<br>Seek lean supporting teams (Schniederjans et al., 2018):<br>Lean supporting teams such as lean training teams and lean problem-solving teams are necessary to help the implementation lean within supply chains (Schniederjans et al., 2018) | | ethical standards between the firm and its partners. This helps to reduce waste since low-quality products are not produced by suppliers as an example and as a result, no time will waste to return the unqualified products. Another approach is to build long-term contracts which help to create trust between the firm and its partners (Schniederjans et al., 2018). Defining ethical standards and building long-term contracts can decrease agility, so in order not to reduce the agility of supply chains, ethical standards should be defined and executed for main products. Also, long-term contracts should be built between firms and strategic partners not all |
| Technologies | Seek to use collaborative robots (cobots):<br>In industry 5.0 environment, the value focus is on human resources besides customers. Cobots are used to enhance the work atmosphere for human resources while they help firms to increase their efficiency and productivity. Cobots can do dull, dirty, dangerous, and difficult parts of jobs while human resources can focus more on managerial, innovation, | Seek to use industry 4.0 technologies to increase sustainability (and not focus on just economies of scale):<br>Using industry 4.0 technologies leads to increase sustainability since (Bai et al., 2020):<br>Considering the economic dimension, they decrease lead times, labor, and customers costs, and increase production flexibility and productivity<br>Considering the environmental dimension, they can | Seek to use industry 4.0 technologies to increase resilience:<br>Using industry 4.0 technologies leads to increase supply chain agility and as a result supply chain resilience since:<br>They help supply chains to respond to customers' needs and expectations and market opportunities faster and more efficiently<br>They help supply chains to have access to the most updated and accurate information: (1) valid information |

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**Table 2** (continued)

| | Industry 5.0 core values | | |
|---|---|---|---|
| LSCM pillar | Human centricity | Sustainability | Resilience |
| | and creativity sides. The cooperation results in creating more efficiency without minimizing job opportunities. In addition, this rapidly changing environment intensifies the need to use cobots to keep supply chains responsive to market needs and being lean. During the covid-19 pandemic, issues like social distancing or unexpected time off come to attention. In these circumstances, cobots can be managed remotely. Thus, supply chains bear the least damage | decrease energy and resource consumption because of their ability to analyze data across supply chain processes. In addition, they play an important role in waste and $CO_2$ emission reduction, for example, due to traceable carbon footprint analyses<br>Considering the social dimension, they help employee health and safety by doing dangerous and harmful jobs for humans | allows supply chains to predict demands correctly which leads to a reduction in overproduction and inventory waste, and (2) accurate information provides visibility into every stage of supply chains. This visibility allows firms to continually monitor each stage such as production, warehousing, transportation, retailing to identify waste, and plan to eliminate it. Also, precise information increases the ability to analyze supply chain problems, bottlenecks, and detects to be well prepared to mitigate potential disruptions |
| JIT production | Seek JIT training for employees:<br>All human resources in different positions and roles do not need to learn the same skills and knowledge at the same time. JIT training refers to learning new skills and knowledge only when human resources need them. On-demand training helps human resources to enhance their knowledge and skills most efficiently. No financial costs are wasted using JIT training. In addition, JIT training can improve human resources performance since employees can apply | Seek a push-pull system:<br>Demand-pull systems reduce waste since whatever is produced will be consumed. Using this system, first, customers must place an order, then the request will be sent back upstream from the final customer (Schniederjans et al., 2018). While JIT inventory management reduces inventory, it increases transportation activity which leads to an increase in greenhouse gas emissions (Ugarte et al., 2016). A push-pull system can reduce waste | Seek standardizing work procedures for a few products or services within the firm (Schniederjans et al., 2018):<br>One of the lessons of JIT principles is to establish trust in supply chains (Schniederjans et al., 2018). Standardization of work procedures increases trust while decreasing agility in supply chains. Since, under industry 5.0 environment, firms need to be flexible to address change in customers' demands, standardization should be only adopted for a few products or |

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**Table 2** (continued)

| | Industry 5.0 core values | | |
|---|---|---|---|
| LSCM pillar | Human centricity | Sustainability | Resilience |
| | what they have learned to their work | while improving environmental sustainability | services. A trade-off between responsiveness and trust should be considered.<br>Seek production leveling and scheduling (Tortorella et al., 2018; Jasti & Kodali, 2015):<br>One of the main sources of waste is variation in production which causes wasted cost, time, and effort. Production leveling is used to decrease the unevenness of the production process and, as a result, reduce waste. Production scheduling may decrease quick responsiveness to the market. Once resources such as materials and staff are scheduled to work, it would be difficult to change the process to align with new demand. Thus, a trade-off between responsiveness and uneven production flow is needed<br>Seek a push-pull system:<br>A pull system may lead a company to run into ordering dilemmas that make the firm unable to be quickly responsive enough to fulfill customers' orders. On the other hand, push systems lead to too many products left in inventory and waste creation. A push-pull system can reduce waste enhancing speed |

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**Table 2** (continued)

| LSCM pillar | Industry 5.0 core values | | |
|---|---|---|---|
| | Human centricity | Sustainability | Resilience |
| | | | response to market demand |
| Logistics management | | Seek to shortening lead time for only some products/services: Short lead time can reduce inventory level and as a result waste. At the same time, short lead time leads to more transportation which means more greenhouse gas emissions. Thus, short lead time may negatively affect sustainability. In LSCM 5.0, providing short lead time should be only for high-priority products/ services not all | Seek to eliminate supply chain flow constraints (Schniederjans et al., 2018): Flow constraints and bottlenecks within supply chains can result in system inefficiencies and poor supply chain performance. So, they should be identified and appropriate solutions to overcome them should be adopted (Schniederjans et al., 2018). Removing flow constraints and bottlenecks leads to a stable flow of products in which waste is eliminated and responsiveness to markets is improved |
| Continuous improvement | | Seek to create a sustainable supply chain value stream mapping (Gargalo et al., 2021): Mapping current flows of materials and information help to identify three groups of activities: value added, nonvalue added but necessary, and wastes (Boonsthonsatit & Jungthawan, 2015). Sustainable value stream mapping extends value stream mapping to include environmental, social, and sustainable manufacturing aspects (Gargalo et al., 2021) and can be obtained by omitting the identified wastes in current flows. | |

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**Table 2** (continued)

| LSCM pillar | Industry 5.0 core values | | |
|---|---|---|---|
| | Human centricity | Sustainability | Resilience |
| | | Sustainable value stream mapping allows to identify of wastes and decreases them on an ongoing basis | |

efficiently utilize resources just in time for their use. When all resources arrive just in time for their consumption, no unnecessary movement of materials, equipment, and products occur, and subsequently, no waste is produced (Schniederjans et al., 2018). Within the third pillar, the JIT production, five LSCM 5.0 principles and practices including seeking JIT training for employees, seeking a push-pull system, seeking standardizing work procedures for a few products or services within the firm, seeking production leveling and scheduling, and seeking a push-pull system are defined.

Considering the impact of inbound logistics on timely manufacturing products and outbound logistics on customer satisfaction (Edirisuriya et al. 2018), eliminating nonadded values activities in transportation, storage and warehousing, packaging and unitization, etc. leads to advancement in entire supply chains. Given the fourth pillar, two LSCM 5.0 principles and practices such as seeking to shorten the lead time for only some products/services and seeking to eliminate supply chain flow constraints are presented.

Continuous improvement, the fifth pillar, is a key element to achieving excellence in LSCM practices (Jasti & Kodali, 2015). In the context of LSCM 5.0, continuous improvement seeks to advance processes in SCM by focusing on enhancing principles and practices that create the most value for varied stakeholders, boost sustainability, and strengthen resiliency while minimizing waste in supply chains. The intersection between the continuous improvement pillar and industry 5.0 core values defines seeking sustainable supply chain value stream mapping as the last LSCM 5.0 principles and practices.

The columns of the matrix show three core values of industry 5.0 – human centricity, sustainability, and resilience. As discussed in this chapter, human centricity value targets to create a collaborative working environment between humans and machines in which human creativity and machine intelligence are combined. Focusing on this value takes away dirty and repetitive tasks from humans and empower them through collaborative learning. Sustainability, the second column of the matrix, is defined as "the balanced and systemic integration of intra and intergenerational economic, social, and environmental performance" (Geissdoerfer et al. 2017). It focuses on creating circular processes to reuse and recycle natural resources to eliminate waste and decrease environmental impact (Breque et al., 2015).

Lastly, resilience acts as guidance for LSCM as well as the development of the matrix. While various definitions of supply chain resilience exist, we borrow from

Ponomarov and Holcomb's (2009) definition: "the adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions and recover by maintaining continuity of operations at the desired level of connectedness and control over structure and function." Building on this definition, we can be informed by the identification of four principles (Christopher & Peck, 2004): (1) supply chain reengineering, (2) collaboration, (3) agility, and (4) supply chain risk management culture.

Since agility is one of the most essential aspects of resiliency (Kamalahmadi & Parast, 2016), redefining LSCM 5.0 principles and practices requires an understanding of the alignment between lean and agility in supply chains. Lean and agility are strategies targeted at two different goals to improve SCM. Lean, as discussed, aims to omit nonadded value activities and can be applicable for predictable demand with limited variety. However, agility is "the ability of a supply chain to rapidly respond to change by adapting its initial stable configuration" (Wieland & Wallenburg, 2013) and is suitable for volatile environments (Nayak & Choudhary, 2022).

Despite varied goals of lean and agility, they have a complementary relationship (Fadaki et al., 2020) leading to the emergence of a paradigm, leagility. It is defined as "integrating the lean and agile manufacturing paradigms in the total supply chain"' (Naylor et al., 1999) where leanness can be decoupled from downstream and employed upstream while agility can be applied in the remaining downstream (Bhamra et al., 2021). According to a survey conducted by Fadaki et al. (2019), 90.3% of Australian firms adopted leagile supply chains rather than purely lean or purely agile supply chains. Their preference may root in the fact that lean and agility combination allows for achieving "the best of both worlds" (Naim & Gosling, 2011).

In the rapidly changing world, lean may need to be evolving over time to address today's needs and be aligned with future expectations. With emerge of industry 4.0, researchers started to view LSCM from a technological perspective (El Jaouhari et al., 2022; Rossini et al., 2022). However, besides the technological aspect, there is a need to expand LSCM principles and practices from other curtail aspects such as human centricity, sustainability, and resilience. These new perspectives may cause a shift in LSCM value creation from mainly focusing on waste minimization to a broader nature of value. In this regard, Table 2 creates an understanding of industry 5.0 and its association with the value defined by LSCM.

## 6 Managerial Implications

With significant increases in automation brought about by the rapid advances in technologies (i.e., artificial intelligence, machine learning, 5G, augmented reality, drones, etc.) companies that strategically deploy these technologies have been provided never-before-seen levels of visibility as well as the ability to streamline almost every transaction and movement of material. Examples of this range from NielsenIQ (a customer relationship management data organization) leveraging image recognition, deep learning, and robotics as well a creation of best-in-class cloud (PaaS) technologies for the purpose of data lake storage allowing for accelerated coverage expansion as well as integrated measurement of various channels for clients (Dol, 2021).

While these and other examples exist, ultimately, supply chains are more than just key performance indicators. They are more than numbers in cash-to-cash cycle time, fill rates, on-time deliveries, customer order cycle time, and inventory turnover. Supply chains, in the end, are about people. At the very start and in the end of each network is a buyer and supply chains exist to serve their needs. Doing so requires a network of collaborators and intelligence involving thousands upon millions of individuals that provide a basis for enhancing customization, customer satisfaction, reducing risk and waste, enabling logistics functions to optimize time of strategic experimentation, improving integration of strategic partnerships and gaining more value through retaining, and transferring knowledge across various characteristics.

This chapter provides a framework for practitioners detailing industry 5.0 values and action guides for organization when it comes to: (1) stakeholder management, (2) implementation and adoption of technologies, (3) JIT production, (4) logistics management, and (5) continuous improvement. While this book chapter advocates taking a long-term approach in these initiatives, understandably, companies will continue to have to balance both the short-term and long-term pressures from investors.

As one example, the Securities Exchange Commission issues a rule that requires publicly traded companies to disclose climate financial risks to all investors. Organizations now assess and mitigate climate-related transition and physical risk as well as strategies on enhancing resilience and shifting to a reduced carbon future. This includes both short-term and long-term actions. Over 40 companies have already supported the net-zero infrastructure package with targets set to 2050 and with most G20 countries pledging carbon neutrality by 2050 or 2070 (Financial Times, 2021). While infrastructure is strong and has the power to transition to net zero, the knowledge and pathways are under pressure to “build neutral now” in order to meet emissions targets (Financial Times, 2021). Unfortunately, these pressures can lead to issues related to companies pursuing green washing. This in turn creates distrust among stakeholders and end consumers leading to a loss of value in the beginning and end of the network. Technologies can be leveraged to mitigate these issues while at the same time providing integration mechanisms across boundaries that allow for greater trust and assurance leading to enhanced value among the individuals that make up the entirety of the value chain. The values provided in this chapter serve as a starting point for these organizations that face both short-term and long-term pressures in order to optimize value.

However, change is both difficult and inevitable. When the future is uncertain, it can lead to various stresses and impacts on systems, governance, and individuals. LSCM has – and we believe will continue – to provide useful guidelines in reducing the number of issues that arise from rapid change. Yet, it is the obligation of the individual to rethink and reevaluate the efficacy of these methods based on the context in which it is presented.

## 7 Research Implications

There is still much work needed to accurately conceptualize LSCM 5.0 given that the call to rethink LSCM (and its definition of value) is still questioned as well as the infancy of industry 4.0 and its potential successor industry 5.0 is still only a concept. Future research can enhance the 15 LSCM 5.0 principles and practices defined in this research through addressing and refining our understanding of the following:

First, lean is no more limited to the manufacturing industry where it first emerged from. Varied flavors of lean exist for different industries in supply chains such as transportation (Parajuli et al., 2022), warehousing (Shaikh et al., 2020), and retailing (Lukic, 2012). Although adopting lean is a universal approach in different industries, the most relevant, necessary, and applicable LSCM 5.0 principles and practices may differ depending on financial, temporal, and managerial limitations and a wide variety of needs and concerns of organizations. For example, an organization focusing on sustainability as its main goal may put a higher priority on seeking sustainable partner selection than an organization focusing on profitability. Another example is an organization with a lack of financial resources may not be willing to adopt industry 4.0 technologies as a LSCM 5.0 practice to improve its resiliency due to the high adoption cost (Sarkis et al., 2020). Hence, more research is needed to identify and prioritize the required applicable LSCM 5.0 for organizations in different industries.

Second, considering the sustainability value of industry 5.0, most LSCM 5.0 principles and practices are defined focusing on the environmental dimension. Hence, what are LSCM 5.0 principles and practices aiming to improve the economic and social dimensions of sustainability? Another question can be how to integrate sustainability dimensions, especially when trade-offs exist. For example, using industry 4.0 technologies can boost the social sustainability dimension by taking away dangerous work from employees to retain their health and safety. However, it can also negatively affect environmental sustainability due to air pollution and exhaustive use of raw materials and energy (Oláh et al., 2020).

Examples of tools leveraging games and system dynamics have enhanced optimization of donations and social good from a humanitarian perspective in times of uncertainty (see Ozpolat et al., 2015). What other tools might be available to enhance social considerations during rapid technological change?

During times of disruptive innovation, the use of analytics and machine learning will likely play a larger role in various decisions including product positioning and pricing (see Chen & Ni, 2020). How might discrete choice modeling be used to further optimize organizational decisions while maintaining values?

Future research might also consider the role (or lack thereof) of policy in enhancing the benefits achieved by LSCM 5.0.

More important than perhaps policy (or related to) might be the role of investment in education and workforce development in promoting the benefits of automation while doing so within a humanistic perspective. What is the role of higher education in training the workforce in this rapidly changing environment? How must policies adjust to the ever-changing infrastructure and environment. As just some examples: How might legal frameworks be adapted to advance transformation of economic systems? How might public funding schemes be redesigned or made more flexible? (EU, 2022).

## 8 Summary and Conclusion

Nearly 30 years have passed since LSCM was introduced. During these 30 years, supply chains have undergone many changes. International relations, policy-driven cooperation among firms, the emergence of new technologies, and unpredictable and fast-changing markets each has added more complexity to supply chain performance.

Issues outside supply chains scope can also affect supply chains severely and augment more complexity. Global pandemics have posed immense challenges for supply chains due to disruption in the flow of materials, fluctuations in demand, lack of resources, etc. According to a survey conducted by McKinsey & Company in 2020, 93% of senior supply chain executives expressed that they intended to make their supply chains more flexible, agile, and resilient. With new industrial revolutions on the horizon with a potential focus on humans, sustainability, and resilience lean scholars and practitioners need to reimagine concepts of LSCM in future dynamic environments. We thus review the values, goals, principles, and activities of LSCM 5.0.

In this chapter, we conceptualized LSCM through an industry 5.0 concept via a matrix presentation specifically focusing on human centricity, sustainability, and resilience. We hope that researchers and practitioners can leverage this information as well as the questions presented above to detail how we might rethink and reevaluate LSCM through new and emerging concepts during times of rapid change to create value from a larger stakeholder context now and into the future.

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# The Role of Quality Management in Healthcare

## A Supply Chain Perspective

Hale Kaynak, Subhajit Chakraborty, and José A. Pagán

## Contents



**Abstract**

In this chapter we first highlight the pressing supply chain management issues plaguing the US healthcare. Because hospitals play a critical role in the healthcare ecosystem and continuous improvement, quality leadership, teamwork, and

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supplier relations are key factors in managing healthcare quality, hospitals are at the center of our research. Proceeding with a conceptual representation of a typical US hospital supply chain in mind, we offer a conceptual framework depicting hospital quality management practices and quality performance. Finally, we discuss two major emergent concerns and research areas in healthcare – population health management and managing stressful environments in healthcare – and offer our insights drawn from quality management in the context of the US healthcare supply chain.

**Keywords**

Healthcare supply chain · Patient-centric hospital · Core processes · Quality outcomes · Population health management · Stressful healthcare environment

## 1 Introduction

The persistence of medical errors is a major issue in healthcare delivery (Heath, 2019) despite the rapid growth in healthcare quality assurance and performance improvement efforts by healthcare systems in recent years. According to the report *To Err is Human: Building a Safer Health System* by the Institute of Medicine (IOM), as many as 98,000 hospital deaths due to medical errors occur per year (Donaldson, 2008). The Fifth Annual HealthGrades Patient Safety in American Hospitals Study (2008) estimated that from 2004 through 2006 more than 220,000 incidents and over 37,000 deaths among hospitalized Medicare patients might have been preventable (p. 6). The following year, HealthGrades, also focusing on Medicare patients during the same period, released a report that estimated as many as 171,424 lives might have been saved and 9,671 major complications might have been avoided if these patients were treated at hospitals performing at the level of Distinguished Hospitals for Clinical Excellence (HealthGrades, 2008 p. 2).

Research findings show that based on patient safety measures, patient care has significantly improved in recent years. According to data collected by the Agency for Healthcare Research and Quality (AHRQ), hospital-acquired conditions (HACs) have consistently decreased over time. Findings show that between 2014 and 2017, HACs dropped 13%, cut $7.7 billion in costs, and saved an estimated 20,500 lives. These improvements in performance built on earlier advances. Between 2010 and 2014, the healthcare industry recorded 2.1 million fewer HACs than in previous years. However, many problems still affect the safe and effective delivery of healthcare services. A Johns Hopkins report notes that "patient safety mistakes accounted for nearly 250,000 patient deaths," greater than the death toll from respiratory disease by nearly 100,000 incidents (Heath, 2019). It may be noted that even though patient safety has emerged as a key aspect of healthcare quality (Pronovost et al., 2006), many detailed quality metrics based on specific health conditions (e.g., stroke, pneumonia, and cardiac arrest), length of hospital stay, and hospital readmission rates have become popular as standardized metrics to measure healthcare quality.

While increasing quality improvement efforts is an important goal in healthcare, decreasing healthcare costs is also critical to have sustainable and equitable healthcare delivery systems. US healthcare is the most expensive per capita among the Organization for Economic Co-operation and Development (OECD) countries (Statista, 2022). In 2019, the *Journal of Operations Management* published a special issue on "delivering effective healthcare at lower cost." Supply chain management (SCM) in healthcare has been considered one area in which cost can be reduced by synchronizing the flow of information and goods throughout the entities in a chain (Chakraborty & Gonzalez, 2018). The critical effect of SCM on healthcare operations has become more apparent during the COVID-19 pandemic. Improving the quality of services available to patients and effectively managing supply chains while reducing costs are currently three pressing needs of the US healthcare system.

In this chapter, we explore quality management and the supply chain of US community hospitals to better understand quality challenges in the US healthcare delivery system. The American Hospital Association defines community hospitals as "all nonfederal, short-term general, and other special hospitals. Other special hospitals include obstetrics and gynecology; eye, ear, nose, and throat; long term acute care; rehabilitation; orthopedic; and other individually described specialty services. Community hospitals include academic medical centers or other teaching hospitals if they are nonfederal short-term hospitals" (AHA, 2022a). The chapter provides an overview of the extended healthcare supply chain of hospitals, care processes, relationships among hospital quality management practices and quality performance, a discussion about population health management and lean systems, and some insights on stressful environments and healthcare quality.

## 2 Background: An Overview of a Hospital's Extended Healthcare Supply Chain

Healthcare is a complex activity that is dependent on the medical treatment processes followed to cure a patient's health condition. During diagnosis and medical treatment, knowledge that physicians rely on depends to a large extent on the philosophy of their medical school education and the specific objectives of a given hospital (i.e., whether the hospital is a teaching, physician-owned, or nonprofit hospital) (Bohmer, 2009). These considerations pose additional challenges to delivering high-quality patient care (Bohmer, 2009).

Many healthcare experts and other stakeholders now agree that hospital SCM is crucial to improving the performance of US healthcare systems (Buttigieg et al., 2020). Although the cost of facilities, clinical support, and their administration still form the major components of total healthcare costs, 20.6% for the cost of supplies is a significant amount, and it is rising every year (AHA, 2022b). Managing supply chains effectively (and therein quality management of the healthcare supply chain as well) is critical to controlling and maintaining the quality and cost of medical supplies. In the context of healthcare, SCM includes both the internal chain (e.g.,

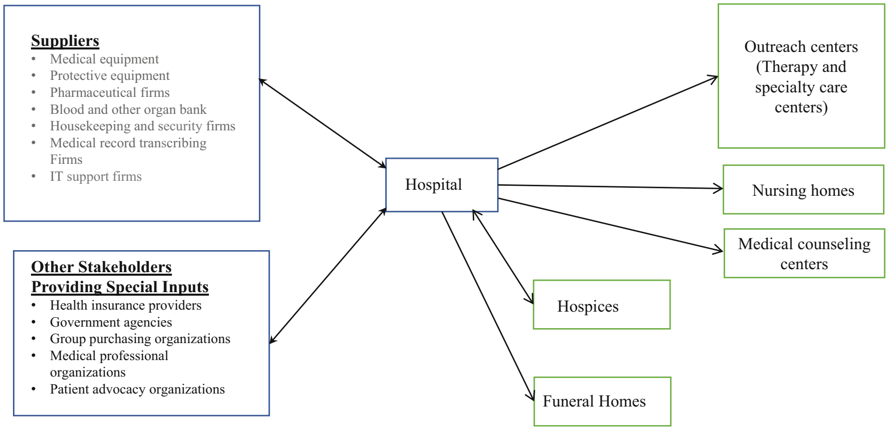


**Fig. 1** A schematic diagram of a typical U.S. hospital's extended healthcare supply chain. (Adapted from Chakraborty and Gonzalez (2018))

patient care unit, hospital storage, and patient) and the external chain (e.g., vendors, manufacturers, and distributors) (Denton, 2013).

Keeping patient flows in mind, a conceptual depiction of the current US healthcare supply chain is presented in Fig. 1. The upstream of a typical US hospital supply chain consists of two entities: (1) suppliers and (2) other stakeholders providing special inputs (Chakraborty & Gonzalez, 2018). Medical equipment firms provide medical and other related types of equipment (e.g., beds) required by hospitals, doctors, and nurses for treating patients. These are broadly classified into the following seven categories: storage and transport medical equipment, durable medical equipment, diagnostic medical equipment, electronic medical equipment, surgical medical equipment, acute care equipment, and procedural medical equipment. Also included in the supply chain are firms that provide furnishings and supporting materials for patients such as curtains and bed sheets and personal protective equipment (PPE) for healthcare team members. Hospital staff wear PPE to reduce the potential for injuries resulting from being exposed to workplace hazards, medical and mechanical, commonly found in hospitals. This protective equipment includes items such as shoes, safety glasses, respirators, and gloves, among other equipment. A pharmaceutical firm could be involved in developing, producing, and marketing drugs licensed for use as medications. Pharmaceutical companies are permitted to sell and distribute generic and/or brand medications and medical devices. Dosage forms include tablets and capsules, injectables, creams, ointments, inhalants, and solutions.

Blood bank refers to the division of a hospital laboratory where blood products are stored, and compatibility testing is performed before transfusion and may also process blood donations, depending on the capabilities of the facility. The term also includes other organ banks such as eye banks, which retrieve and store eyes for corneal transplants and research, and amniotic stem cell banks, which store stem cells derived from amniotic fluid for future use. Housekeeping and security firms provide environmental services such as security services and housekeeping services that include cleaning rooms, medical equipment, and laundry. These firms also stock and keeps track of basic hospital amenities in hospital rooms, especially in the emergency rooms and intensive care units. Medical transcription is the process of converting voice-recorded reports as dictated by transcribing firms, physicians, and other healthcare professionals into text. A few specialized firms provide such transcription services to their clients. Information technology (IT) support firms typically provide some or all IT services, from computer support, IT consulting, IT outsourcing, helpdesk services, data backup, disaster recovery, application hosting, and email hosting to chief information officer–level consulting, managed services, and call centers.

Health insurance providers are firms that provide health insurance services. Health insurance protects a patient from the prohibitive cost of medical care by providing coverage for providers of specific healthcare services. The three broad types of health insurance are: consumer directed, fee-for-service (often known as "indemnity" plans), and managed care. These plans cover medical, surgical, and hospital expenses. Some cover prescription drugs and offer dental and behavioral and mental health coverage as well. Government agencies that monitor and test product safety include the Food and Drug Administration (FDA), the Centers for Disease Control and Prevention (CDC), and the Department of Defense's Office of the Surgeon General. Agencies that monitor the operation of healthcare programs such as Medicare and Medicaid are authorized to audit, investigate, and inspect any facility.

A group purchasing organization (GPO) is an entity that helps healthcare providers such as hospitals, nursing homes, and other health agencies realize efficiencies by aggregating purchasing volume into bulk and using that leverage to negotiate discounts with suppliers. As measured by the total number of member hospital beds, Premier Inc., MedAssets, Vizient, Intalere, Cardinal Health, McKesson Pharmaceutical, AmerisourceBergen, HealthTrust Purchasing Group (HPG), the Department of Veterans Affairs, and Provista are some of the large GPOs. Professional associations such as the American Medical Association (AMA) help doctors by uniting physicians and medical students to work on the most important professional and public health issues. Professional fraternities are organizations whose primary purpose is to promote the interests of a particular profession and whose membership is restricted to students in that particular field of professional education or study. Common medical fraternities are Phi Beta Pi, Theta Kappa Psi, Phi Delta Epsilon, Phi Rho Sigma, and Phi Chi. Patient advocacy organizations are nonprofit organizations that provide patients a voice in improving access to and reimbursement for high-quality healthcare through regulatory and legislative reform at the state and federal levels. Examples are National Patient Advocate Foundation, HealthHIV, and the National Association for Hearing and Speech Action.

At the center of a typical US healthcare supply chain is the hospital, which is generally the primary facility for most healthcare services that any person receives, ranging from diagnostic services to surgery to continuous nursing care and advanced disease and other medical treatments. Hospitals vary from small, free-standing rural facilities to a vast, multifacility, geographically dispersed but integrated system. Some hospitals specialize in the treatment of a particular disease such as HIV/AIDS, cancer, or for particular types of procedures such as cardiology and heart surgery. Others are full-service hospitals that prioritize medical treatment for most ailments.

Next, moving to the downstream side of a typical US hospital supply chain, discharged patients who are not fully cured may need such specialized services as outreach or medical counseling centers, or they may be candidates for a nursing home. Patients that die in the hospital are sent to funeral homes. Hospices provide medical care for people with an anticipated life expectancy of 6 months or less, when a cure is no longer possible, and the focus of care shifts to symptom management and quality of life.

Outreach centers can provide both therapy and specialty care. Therapy centers provide developmental and rehabilitation services such as speech-language therapy, pediatric occupational therapy, and pediatric physical therapy services. Specialty care centers provide high-quality medical services such as radiation treatment, stem cell care centers, transplantation, and cellular therapy. A nursing home is a residence for people who require constant nursing care and have deficiencies that render them incapable of performing the activities of daily living. Residents generally are elderly and younger adults with physical or mental disabilities. Patients in a nursing facility could also receive physical, occupational, and other rehabilitative therapies following an accident or illness. Medical counseling centers generally take a team approach to patient care in which psychiatrists and other therapists regularly collaborate on a patient's care to determine the best treatment option. Patients in medical counseling centers are primarily those who suffer from such disorders as depression, bipolar anxiety, panic attacks, obsessive-compulsive disorder (OCD), or from life-threatening diseases such as HIV or cancer. These centers typically offer a variety of services, from medication management to counseling on how to cope with a patient's affliction.

## 3 Care Processes in Patient-Centric Hospitals

As in all service processes (Jacobs & Chase, 2020), the customer (patient in healthcare) is the focal point of hospital operations. Doctors, nurses, and all other infrastructure support systems are designed to serve the patient in the most effective and efficient manner. The infrastructure support system includes all departments and units in a hospital. Other care processes include internal stakeholders that receive the services – patients and their friends/relatives as well as those who provide the services such as physicians, nurses, and support staff.

As we will discuss in the next section, to provide high-quality patient care, all these processes need to be designed keeping quality management (QM) principles in mind. In other words, QM must be the foundation of care hospital processes.

## 4 Quality Measurement in Hospitals

QM is defined as a holistic management philosophy that guides continuous improvement in all functions of an organization (Kaynak, 2003). In healthcare settings, in order to implement QM, hospitals need to strive for continuous improvement, beginning with the acquisition of resources to the care of patients and other stakeholders. The Malcolm Baldridge National Quality Award (currently known as the Baldrige Excellence Award) was established in 1987 (Kaynak, 1997) to encourage quality improvements in firms**,** and it was followed by the European Foundation Quality Award in 1988 (Nabitz et al., 2000), which also encourages quality improvements in firms. In 1998, the scope of the Malcolm Baldridge National Quality Award was expanded by the US Congress to include the healthcare industry (Baldrige, 2022). Since then, many healthcare organizations in the USA, Europe, and around the globe apply the quality improvement efforts introduced in these frameworks, even during the COVID-19 pandemic (Shah et al., 2021). The results of a study by Shah et al. (2021) show that the use of quality improvement approaches by healthcare organizations increased during the COVID-19 pandemic in England.

In this chapter, we discuss the relationships among QM practices implemented in a hospital and quality performance measures drawing from the extant literature in healthcare, particularly from the arguments in Chakraborty and Kaynak (2018), Chakraborty et al. (2021), and Kaynak and Hartley (2008). Suggested practices also have been documented in numerous studies that have investigated the implementation of QM in healthcare organizations (see Table 1 for major studies). We identify eight QM practices in the context of hospitals – hospital quality leadership, healthcare training, healthcare teamwork, hospital quality data and reporting, patient focus, supplier quality management, hospital services design, and hospital process management. These healthcare-applicable QM practices, along with the major studies that discuss these practices, are indicated in Table 1. Although there are similarities between the practices in our framework and those shown in Malcolm Baldridge, some differences are also evident. For example, the Malcolm Baldrige healthcare criteria for 2021–2022 does not identify supplier quality management as a distinct practice of QM, although some related questions are included under strategy development. Furthermore, patient care and patient satisfaction are not clearly differentiated. Thus, we believe that the QM practices we offer are more detailed and informative than those in the Malcolm Baldridge framework.

One of the most important antecedent variables is hospital quality leadership. The structure that leaders impose on an organization and the care they take to provide daily encouragement to all levels of staff are crucial to the successful implementation of quality in an organization. Different resources are necessary for training people in the use of new principles and tools and creating a work environment in which employees are engaged with changes in the organization and its work culture (Kaynak, 2003). Stable processes are essential to maximizing patient satisfaction and success in the marketplace, a principle a quality leader recognizes (Smith, 2018). It is the hospital leadership’s responsibility to implement practices that will improve the quality of patient care.

**Table 1** Quality management (QM) practices implemented in healthcare organizations

| QM Practices | Definition | Recent healthcare studies |
|---|---|---|
| Hospital quality leadership | Hospital leaders' acceptance of quality responsibility. It refers to the participation in quality improvement efforts and direction to workers and managers by senior management, having specificity of quality goals, with importance attached to quality in relation to cost and schedule and comprehensive patient care quality planning | Chakraborty et al. (2021) |
| Healthcare training | Quality-related training and statistical training for hospital management and all healthcare (HC) employees | Zaka et al. (2020) |
| Healthcare teamwork | Implementation of employee involvement and teamwork, open employee participation in quality decisions; continuous quality awareness of all HC employees; responsibility of HC employees for quality; recognition of HC employees for superior quality performance | Rosen et al. (2018) |
| Hospital quality data and reporting | Timely and reliable quality measurement; availability and timeliness of quality data to HC employees and managers for problem solving; use of poor-quality cost data to manage healthcare quality | Geraedts et al. (2018) |
| Patient focus | Continuous assessment of patients' needs; use of patient feedback surveys, focusing on achieving greater patient satisfaction | Greene et al. (2012) |
| Hospital supplier quality management | Timely and accurate delivery of supplies; reliance on supplier quality system; coordination and cooperation between internal and external suppliers and hospitals and HC employees (internal customers) | Priestman et al. (2019) |
| Hospital services design | Patient hospital services design based on patient preferences; involvement of all affected departments in hospital services design and reviews; review and test of new hospital services prior to their introduction to patients | Zepeda and Sinha (2016) |
| Hospital process management | Hospital service process management for continuous service quality improvement; use of statistical process control; fail-safe process design; use of preventive quality controls to provide quality hospital services | Smith (2018) |

Table is adapted from Kaynak and Hartley (2008)

Hospital leaders' awareness of all risks associated with improper patient care procedures and ensuring that staff at all levels understand these risks and how to mitigate them is essential to the creation of an environment in which patient safety initiatives can take hold (Saint et al., 2010). A critical practice of both QM and SCM is the interaction with customers (Robinson & Malhotra, 2005), and the development of strong relationships with patients or customers, and customer (patient) focus is a function of quality leadership. Creating policies and designing structures that create a work environment in which the attention of employees – physicians, nurses, and healthcare teams – is focused on serving the customer is a crucial function of hospital leadership.

Patient feedback surveys could be used to promote patient involvement thereby improving quality of care. Patient satisfaction can be improved if quality leaders make consistent effort to focus on and assess patient needs (Asif et al. 2019). Effective management of relationships with key suppliers is essential to SCM, especially in life-threatening situations such as those encountered often in hospitals. It is hospital leaders' responsibility to ensure an elevated level of integration when designing healthcare services not only within the hospital but also across the hospital supply chain. Hospital administrators manage a wide range of suppliers serving all functions in a hospital, and effective leadership can promote mutually beneficial relations with these suppliers by emphasizing quality and delivery performance over price when developing, selecting, and certifying them for quality of supplied materials or items. Moreover, both hospitals and their suppliers can benefit from facilitating the exchange of proprietary and competitive information.

Training increases staff engagement with the attention to quality-related issues. Healthcare staff need to be trained on the collection and use of quality data, but training alone will not sustain an improvement effort. Staff must receive quality data in a timely manner and use it effectively. Training in quality-related issues that emphasizes problem-solving in teams, effective communication, and statistical process control transform healthcare employees into creative problem solvers (Moore et al., 2018), which, in turn, enables staff members at every level to understand patients' needs, identify their requirements, and communicate effectively with them (Moore et al., 2018).

A team may be defined as a collection of three or more people in an organization whose members take pride in their collective identity and collaborate on one or more common tasks. Teamwork is defined as the action of a group working together with a common, well-defined objective. In hospitals that have implemented electronic health record (EHR) system, high-quality data on patients that is timely and accurate is available to the healthcare team members, which in turn will improve the teamwork and the effectiveness of the team as a whole (Graetz et al., 2015; O'Malley et al., 2015).

Whether it is in manufacturing or in services, the collection and analysis of quality information is important for successful implementation of QM practices. Also key to SCM is the sharing of information among supply chain members (Kaynak & Hartley, 2008). The use of quality data and reporting in hospitals is necessary for improving supplier quality management, as it allows buyers to monitor and assess the performance of suppliers, which is also improved by measuring their performance and providing feedback (Gonete et al., 2021). Quality data disseminated throughout a hospital in a timely manner is also a crucial factor when designing hospital services, for it facilitates the feedback from healthcare teams during the service design stage. Timely and effective use of quality data impacts a hospital's process management. Healthcare staff members are alerted quickly to process changes so they can fix problems before undesirable and inferior services become a problem.

Kaynak's (Kaynak, 2003) study suggests that supplier quality management is effective because of its direct relationship with service design and process management. Successful relationships could emerge whereby, for example, suppliers become engaged early in the design services of a new electronic data interchange (EDI) program at a hospital's pharmacy encouraging them to offer suggestions regarding the type, quantity, and frequency of the medical supplies that the hospital could order from the supplier, which would ultimately enhance the quality of patient care (Priestman et al., 2019). Under SCM, suppliers are integrated (Robinson & Malhotra, 2005) because improved quality of supplies positively affects process management by eliminating or reducing variation in healthcare services (Hughes, 2008).

Effective supplier management shrinks inventory and reduces waste in the supply chain (cf. Kaynak & Hartley, 2008), which reduces inventory costs, a goal of SCM. Improving quality by collaborating with suppliers also reduces the need for safety stock inventory. If the number of suppliers can be reduced, organizations can work more closely with those retained. As Chakraborty and Gonzalez (2018) explain, supplier quality management plays a critical role in a hospital's continuous quality improvement effort (McLaughlin et al., 2004). Successful and sustained quality improvement initiatives require that hospitals develop long-term and mutually beneficial partnerships with key suppliers to reduce inventory while still meeting service quality standards for patient care (Dahlgaard et al., 2011).

It is during service design that the processes employed in a firm and within its supply chain are established. Kaynak and Hartley (2008) empirically validated the proposition that effective product design is related to efficient process management, and this relationship applies to hospitals as well.

If hospitals are to realize the full benefits, hospital leaders must recognize that QM practices are interdependent and need to be implemented as a system. The ultimate objective of implementing QM is to improve outcomes for at all three major stakeholders**:** the patients, who need care; the healthcare team, which provides the treatment most likely to make the patients better; and the hospital, which needs to enhance its reputation so that it will attract new patients and enable its healthcare teams to thrive (Chakraborty & Gonzalez, 2018). Next, we describe these outcomes in detail.

## 5 Quality Outcomes in Hospitals

Nerenz and Neil (2001) suggest that scholars should integrate a range of aspects of healthcare performance: quality of care, utilization, cost, efficiency of hospital resources, patient satisfaction, and reports of care and financial performance. We offer a conceptual framework for quality measurement in hospitals (Fig. 2) that

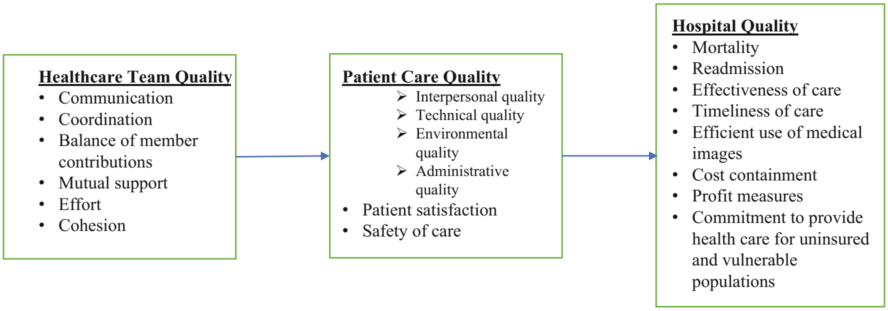


**Fig. 2** A framework for quality measurement in hospitals. (Adapted from Chakraborty and Kaynak (2018)). Copyright © American Society for Quality, reprinted by permission of Taylor & Francis Ltd, http://www.tandfonline.com on behalf of American Society for Quality

unifies three dimensions of the healthcare system: the team, the patient, and the hospital. Our framework emphasizes the fact that quality healthcare teamwork is positively related to patient care quality (PCQ), and PCQ is positively related to hospital quality performance. In the rest of this section, we discuss each dimension of quality measures in hospitals.

### 5.1 Healthcare Teamwork Quality

In healthcare, a patient's medical treatment and cure generally involves work of a resolute healthcare team. *Healthcare teamwork quality* is defined as the ability of the members of a healthcare team to collaborate well with each other to achieve their team objective(s).

Care teams are the norm in all areas of healthcare delivery. For example, members of small surgical teams are able to quickly learn from each other due to workload sharing and team helping, especially when task complexity is very high (Vashdi et al., 2013). Healthcare teams generally use physician empathy and nurse emotional involvement to positively influence the interpersonal relationships that they are able to establish with their patients. They typically take an active interest in their patients' medical condition, empathize with their suffering, communicate clearly to the patient and kin about their medical condition, and work together to rapidly improve health outcomes. Members of a healthcare team try to avoid medical errors, check schedules and room/equipment availability in advance of patients' medical procedures, take steps to prevent infections in hospitals, and keep the patients' care at the forefront of their decision-making. In addition, they generally follow hospital procedures or established workarounds, take all necessary precautions related to hygiene, and ensure that all physical elements of the hospital including the beds and other medical and surgical equipment are thoroughly cleaned and disinfected before use on any patient (Carling et al., 2008).

Overall, there are three major advantages of working in integrated healthcare teams – increased task effectiveness, which improves the patients' health and thereby their satisfaction with care; improved morale and mental well-being of the healthcare team members; and team viability which indicates the degree to which a team will function effectively over time. Based on the above discussion, we suggest that the measurement of the quality of teamwork is essential, not only to improve the quality of patient care, but also to help maintain healthcare team viability and keep them going on to serve patients. In summary, healthcare teams play a pivotal role in providing patient care and in continuously improving PCQ. Teamwork is one of the QM practices (Kaynak & Hartley, 2008) and its relation to healthcare team quality.

## 5.2 Patient Care Quality

PCQ may be defined as the excellence of medical care received by admitted patients in hospitals (Nelson & Niederberger, 1990). In extant literature, many studies have focused on identifying the determinants of PCQ both in hospital and clinical settings. Based on a synthesis of the multidimensional nature of patient care quality discussed in extant literature, Chakraborty and Kaynak (2018) identify the following four facets – *interpersonal, technical, environmental,* and *administrative quality.*

*Interpersonal quality* refers to the relationship developed and the dyadic interplay that occurs between the patient and the healthcare team (Sweeney et al., 2015) that comprise doctors, nurses, and support staff working together as a group to care for admitted patients in most hospitals. It includes issues such as whether healthcare teams treat their patients with respect, healthcare team members listen to what patients have to say, members give personalized attention to patients, and whether team members are willing to answer questions that the patient or their kin may have.

*Technical quality* identifies with the expertise, professionalism, and competency of the healthcare team in delivering treatment. It takes into account whether patients are administered the correct medical treatment that is required to cure their ailment, tests (e.g., X-rays and lab tests) are ordered on patients only when required, healthcare team members are qualified, and whether they carry out their tasks competently.

*Environmental quality* includes hospital atmosphere such as cleanliness and order and tangibles like hospital bed and required equipment for patient health needs. Whether the design of the hospital is patient friendly, the lighting at the hospital is appropriate, the temperature at the hospital is pleasant, and whether the furniture at the hospital is comfortable are issues considered in this PCQ facet.

*Administrative quality* alludes to the support provided by the administrative and support staff that facilitates the medical treatment while adding value to the patient. Considerations such as whether the internal hospital services (e.g., pathology) work well, waiting time at the hospital is minimal, the hospital provides patients with a range of patient support services, and whether the hospital records and documentation (e.g., billing) are error free are in the domain of this PCQ facet.

### 5.3 Hospital Quality Performance

*Hospital quality performance* is defined as a comprehensive reflection of how well the hospital is performing on a wide variety of quality-related parameters. Many scholars have already investigated the impact of QM practices on a firm's quality performance (Fynes & Voss, 2001). Hospital quality performance intends to capture all aspects of quality of the medical treatment processes and other products and services that are used in providing patient care which affect the hospital's overall quality performance.

Hospital quality performance measurement has been a continuing concern for quite a few years now, albeit it may be known by different names such as overall hospital star rating and may be calculated differently by many organizations. On one hand, it could be fairly sophisticated as using ten Hospital Quality Alliance (HQA) performance indicators to calculate a summary performance score for each of the three clinical conditions – acute mesenteric ischemia acute myocardial infarction (AMI) or heart attack, congestive heart failure (CHF), and pneumonia (Jha et al., 2007). On the other, it could be as simple as averaging all hospital star ratings given by patients or their kin on websites like Healthgrades, RateMDs, Vitals, and Yelp. As a third example, the overall hospital star ratings introduced by the Centers for Medicare and Medicaid Services (CMS) could be considered. The current (2016) CMS overall hospital rating follows a detailed methodology using 57 items from the Hospital Consumer Assessment of Healthcare Providers and Systems (HCAHPS) survey grouped into seven subcategories. HCAHPS is the patient satisfaction survey required by CMS for all hospitals in the USA (Cahill & Wang, 2012).

In Table 2, we offer a detailed research design for quality measurement. For each dimension, we also identify a few existing and enhanced instruments that can be used in hospitals that involved in quality measurement. One of the pillars of our quality measurement framework is the patient (either admitted into the hospital or visiting the outpatient clinic). Along with the patient(s), the other key stakeholder is the patient's relatives and friends, who stays with the patient/visits the hospital during the period of admission or accompanies the patient to the outpatient clinics. PCQ can be measured by tapping the patient's health record(s) from the EHR system (Middleton et al., 2013) and their perceptions of the quality of care that he/she experienced in the hospital using the HCAHPS survey questionnaire. EHR is the software platform extensively used in US hospitals by the nurses, staff, and physicians to electronically record all patient information beginning with their name and demographics to their body temperature, medication history, medical procedures, allergies, and several other relevant medical information. The HCAHPS survey, administered mostly by independent survey contractors and sometimes by hospital staff to patients in the hospital, is currently used by CMS to collect patient data on PCQ and several other aspects of hospital operations for its own annual reporting to

**Table 2** Quality measurement in hospitals

| Quality measures in hospitals | What | How | Why | Existing healthcare quality measurement instruments/sources |
|---|---|---|---|---|
| Healthcare team | Teamwork quality with six dimensions: communication, coordination, balance of member contributions, mutual support, effort and cohesion | ● Randomly select one or more healthcare teams in hospitals such that each team includes all the physicians, nurses and the staff who come into direct contact with patients and administer them the teamwork quality questionnaire | Contributes to healthcare team viability | ● HCAHPS survey questionnaire<br>● Hospital's internal quality improvement surveys |
| Patient | Patient care quality (PCQ) with four dimensions: Interpersonal, technical, environmental and administrative quality | ● Use HCHAPS survey to get patient data. Randomly select several patients with different ailments at every hospital using improved HCHAPS survey<br>● Data mining to obtain customer complaint themes from websites for the hospital from four common websites (Healthgrades, RateMDs, Vitals and Yelp) to help augment HCHAPS survey domains | Contributes to patient cure from sickness/ ailment | ● HCAHPS survey questionnaire<br>● Complaints to the Joint commission, the state QIO, if using Medicare<br>● Complaints posted by patients/kin on websites such as Healthgrades, RateMDs, Vitals, Yelp |
| Hospital | Hospital quality performance with seven dimensions: mortality, safety of care, readmission, patient experience, effectiveness of care, timeliness of care and efficient use of medical imaging | ● Use augmented HCHAPS survey to collect the data based on which CMS calculates the overall hospital star rating<br>● Use hospitals' internal data collected on other quality measures if any, to supplement the overall hospital star rating | Contributes to hospital reputation | ● CMS' *Hospital Compare* website<br>● Annual report to U.S. Congress |

*CMS Centers for Medicare and Medicaid Services* is the nodal body tasked with tracking hospital quality improvements. *The Joint Commission* is an independent, not-for-profit body to which patients can complain about their hospital issues. *QIO Quality Improvement Organization* is the organization to complain to if the patient is receiving Medicare; there are separate bodies for each state. *HCAHPS* the *Hospital Consumer Assessment of Healthcare Providers and Systems* is the (survey) method of data collection currently used by CMS. Table is adapted from Chakraborty and Kaynak (2018) the US Congress. Systemic analyses of patient complaints could help healthcare researchers find recurring themes among patients' complaints for each hospital, and the recurring themes among similar hospitals across the USA, which could be considered as areas of enhancement of the HCAHPS survey. These gaps or areas of improvement could also prove to be directly helpful for the hospitals in their effort to improve PCQ.

Most hospitals have three primary responsible stakeholders who work in teams and interact very closely with the patient – the physician, the nurse, and the healthcare staff – who could be playing one or more of the following roles: physician assistant, dietician, pharmacist, therapist/rehabilitation specialist, or hospital administrative/support personnel. We refer to these three stakeholders collectively as the healthcare team.

Measuring teamwork quality is important because it not only affects PCQ on one hand but is important for the healthcare team members' viability and mental well-being on the other. All hospitals need to routinely measure how effectively their team members interact and work on providing patient care (Poulton & West, 1993, 1999). In addition, human resource utilization should also be checked using the hourly work schedule for all team members to ensure that all team members are optimally utilized. For the in-house team surveys, hospitals could randomly select one or more of their healthcare teams who come into direct contact with patients. Further, data on the number of patients handled by the healthcare team in a month and the number of hours worked each day by every team member could be used from hospital records to gauge team success.

We suggest that the focus of a quality measurement framework should be to measure all aspects of PCQ including its four dimensions – interpersonal, technical, environmental, and administrative quality. Patient satisfaction with the medical treatment is also important because ultimately the patient must not only recover fully from the disease/ailment but must also be satisfied with the treatment and its associated costs. Patient perception and satisfaction data for every hospital could be mined from four common websites (e.g., Healthgrades, RateMDs, Vitals, and Yelp) to obtain customer complaint themes and all the individual data for the hospital collected in a month to be grouped to ultimately enhance/augment the HCHAPS survey domains.

Finally, we advocate that the focus of measuring hospital quality performance should be based on the care provided in the hospital. In this context, a lot of existing detailed hospital-level averaged data already tracked by CMS and published in the *Hospital Compare* website could be used. A few examples of detailed metrics currently used in hospitals include the following: (1) the 30-day risk-standardized mortality rates for each of the three ailments – acute myocardial infarction (heart attack), heart failure, and pneumonia, and (2) the 30-day risk-standardized readmission rates after each of the four medical procedures – acute myocardial infarction (heart attack), heart failure, pneumonia, and hip/knee surgery.

There are five other key stakeholders that routinely interact and collaborate with CMS and a few others that occasionally interact with CMS in quality measurement and management efforts as and when required. The Joint Commission and the state quality improvement organizations (QIO) are two important stakeholders. The Office of the National Coordinator (ONC) for Health Information Technology (IT), the federal body responsible for coordinating nationwide efforts to implement electronic exchange of health information using the national healthIT.gov network, is a third stakeholder. Similarly, the American Medical Association (AMA) which helps physicians help patients by uniting doctors and medical students nationwide to work on the most important issues and medical universities that teach/train all budding physicians, nurses, and other healthcare staff are two other important stakeholders in quality measurement because together they guide all physicians, nurses, and medical research teams with the care issues and help determine the evolving medical standards. For a broader discussion of the different systems that help a hospital measure its overall quality, see Chakraborty and Kaynak (2018).

## 6 Emerging Concerns, Existing Research, and Future Directions

### 6.1 Population Health Management (PHM) and Lean Systems

Population health management (PHM) has emerged as an important strategy to address the triple aim of enhancing the individual care experience, reducing healthcare costs per capita, and improving health. Although PHM initiatives are being adopted widely, the term is used somewhat loosely – population health, population medicine, community health, public health, and disease management – and the components of PHM vary across different healthcare organizations (Kaynak et al., 2017). As commented upon by Vic Zuccarello (2015) in this 2015 *Health Affairs Forefront* blog by David Kindig, "population health" is "the health outcomes of a group of individuals, including the distribution of such outcomes within the group." It is an approach to health that aims to improve the health of an entire human population (Kindig & Stoddart, 2003) whereas PHM is "the technical field of endeavor which utilizes a variety of individual, organizational and cultural interventions to help improve the morbidity patterns (i.e., the illness and injury burden) and the healthcare use behavior of defined populations" (Coughlin et al., 2006). Hospitals utilize PHM tools (e.g., data dashboards, registries, and care coordination) to not only manage their patient population but also to meet healthcare quality targets and participate in value-based care initiatives.

Effective implementation of PHM requires continuous improvement, leadership, and teamwork – the topics we have addressed in this chapter – as well as lean systems. Implementing lean systems has its own challenges. Even before the COVID-19 pandemic hit, lean or just-in-time (JIT) system was not overwhelmingly popular among healthcare providers and hospital leaders. The reason for practitioner reluctance is simple: becoming and continuing to be lean is not easy and many do not end up as successful and some give up midway once their leadership changes. A quick search showed that lean is not widely implemented in either US (Po et al., 2019) or in European hospitals (Marsilio et al., 2022).

Among the 288 public hospitals that responded to the survey, 54.2% reported that they had adopted lean. The average length of time of lean implementation was 4.58 years. The mean number of units in which lean was implemented was 11.9 out of 29 possible hospital units, with the emergency department (ED) being the unit in which lean was most frequently implemented (Po et al., 2019).

However, there are also successful implementation accounts of lean systems. For example, Washington Hospital looks at the value added and waste from the patient's perspective to focus on the patient experience. Their lean management system is based on two concepts: continuous improvement and respect for people (Washington Hospital, 2016).

Needless to say, further research is essential to better understand PHM and its implementation in hospital settings. Currently, the focus seems to be on the clinical management of subgroups of patients by health systems and payers. Future research can focus on performance measures at each level (e.g., geographic population, an entire community) and for every stakeholder, in a way that it can support the strategies of hospitals or groups of hospitals to improve population health in their service area. Directly addressing social determinants of health and paying for these strategies can be other fruitful research topics as only 20% of health is determined by healthcare utilization, the rest is due to income, housing, social isolation, and the environment (Gottlieb et al., 2019).

### 6.2 Managing Stressful Environments in Healthcare

As we discussed in the beginning of this chapter, although the jury is out about the specific number of deaths due to medical errors, everyone agrees that patient safety and healthcare quality must be improved to reduce preventable deaths. One reason for medical errors is the occupational stress that "U.S health care clinicians, clinical students and trainees" (p. 1) are experiencing, with burnout rates at approximately 50% (Marchalik et al., 2020). The recent COVID-19 crisis and shootings in hospitals have certainly been adding to the healthcare workers' stress level. Increased burnout rates among healthcare workers have three major implications: (1) a healthcare workforce shortage due to stressful working conditions; (2) low job satisfaction, high absenteeism, and high turnover; and (3) a decline in patient care and hospital quality performance (National Academies, 2019).

A review of the extant literature indicates that healthcare organizations can create an environment in which healthcare staff can feel their jobs are meaningful. "Meaningful work refers to work that is experienced as worthwhile, significant, purposeful, important, and valuable to oneself or others" (Cf. Kimakwa et al., 2021; Allan, 2017; Pratt and Ashforth 2003), which can reduce occupational stress. A study of meaningful work in healthcare can be conceptualized as antecedents of meaningful work as inputs, meaningful work as process, improved employee well-being as output, and patient care quality as outcome. Antecedents of meaningful work include leadership (e.g., Arnold et al., 2007), information technology (to reduce administration work) (e.g., National Academies, 2019), worker empowerment, worker development/learning environment (e.g., Albuquerque et al., 2014), and safe work environment (e.g., Linzer et al., 2009). In other words, the antecedents are the facilitators of meaningfulness. We posit that the outputs of meaningful work are reduced burnout reflected on increased job satisfaction, reduced turnover, and increased work effort, leading to the outcomes – patient care quality and hospital quality performance.

The experience of NYC Health + Hospitals during the COVID-19 pandemic makes it clear that there is a need for further research to fully understand the antecedents of meaningful work and the factors that influence employee well-being given its potential impact on healthcare quality. The leadership at NYC Health + Hospitals was able to use information technology, worker development, and learning tools to create a supportive staff environment during the most stressful part of the COVID-19 pandemic (Salway et al., 2020). Efficient staff redeployment and onboarding processes together with distinct types of support certainly helped the public healthcare delivery system of NYC to manage workforce burnout as well as possible.

## 7 Summary and Conclusion

The COVID-19 pandemic has made it more evident than ever that healthcare systems should continuously improve to be able to provide excellent, equitable care to everyone at reasonable cost (Chakraborty et al., 2021). Hospitals play a critical role in the healthcare ecosystem and – as our discussion in this chapter reveals – continuous improvement, quality leadership, teamwork, and supplier relations are key factors in managing healthcare quality. The supply chain of a hospital is extensive and complex, and the patient is the focal point of its operations. Physicians, nurses, and all other infrastructure support systems are designed to serve the patient in the most effective and efficient manner.

The provision of high-quality patient care requires a supply chain that keeps quality management principles at the front and center of all hospital processes. Quality management practices that are essential in the context of hospitals include hospital quality leadership, healthcare training, healthcare teamwork, hospital quality data and reporting, patient focus, supplier quality management, hospital services design, and hospital process management. Hospital quality leadership is the crucial factor for the successful implementation of quality initiatives and efforts in these organizations. Effective leaders can leverage resources, increase staff engagement, and stabilize processes to move a hospital through its own quality improvement journey. Quality healthcare teamwork is positively related to patient care quality which, in turn, is positively related to hospital quality performance.

An emerging area of work is how population health management can be used as a strategy to enhance the patient care experience, reduce healthcare costs, and improve health. Hospitals can use population health management tools such as data dashboards, registries, and care coordination to manage patient populations more effectively, achieve healthcare quality targets, and participate in value-based care initiatives. The effective implementation of these ideas requires a continuous improvement mindset, leadership, teamwork, and lean systems. Being lean is not easy to accomplish and maintain, but successful lean management systems incorporate continuous improvement at their core.

Lastly, occupational stress and burnout should not be ignored. Burnout in healthcare leads to workforce shortages, low job satisfaction, high absenteeism, increased turnover, and declines in hospital quality performance. Healthcare organizations need to create environments where healthcare staff members feel safe and that their jobs are meaningful to reduce occupational stress and improve healthcare quality.

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# Perspectives on the Bullwhip Effect in Supply Chains

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## Contents



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**Abstract**

An efficient supply chain management system is the key to running product- and service-oriented businesses. In a perfect world, an efficient supply chain provides accurate information to all supply chain players from the downstream (retailers) to the upstream (supplier's suppliers). This helps in ensuring an uninterrupted flow of products and services to the customer. The supply chain is usually a complex network of companies that work together to meet customer demand for a product or service by allowing each company to focus on its specific process to maximize supply chain profit. Uncertainties threaten this coexistence of organizations in a supply chain. Uncertainties such as changes in market conditions and customer demand can lead to inaccurate forecasts and supply chain inefficiencies that may strongly affect a supply chain. The bullwhip effect (BWE) is one such inefficiency. This chapter focuses on the BWE in supply chains. To give the reader an understanding of the BWE, a brief review of some critical perspectives on the BWE in supply chains as well as some proposals discussed in the literature in the recent years has been carried out. The chapter also describes the context within which the BWE has emerged and its characteristics. It also reflects on its relationship with the current trends of sustainability, nonlinear supply chain networks, intangible products (services), monetary and financial issues, competition in supply chains, and the BWE during the COVID-19 pandemic, among other trends, to reveal new research interests on the topic.

**Keywords**

Bullwhip Effect (BWE) · Supply chains

## 1 Introduction

The bullwhip effect (BWE) is one of the oldest and most studied topics in supply chain management. A random search in Google Scholar of the words "bullwhip effect" can result in more than 30,000 results in less than 5 s. The topic is old, spanning from the age of production and inventory control (before 1958), through the stages of the *beer game* (1989–1997), to the age of avoiding the BWE (after 2000). The history of the BWE has been documented by authors such as Jia, Wang, and Luo (2011) and Holweg and Disney (2005), among others.

However – as old as the topic is – it is still one of the main concerns in supply chain management with new research emerging with each passing year. In an argument as to why it is still necessary to study the BWE, Fransoo and Wouters (2000) mentioned how existing studies analyze BWE in a simple supply chain, consider different business environments, and have limited assumptions made regarding practical supply chains which are more complex. This situation happens because adjusting even one parameter in the system would significantly affect other parameters and influence the supply chain behavior.

More recently, the BWE received additional attention after extreme disruption situations such as the COVID-19 pandemic (Moraes & Yuan, 2021). The COVID-19 pandemic has raised the importance of studying both the operational and behavioral causes of the BWE due to frequent stockouts in supermarkets for basic products and the scarcity of lifesaving drugs, ventilators, and personal protective equipment (PPE). These stockouts are some of the consequences of having unexpected fluctuations in demand, and these justify the study of the BWE even after all the years of studying the topic (Moraes & Yuan, 2021). Besides the pandemic, BWE has been shown to be a consistent and present concern as shown by two recent independent empirical studies from the USA and China that demonstrated the existence of the BWE within almost two thirds of the analyzed cases (Wiedenmann & Größler, 2019). This pernicious existence of BWE in supply chains after 60 years of study justifies the need to further study the topic.

The BWE has been defined as an *almost ubiquitous problem* occurring in supply chains (Lee et al., 1997). This *almost ubiquitous problem* was the BWE referred to by Dominguez, Cannella, and Framinan (2014) as a "phenomenon by which even small variations in customer demand may generate high alterations in upstream production of suppliers" (p. 2).

"The bullwhip effect is a supply chain phenomenon comprising two information distortion mechanisms, the demand distortion and the variance amplification" (Fransoo, 2021, p. 130). In BWE, the demand distortion occurs for a given firm; the orders it places to its suppliers tend to be more variable than the demand it observes from its customers. This demand distortion increases the further a firm moves upstream and away from the final consumerm causing variance amplification. The combined effects of demand distortion and variance amplification generates a demand shock downstream that creates demands that oscillate with increasing amplitude at each successive stage of the supply chain (Fransoo, 2021).

The BWE is usually characterized by:

- Amplification of demand variation across the supply chain (Lee et al., 1997)
- Lack of coordination between companies in the chain (Bhattacharya & Bandyopadhyay, 2011)
- Lack of transparency in information (Lee et al., 1997)
- Formation of excess inventories in the supply chain aimed at preventing demand variation (Sucky, 2009)
- Product unavailability (Sun & Ren, 2005)

When managing inventories and operations, the BWE is an interesting and important topic to study. The reasons, as we introduced above, are manifold. It is because of the costs associated with the phenomenon such as "setup and shutdown of machines, idling and overtime in the workload, hiring and firing of the workforce, excessive upstream inventory, difficulty in forecasting and scheduling, systems' nervousness and poor supplier or customer relationships among other consequences" (Wang & Disney, 2016, p. 691).

This chapter aims to explore emerging trends and issues in BWE research and practice brought about by emerging supply chain developments such as digitization, sustainability, and e-commerce. The chapter will also explore topics on the BWE that arose because of supply chain disruptions caused by natural disasters and pandemics such as the COVID-19. Section 2 of the chapter will give a brief background on the BWE in supply chains and explore other definitions of the BWE outside of manufacturing and operations management. Section 3 will look at current trends in BWE research, and Sect. 4 will explore emerging research topics on the BWE because of the COVID-19 pandemic. Section 5 will explain some future research directions worth exploring on the BWE. Section 6 will explain the managerial implications of the BWE, and Sect. 7 will conclude the chapter.

## 2 Background

The study of the BWE has evolved over the years, and the topic continues to be interesting and study worthy to both industry and academia. Studies on the topic started before 1958 in the period of production and inventory control as documented by Holweg and Disney (2005).

In this early period, production and inventory control models were built based on control theory, and the dynamic characteristics of production and inventory control systems were discussed. Authors such as Simon (1952) and Vassian (1955) introduced the servomechanism theory and its use in production and inventory control problems. The authors clearly stated the dependence of the inventory level on the sales forecast error and system constants. In the same period, there existed books by Magee (1958) and Brown (1963) that formally described the use of z transforms in production and inventory problems.

This earlier period paved way for the stage of smoothing production between 1958 and 1969. An important discovery in this stage was by Forrester (1961) who built original system dynamics models of the supply chain using DYNAMO revealing the counterintuitive phenomenon of fluctuations in the supply chain. This approach formed the basis of system dynamics modeling. Contributions have included a focus on demand signal amplification in supply chains with more than one echelon. In this stage, authors recognized the importance in how production and inventory control systems influence the stationary variance of inventory levels. Seasonal fluctuations in inventory and demand amplification were gaining attention, but the terms BWE and stability of supply chains were not formally proposed. The emphasis of research in this period was traditional production management.

An important stage in the history of the BWE research was the stage when the *beer game* was introduced between 1989 and 1997. This is the stage when system dynamics became popular as a method of modeling supply chains to study the behavioral effects in supply chains. Sterman (1989) suggested a general stock management model after doing some experimental studies on the *beer game* at the Massachusetts Institute of Technology (MIT).

Many studies emerged because of this beer distribution game. The term *bullwhip effect* was defined in the period from 1997 to 2000 (Lee et al., 1997) with exploratory research on the main causes of BWE. Four factors were identified: (1) demand signal processing, (2) rationing game, (3) order batching, and (4) pricing variations (Lee et al., 1997). This early work formed the basis of research on BWE as most research was centered on either some or all of these factors. A key focus of this stage was investigating relationships and causes of BWE.

The period from 1997 to 2000 identified the causes of the BWE, classifying them as either behavioral or operational causes. Operational causes of the BWE are usually a result of supply chain structures and processes, material and information lead times, and supply variability, among other reasons.

Behavioral causes of the BWE happen because "both in real-life and in experiments, humans operate in ways that deviate from theoretical predictions. We make mistakes. We exhibit psychological biases that affect our decisions" (Udenio et al., 2017, p. 980). The operational and behavioral causes of the BWE have been summarized in Table 1.

Table 1 shows how the BWE cannot just be eliminated by just eliminating the four causes first identified by Lee et al. (1997). It is interesting to note that simple things like personality differences can cause the BWE in a supply chain. The table demonstrates how the existence of the BWE in various supply chains is because of a combination of both behavioral and operational causes. This makes it more complex to study and eliminate the BWE. These multiple relationships are another reason why the topic has evolved over decades, and it is still evolving. Many causes of the BWE have been investigated in isolation.

There have been attempts to mitigate and eliminate the BWE. This reduction of BWE was and still is the focus of most research after the year 2000. Methods have been suggested in literature to mitigate and eliminate the BWE. These include information sharing, integrated supply chain information systems, joint planning, vendor managed inventory, shorter lead times, and synchronized deliveries. However, Yang et al. (2021) mentioned that in spite of such preventive measures, the BWE still exists in supply chains. In their research, the authors demonstrated that human and behavioral factors cannot be ignored when examining the BWE. Such human and behavioral factors include individual cognitive limitations, social interactions with others, and cultural evolution and transmission.

## 3 Other Forms of BWE

Although the demand and information variance (defined by Lee et al. (1997)) in product manufacturing supply chains is the most common form of BWE explored in literature, other forms of bullwhip have also been identified. This section explores other forms of BWE mentioned BWE the literature including the reverse BWE, cash flow BWE, green BWE, service BWE and data quality BWE.

**Table 1** Operational and behavioral causes of the BWE

| BWE cause | Type | Associated with | Explanation | Authors |
|---|---|---|---|---|
| Demand forecast updating | Operational | Supply chain structure and processes | Reliance on past demand information for present demand situation | Lee et al. (1997) |
| Order batching | Operational | Supply chain structure and processes | Batching of orders to minimize unit ordering cost and production cost. Causes distortion of demand information | Lee et al. (1997) |
| Rationing and shortage gaming | Operational | Supply chain structure and processes | In an environment where there is a shortage, buyers tend to over-order to secure resources, and suppliers tend to correct this by rationing to smaller quantities | Lee et al. (1997) |
| Price variations | Operational | Supply chain structure and processes | Promotions and discounts disrupt regular buying patterns buyers will want to capitalize on the discount offered during a short period, while the manufacturer suffers an uneven production schedule, unnecessary inventory costs, and distorted demand information | Lee et al. (1997) |
| Material and information lead times | Operational | Material and information lead times | An order placed by one business unit reaches an upstream supplier after an information lead time, and as the product is made, the order is completed and delivered and there is a material lead time. As demand for materials may change from the time the order is placed to the time the material is received, difficulties arise in effective management of a supply chain | Paik and Bagchi (2007) |
| Machine breakdown | Operational | Supply variability | Potential to exaggerate demand due to over-ordering in times of breakdowns and shortage is perceived by downstream players in the supply chain | Paik and Bagchi (2007) and Forrester (1958) |

(continued)

**Table 1** (continued)

| BWE cause | Type | Associated with | Explanation | Authors |
|---|---|---|---|---|
| Capacity limit | Operational | Other | Decreases in capacity levels cause excessive swings in the supply chain once production problems are detected down the chain. This causes erratic ordering by downstream members and causes a BWE | Paik and Bagchi (2007) and Forrester (1958) |
| Number of echelons | Operational | Others | Removal of one echelon removes the amplification caused by the pipeline and inventory accumulation in that echelon | Paik and Bagchi (2007) |
| Lead time variability | Operational | Others | The level of lead time changes and increases does not initiate the BWE, but the quality of information does | Chatfield et al. (2004) |
| Workloads | Operational | Others | As higher workloads deteriorate process quality, more rework is required, which in turns results in higher workloads | Akkermans and Vos (2003) |
| Communication and coordination | Behavioral | Social interaction | Social interactions that can provide additional information feedback about the dynamic system in supply chains to decision-makers | Sterman (2000) |
| Information sharing and exchange | Behavioral | Social interaction | Sharing point of sale information in the downstream of the supply chain and reducing delays in information delay | Croson and Donohue (2006) |
| Trust | Behavioral | Social interaction | If participants believe in their partners and their abilities, it improves supply chain performance | Croson et al. (2014) |
| Perception | Behavioral | Information feedback | The way information is organized, selected, and interpreted so that the environment can be represented and understood | Haines et al. (2017) |
| Ambiguity | Behavioral | Information feedback | Results because of limited information and decision-makers tend to make decisions based on known information and causality | Yang et al. (2021) |

(continued)

**Table 1** (continued)

| BWE cause | Type | Associated with | Explanation | Authors |
|---|---|---|---|---|
| Debiasing | Behavioral | Information feedback | An intervention and a method to improve decision-making in supply chains, e.g., training | Tokar et al. (2012) |
| Rationality | Behavioral | Mental models | Reasoning to achieve goals within mental models | Cantor and Macdonald (2009) |
| Judgment | Behavioral | Mental models | Human judgmental interventions strongly influence adjustments in forecasting and ordering | Syntetos et al. (2011) |
| Decision patterns | Behavioral | Decision strategy | How players make decisions in both the presence and absence of demand information | Delhoum and Scholz-Reiter (2009) |
| Risk aversion | Behavioral | Decision strategy | A strategy or decision rule that decision-makers apply under risk | Cannella et al. (2019) |
| Decisions | Behavioral | Others | The behavioral implementation after the decision-making process | Sterman and Dogan (2015) |
| Personality | Behavioral | Individual traits | Influential factor in decision-making and it varies from person to person | Bloomfield and Kulp (2013) |
| Age and experience | Behavioral | Individual traits | Comparing decision-making based on age and professional experience | Turner et al. (2020) |

### 3.1 The Reverse BWE

The reverse BWE is caused by "the variability in delivery from the supplier to customers, through retailers, as opposed to the straight BWE caused by the variability in customer's demand from the customer to the suppliers, through the retailers" (Shukla, 2014, p. 7).

The reverse BWE is the opposite of the BWE defined by Lee et al. (1997). This BWE characterization has not been explored by many studies. There could be investigation into conditions that lead to reverse BWE in supply chains where decisions on pricing and order replenishment are jointly made.

Ozelkan, Lim, and Adnan (2018) defined the reverse BWE as, "amplified price variability as one moves downstream the supply chain due to the impact of upstream supply chain price variability on the downstream retail prices and supply chain mechanisms" (p. 2). The authors provided empirical evidence of the reverse BWE in the natural gas, currency exchange, and food product pricing. They argued that this reverse BWE is increased by procurement practices that use auctions and reverse auctions where decision-makers compete on price. This situation creates fluctuations in procurement price.

The reverse BWE may not only occur in pricing but also in product flow (Rong et al., 2017). A reverse BWE is characterized by a growing variability in the demands downstream from the suppliers caused mainly by interruptions in delivery. The reverse BWE in product flow may also be caused by either a delivery interruption or the product shutdown in an upstream supply chain echelon (Dias Brito et al., 2020).

Although multiple forms of reverse BWE are mentioned in the literature, the topic has not seen as much investigations and requires significantly more research to understand the phenomenon.

## 3.2 The Cash Flow Bullwhip (CFB)

The “cash flow bullwhip (CFB)” – a term introduced by Goodarzi, Makvandi, Saen, and Sagheb (2017) – is “a phenomenon which is derived from the oscillation of the Cash Conversion Cycle (CCC) that takes place throughout the cash flow of the supply chain” (p. 640).

In addition to information, cash also flows in a supply chain, and this flow of cash within the supply chain can be affected by other activities of the supply chain. The presence of the BWE in a supply chain brings about the CFB (Tangsucheeva & Prabhu, 2013). Lead time is a main factor for CFB control. Factors that have a large effect on the BWE will have a great impact on the CFB (Goodarzi et al., 2017). In addition, Lamzaouek, Drissi, and El Haoud (2021) explained that the amplification of stocks caused by the BWE extends the time needed to transform them into cash, leading to cash flow problems. Companies suffering from the CFB can be held hostage by their inability to finance their activities even though they are profitable. To mitigate the CFB, Goodarzi et al. (2017) advise managers to pay more attention to work in progress (WIP) to decrease cash-to-cash cycle fluctuations and the CFB.

A variation of the CFB was introduced by Vousinas (2019) who defined the “supply chain financial BWE” as a phenomenon on the financial flow level of the supply chain that involves the amplification of financial distortion along it. This type of BWE is said to occur when there exists an oscillation in the financial flows from the financing institutions, due to both internal and external factors causing cash flow fluctuations and financial distress at the firm and economic level. This phenomenon can also be studied across global supply chains.

Although there are a number of publications on CFB, this is another form of BWE that is still underexplored and provides a gap for further research. Wang and Disney (2016) mentioned the CFB, as an extended concept of the BWE that is among the current trends and issues in BWE research.

### 3.3 The Green BWE

While the ordinary BWE considers inventory flow, there is another form of bullwhip that looks at environmental regulations applied to products. This form of BWE is termed the green BWE. Lee, Klassen, Furlan, and Vinelli (2014) explained that the green BWE is a "dynamic phenomenon whereby environmental obligations flow back upstream in the supply chain with significant variation" (p. 40).

The authors also defined the green BWE as an "event motivated by changes in environmental requirements such as new regulations and the industry needs to respond to environmental incidents, practicing urgency when it comes to meeting new environmental pressures from customers and moving them upstream in the supply chain" (p. 40). These changes can create risks and uncertainties, complicating the response to them and managerial planning in the supply chain. The following characteristics of the green BWE are as follows (Lee et al., 2014):

- Rigor of demands on products and materials based on environmental characteristics tend to increase as one moves upstream of the supply chains.
- Deadline of meeting the requirements based on environmental issues tends to get shorter at each upstream level of the supply chain.
- The responses to the green BWE may vary in accordance with the characteristics of the relationships between customers and suppliers.

In the green BWE, the position in the supply chain can play a role in intensifying green BWE outcomes (Pais Seles et al., 2016). The argument is that the further the organization is from the end customer, the more delayed the environmental pressures will be, leading to the organization to compensate intensely to respond to the environmental pressures. While the BWE is a negative phenomenon, the green BWE can have positive results if focal companies provide shared environmental training and shared development of technologies with their suppliers.

The green BWE needs greater exploration.

### 3.4 The Service BWE

The service BWE is not exactly a new phenomenon as it was first explored decades ago (e.g., Akkermans & Vos, 2003). By then, many authors had mixed feelings as to the differences between manufacturing supply chains and service supply chains. The service BWE has the same definition as defined by Lee et al. (1997); however, the BWE is being experienced in service industries such as hotels and airlines rather than manufacturing organizations.

There are both similarities and substantial differences to product supply chains in terms of the nature and cause of amplifications (Akkermans & Vos, 2003). Service supply chains tend to focus on backlogs on orders rather than inventory buildup like product supply chains do. Other triggers for amplification in service supply chains have been identified and include interactions between workload and quality, sales campaigns, overloads, and errors (Akkermans & Voss, 2013).

An extension to the service BWE is when manufacturing and services are integrated to form what are termed *integrated manufacturing and service networks (IMSN)*. An IMSN is "a group of companies working together to offer a bundle of products and product-related services that deliver value to customers over the entire useful life of the product, from purchase to disposal" (Viswanadham et al., 2005, p. 3005).

On investigating the BWE in an IMSN, Viswanadham, Desai, and Gaonkar (2005) observed that the service system exhibits oscillatory behavior in resource levels for repair crews, spare parts, etc. The authors used system dynamics modeling to demonstrate that integration and collaboration between the manufacturing and service operations with two-way information flow between them enhances profitability and minimizes the BWE within repair centers.

The BWE in service supply chains is also one of the topics mentioned by Wang and Disney (2016) as a trending and interesting topic to look into as far as the BWE in supply chains is concerned.

### 3.5 The Data Quality BWE (DQBE)

Information sharing has been mentioned as one strategy for reducing the BWE in supply chains. However, new research has emerged as to the impact of the quality of data shared in supply chains. Ge, O'Brien, and Helfert (2017) defined a new form of BWE which they claimed to be almost similar to the ordinary BWE. They termed this the *data quality BWE* (DQBE) and defined it as an "increase in the variability of data quality success over time" (p. 158). The DQBE is said to be affected by delays and reluctance to react to data quality problems on the part of the supply chain players. There is an argument that if variability in data quality can be predicted, then the DQBE can be reduced.

There is only one article on this form of BWE. This means that DQBE needs to be explored further with other studies to see what conforms or does not conform to basic BWE.

## 4 Trending Topics on the BWE

In an invited review, Wang and Disney (2016) explained the evolution of BWE research and what is still being expected in the coming years. In their narrative literature review, the authors identified main topics of interest that are emerging under BWE research and which serve as a reminder that the BWE is still an interesting topic of research; this section explores some extensions and trending topics on the BWE. Some of these topics have already been discussed as other forms of the BWE, for example, the BWE in service supply chains and the CFB. This section explores some of the trending topics on the BWE mentioned by Wang and Disney (2016).

## 4.1 BWE in Complex Systems

There is an argument that supply chains are complex systems, and a representation of supply chains with just cascading echelons is not enough. The decomposition assumption was accused of underestimating bullwhip measures by Chatfield (2013). The consideration of arborescent supply chains by Beamon and Chen (2001) helped to explain that sometimes there is more than one player at each echelon of a supply chain. "Future research on complex systems will investigate other kinds of non-linear mechanisms in more realistic supply chain models such as capacity constraints, lost sales, bargaining, competition and transhipment" (Wang & Disney, 2016, p. 697).

The concept of complex supply chains was also introduced by Ma, Wang, He, Lu, and Liang (2015) when they presented an argument that the BWE in supply chains cannot be investigated without considering the interactions among supply chains. They investigated parallel supply chains with interacting price-sensitive demand and concluded that managers who ignore interactions between supply chains are likely to overstate or underestimate the BWE in the supply chain. Ma and Ma (2017) claimed that market competition monotonously impacts the BWE, but it is a simple factor. Lee et al. (1997) did not list these factors, but they are factors worth investigating.

Different supply chain network structures were also investigated by Tombido, Louw, and van Eeden (2020) who compared series and divergent supply chain networks for both forward and closed-loop supply chains. The authors concluded that in closed-loop supply chains, increasing the number of collectors in the reverse chain increased the BWE in all supply chain configurations. Therefore, it seems to be more beneficial for a closed-loop supply chain to have one reliable collector supplying used products than more than one collector with uncertainties in the quantity of products returned. Tombido et al. (2020) also revealed that a serial network is more sensitive to changes in the reverse chain in terms of the number of parties involved compared to a divergent supply chain. A similar study was carried out by Osadchiy, Schmidt, and Wu (2021), who studied the BWE from a supply network perspective. Although they did not focus on closed-loop supply chains, Osadchiy et al. (2021) argued that variance amplification can be lowered when suppliers serve multiple customers, and this offsets the impact of individual customer's demand distortion. The authors presented another argument that firms may mitigate the BWE and its impact through their choice of customers and suppliers that change their customer base on average experience subsequent reduction in demand variability.

Studying the BWE in complex supply chains has become a new norm and an interesting topic; however, there is still need to explore different supply chain network structures. The supply chain has also been complicated by the introduction of e-commerce. Supply chains have started using dual channels (online and offline) not just for selling products but also for reverse logistics. In their review on dual and multichannel closed-loop supply chains, Tombido and Baihaqi (2022) mentioned that there is a need for more studies on the impact of having dual and multichannels on supply chain dynamics and the BWE in supply chain dynamics as a way of studying the BWE in complex supply chains.

### 4.2 Bullwhip in Make-to-Order Supply Chains

Most research assumes tangible products in a make-to-stock environment where inventories can be stored as a cushion for variations in demand. There is barely consideration for the make-to-order supply chains where production and consumption occur simultaneously. A search in the web of Science and Google Scholar shows no record of any research on the BWE in make-to-order supply chains. This means that this topic on its own presents a new area for investigation.

### 4.3 BWE Models Incorporating Price and Negotiation Processes

Wang and Disney (2016) mentioned, “Research on the influence of process on the BWE requires models that incorporate price setting and negotiation processes, dramatically increasing the complexity of the model” (p. 697).

Drift (2012) argued that present research toward solutions on the BWE has focused mainly on the systemic and operational causes of the BWE, resulting in solutions that require high levels of organizational integration, central coordination, and information sharing. They argued that such solutions are not always feasible within actual complex supply chains and are not acceptable toward the strategic perception of sensitivity of operational information, nor suitable within the authority and responsibility structures of organizations. In their research, the authors developed and proposed forecast accuracy discount agreements as decentralized solutions. These solutions incentivize customers to smoothen their purchase orders by rewarding predictable ordering according to previously shared forecasts of their own expected future orders. Qu and Raff (2020) also agreed that decentralized supply chains where upstream players use linear wholesale prices may be less susceptible to the BWE than vertically integrated supply chains as they may experience lower upstream production and downstream sales volatility.

Unique research by Ma, Lou, and Wang (2021) combined two trends mentioned by Wang and Disney (2016), that of competing supply chains and price considerations. The authors studied the BWE influenced by a pricing strategy in two parallel supply chains distributing price-sensitive and price-substitutable products. They discovered that the BWE in two parallel supply chains is affected by lead time, product substitution rate, and the pricing coefficient. Their main conclusion was that the BWE in two supply chains with alternate products could be lowered by having a higher degree of substitution between the products.

Recent research by Moghadham and Fazel Zarandi (2022) focused on the management of the BWE in a four-echelon supply chain through information sharing and cooperation. In their research, the authors proposed a fuzzy reverse ultimatum automated negotiation model based on game theory to determine the ordering policy of the supply chain as a way of lowering the BWE.

Although the idea of incorporating price and negotiations in BWE research seems to have more recent publications, also another evolving topic without solid conclusions leaves a considerable gap for research.

## 4.4 Bullwhip with Resource Competition

Resource competition is a phenomenon that was investigated by Lee et al. (1997) in the form of rationing and shortage gaming. This occurs when retailers perceive a shortage in a commodity and they buy more than necessary to cover for the period when there is a shortage. However, competition may also arise in the form of retailers competing to sell their products. Yuan, Zhang, and Zhang (2020) analyzed the impact of different forecasting techniques on the BWE in two parallel supply chains with competition.

In their research, market demand was affected by self-price sensitivity coefficient, the cross-price sensitivity coefficient, market share, and demand shock of two supply chains with one manufacturer and one retailer. Similar research was carried out by Yin (2021) and Ma and Ma (2017) who measured the BWE in supply chains with one supplier and more than one retailer competing. Yin (2021) captured the degree of market competition using copula and concluded that market competition does have a significant impact on the BWE. Ma and Ma (2017) measured the BWE under moving average forecasting technique and investigated the effects of lead time, span of forecast, market competition, and the consistency of demand volatility on the BWE.

## 4.5 Bullwhip and Sustainability

Environmental laws and regulations have been addressed in what is termed the "green BWE." However, the majority of research that has studied the BWE and sustainability has focused on the BWE in closed-loop supply chains.

Studies such as those by Tang and Naim (2004), Zhou, Disney, Lalwani, and Wu (2004), Turrisi, Bruccoleri, and Cannella (2013), Das and Dutta (2013), Zhang and Yuan (2016), Tombido and Baihaqi (2020), Tombido, Louw, and van Eeden (2020), Tombido, Louw, van Eeden, and Zailani (2021), and Zhou, Naim, and Disney (2017) studied the BWE effect in closed-loop supply chains. Overall, they concluded that an increase in the return rate decreased the BWE in a supply chain.

The main factors of interest in this research included return rate, lead times, and remanufacturing rate. Additional factors investigated were capacity limitations

(Tombido et al., 2021), product substitution (Tombido & Baihaqi, 2020), supply chain structure (Tombido et al., 2020), impact of different recovery options (Sy, 2017), inventory holding rates (Corum et al., 2014), return policy, and number of echelons (Cannella et al., 2016).

There are studies who did not agree that increasing product returns reduces the BWE. These include Ding and Gan (2009), and Adenso-Díaz, Moreno, Gutiérrez, and Lozano (2012) argued that when remanufacturing is introduced in a supply chain, BWE increases in the closed-loop supply chain, and it increases with an increase in product returns. This is one topic with a growing number of publications; however, there are still disagreements as to the impact of product returns on the BWE. This issue arises because studies differ in modeling assumptions and methods. This means that the BWE in closed-loop supply chains will continue evolving over time.

### 4.6 BWE as an Extended Topic

Although most of what Wang and Disney (2016) considered as BWE as an extended concept has been covered in most of the sections, a special BWE was introduced by Asgary and Li (2014) caused by unethical operations. In this type of BWE, risk amplification moves from the supply side to the demand side due to unethical operations conducted along the supply chain. Asgary and Li (2014) argued that this form of BWE originates from a minor unethical operational decision in the supply chain and results in a significant economic loss of a company's reputation and bottom line on the demand side.

It is interesting to note that since the introduction of the trends observed by Wang and Disney (2016), there has been an increase in the number of articles on the proposed trending issues on the BWE. However, there is still a need to explore all these trending issues.

## 5 BWE and the COVID-19 Pandemic

In this section, some research topics on the BWE introduced by the COVID-19 pandemic are explored. The COVID-19 pandemic started in early 2020 and is still in existence to date. This means that research needs to address this pandemic and future pandemic supply chain issues, and research on the BWE is no different.

The BWE during the COVID-19 pandemic has been known to be caused by changes in "customers' purchasing behaviour during the pandemic and businesses anticipating the situation inaccurately" (Zighan, 2022). In an exploratory research based on online interviews with 41 firms, Zighan (2022) investigated how firms can deal with the BWE caused by the COVID-19. Additional causes of the BWE during COVID-19 were identified by Zlotskaya (2021) who focused their investigation on information and technology and firms. They argued that there was an increase in demand in information and technology firms, and this led to fluctuation in prices, order delays, deviations from supply, and poor communication across channels, which are the main causes of the BWE during COVID-19.

Zighan (2022) identified situational analysis, localization of supply chains, and supply chain digitalization as the best ways of mitigating the BWE during the COVID-19 pandemic. Hsu, Yang, Zhang, and Chang (2021) also proposed a multi-criteria decision management framework for identifying key data enablers to enhance supply chain agility and mitigate the BWE, and Ran, Wang, Yang, and Liu (2020) also argued that the application of higher digital technologies can improve the BWE in a broader range, but it increases the production cost.

Research on the BWE during the COVID-19 pandemic did not just focus on the causes and mitigation – new research topics emerged on the BWE as a result of the COVID-19 pandemic. Since the pandemic started in China, Zhang (2021) investigated the BWE of Chinese exports. They discovered that the outbreak of COVID-19 in foreign countries caused a lagged import substitution toward Chinese products that initially reduced negative demand shocks that were prevalent during the initial stages of the COVID-19 pandemic. The author also concluded that the BWE is stronger in regional supply chains, among geographically close countries that are closely connected in terms of trade volume.

With the COVID-19 pandemic came the introduction of the COVID-19 vaccine supply chain that is expected to be strongly affected by the BWE as companies struggle to predict demand for the vaccine. Focusing on the BWE in the COVID-19 vaccine supply chain, Hosseini Bamakan, Malekinejad, Ziaeian, and Motavali (2021) designed a cognitive map based on influential factors for reducing the BWE. They argued that by improving inventory management and reliability, it is possible to control lead time and therefore overcome the BWE in the COVID-19 vaccine supply chain.

The COVID-19 pandemic also led to most companies focusing on supply chain resilience as an important goal. However, this did not eliminate the importance of studying the BWE. As a result, it became necessary to establish interrelationships between supply chain resilience and the BWE. Thomas and Mahanty (2020) examined interrelationships between resilience, robustness, and the BWE in an inventory- and order-based production system being subjected to operational disruption in the customer demand process. Their main conclusion was that resilience and robustness are two conflicting performance characteristics that exist in trade-off relationships and that the improvement in both supply chain resilience and the BWE can be achieved simultaneously if there is a proper selection of control parameters.

Lastly, the COVID-19 pandemic increased the use of online delivery apps as people avoided contact during lockdowns. Online delivery apps were used for the delivery of food and medicines among other products. Online delivery apps have an impact on the demand in a supply chain as the "e-supply chain causes price variations and result in poor forecasts and hence enhance the BWE" (Jain et al., 2020, p. 2).

In their research, Jain et al. (2020) investigated the impact of food delivery apps on the BWE in a food supply chain. Their argument was that the availability of many eateries at a single online platform with large price variations and different fame has increased competition and has imposed a threat on quantifying the demand of food on the online food industry. Online food delivery apps have shifted the demand of food from push to pull. They quantified the BWE differently and concluded that e-supply chain generated by food delivery apps reduces the BWE by increasing efficiency and effectiveness and increases value in the supply chain.

## 6 Emergent Concerns and Future Research Directions

The BWE is one topic that has evolved over decades, yet new topics and trends have emerged. This supply chain issue and topic that is not going away any time soon given that the structure and behavior in supply chains will make it a continuing issue. In this section, the chapter will identify some research gaps for future research on the BWE. These gaps are explained in the following sections and include gaps in BWE mitigation, other forms of BWE, and behavioral aspects of the BWE.

### 6.1 BWE Mitigation

It is evident that the majority of study and investigations have focused on the BWE as defined by Lee et al. (1997). In carrying out research on mitigating the BWE in supply chains, studies have mostly targeted causes of the BWE. Most research focuses on the operational causes on their own or the behavioral causes on their own. However, operational and behavioral causes of the BWE do not exist in isolation. Future study investigations should consider both operational and behavioral causes of the BWE together as a way of mitigating its outcomes and not just isolate the causes. In addition, more empirical evidence is needed on the study of the BWE, especially when trying to mitigate the BWE. Most studies have resorted to mathematical modeling and simulation with limited empirical evidence. It is necessary to have more of empirical evidence where mitigation is successful – detailed case studies will also be helpful from both a research and practical perspective.

In terms of the behavioral causes of the BWE, it should be interesting to investigate the impact of different technological developments such as Industry 4.0 and supply chain digitalization on the behavioral causes of the BWE. Currently, most supply chain players make decisions in groups, and it is also necessary to investigate the impact of group decisions on the behavioral causes of the BWE.

### 6.2 Other Forms of the BWE

A search for the BWE on Google Scholar results in more than 10,000 articles; however, a search for the other forms of the BWE such as the service BWE, CFB, reverse BWE, and green BWE results in less than 10 publications for each, respectively. There is a need for more investigation on other forms of BWE, from their causes, ways of modeling and measuring them, and their mitigation. This emergent concern needs to be addressed.

The service BWE was first mentioned in 2003, yet there are less than ten publications that exist on the topic to date. Another interesting research topic is that of the BWE in IMSN. Organizations are now integrating manufacturing and services as customer needs change. It becomes necessary to study such networks by defining the BWE, finding ways of measuring it, and providing empirical evidence of the BWE in such networks.

Companies are now focusing on maintaining their social responsibility by incorporating environmental issues in their supply chains. This focus has made green BWE study more important. Although there are publications on the green BWE, there are not enough to make consensus conclusions on the topic. The response to the green BWE in a supply chain depends on the characteristics of relationships between supply chain players. On this topic, it is necessary to explore relationships between supply chain players that can mitigate green BWE in supply chains. It is also necessary to study conditions that can make green BWE a positive phenomenon in the supply chain. It is quite evident that no one has studied the behavioral causes of the green BWE in a supply chain. That is also an interesting gap as relationships between supply chain players are sometimes a result of behavioral issues such as trust among other issues.

The reverse BWE can be caused by a delivery interruption or a production shutdown in an upstream supply chain echelon. Both these causes were experienced during the COVID-19 pandemic as industry shut down, and there were lockdowns that led to delays in delivery. However, it was also interesting to note that there were no studies specifically focusing on the impact of the COVID-19 pandemic on the reverse BWE in supply chains. This research gap can be explored with empirical evidence. The reverse BWE has also been studied more from a pricing point of view rather than from a product flow point of view. This also an emerging gap especially with the COVID-19 pandemic.

Although the CFB has been well defined in literature, much of the topic still remains a mystery, for example, the impact of the CFB on the profitability of a company and its investment capacity. The CFB has also not been studied from the COVID-19 perspective. There is also a need to study CFB control mechanisms and the dynamics associated with the CFB from the perspective of the omni-channel commerce.

Data quality BWE also represents an area in dire need of study as there is only one publication on the topic. Data quality BWE still needs further investigation in terms of its existence, causes, and mitigation. These investigations need to be backed by empirical evidence.

It is quite possible that a supply chain can have more than one form of BWE existing concurrently. This concurrency of multiple BWE types requires investigating the existence of different forms of BWE in one supply chain and establishes interrelationships between these forms of BWE. Another related type of investigation would be how mitigating one form of BWE might affect BWE types existing in that supply chain.

As supply chains introduce digital technologies, it is necessary to investigate the role of digital technologies in reducing each BWE type. It is also important to study these forms of BWE using different supply chain structures and not just the simplified one echelon supply chain. Supply chains rarely contain one manufacturer and one retailer, so it is necessary to consider other supply chain structures. Usually, supply chains exist in competition; it is also necessary to study these forms of BWE under conditions of competition between supply chains.

## 7 Managerial Implications

The analysis of BWE assists managers in evaluating their supply chains. By understanding the forms of BWE in their supply chain, managers can avoid costly losses and maintain a competitive edge in their supply chains.

The demand shocks, shortages of products, and economic decline that came about because of the COVID-19 highlighted the necessity of studying the BWE in all types of supply chains, be it manufacturing, processing, or service supply chains. The BWE moves in all directions of the supply chains and not just from downstream to upstream. As a phenomenon, the BWE is no longer associated with just demand variability but also data quality, environmental regulations, transportation disruptions, refers logistics, remanufacturing and cash flow among other things. This makes it more complicated, and managers need to understand the forms of BWE associated with their supply chain operations and continuously find the best strategy to mitigate the BWE. Companies need to assess how every decision they make might cause the BWE.

In a situation where every organization is trying to recover from the blows of COVID-19, studying the BWE at every angle and in every form becomes necessary because of the waste associated with BWE – such as overstocking, among others. Most organizations are focusing on recovery, and they cannot avoid such waste.

In addition, while most organizations are focusing on recovery and supply chain resilience in the face of future pandemics, it becomes necessary to investigate the impact of recovery and resilience strategies on the BWE as an organization might solve one problem by creating another. The implications of BWE in a global setting also arose; whether local or regional BWE impacts differ would be interesting for practitioners in terms of where to source from BWE and resilience perspectives.

The pandemic COVID-19 has reminded supply chain managers the importance of supply chain risk management. Disruptions caused by the pandemic are propagated in many directions. Managers must take into account the various forms of the BWE in their supply chain risk management.

## 8 Summary and Conclusion

This chapter introduced the concept of the BWE, its evolution, causes, characteristics, mitigation, and different forms. Current trends in BWE research and some trending research gaps were offered in the chapter. The chapter also explored research on the BWE introduced by the COVID-19 pandemic. By explaining some managerial implications, the chapter highlighted why studying the BWE has become more necessary now than ever, even though the topic has been studied for decades.

The BWE is a topic that has been studied for decades, yet it still evolves and new research gaps keep on emerging. Investigations on the operational causes of the BWE have mostly focused on make-to-stock environments; however, nowadays customers have gained the upper hand as they can demand customized products through online channels. This makes research on the BWE in make-to-order environments and interesting concept.

The COVID-19 saw the growth of online delivery apps. Online delivery apps are being used in different industries, including food, clothes, and medicines, among other industries. It is necessary to compare the impact of these online delivery apps on the various forms of the BWE for different industries as their impact may differ with industry and also the form of BWE.

In addition to introducing the vaccine supply chain, the COVID-19 pandemic also made some existing supply chains popular, for example, PPE, medical devices, and some pharmaceuticals. Since the COVID-19 pandemic is still in existence, there is a need for research investigating both the BWE in such supply chains.

Lastly, there is a need to expand research on the trends on BWE topics mentioned by Wang and Disney (2016). There has been research on the trending topics; however, there is a need to expand on each and every one of the topics.

To conclude, the BWE is a concept that has bothered supply chain managers and has been studied for decades. After studying the topic for decades, however, the BWE still exists in supply chains, and it is still a cause for concern. The COVID-19 pandemic has also revealed weaknesses in various supply chains, thereby highlighting the importance of studying the BWE. This chapter has shown that there is a need for more research on the BWE and that the topic is still evolving even after decades of study.

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# Supply Chain Performance Measurement: Current Challenges and Opportunities

Sharfuddin Ahmed Khan and Syed Imran Zaman

## Contents




**Abstract**

This chapter considers factors associated with supply chain performance (SCP) and investigates linkages between SCP and a variety of issues, which include enterprise resource planning systems, blockchain technology (BCT), data analytics, and supply chain sustainability. The chapter also provides an illustration of how these issues relate to (SCP). A holistic model to enhance SCP is presented. The chapter can help enhance supply chain operation efficiency.



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**Keywords**

Supply chain management · Supply chain performance · Blockchain technology · Lean practices and SCP · Supply chain integration · ERP · Data analytics · Supply chain resilience · Supply chain sustainability

## 1 Introduction

COVID-19 and the rising degree of competition in the global economy mean supply chains need to have effective supply chain performance measurement (SCP) (Kumar et al., 2017). Traditional supply chains have difficulty satisfying customer demands for high-quality goods at affordable prices. The current tendency is to incorporate new components while simultaneously making the present system more intelligent, automated, and environmentally friendly (Yadav & Singh, 2020). Issues businesses face, such as wasting time on the analysis of inaccurate and irrelevant data and dealing with difficulties like how to store and access massive amounts of data, lead to a decline in supply chain overall performance, efficiency, and organizational profits (Gopal et al., 2022). In this chapter, we introduce potential solutions to these problems. Solutions include boosting resilience, embracing blockchain technology (BCT), improving sustainability, deploying enterprise resource planning (ERP) systems, and integrating supply chains more effectively.

Performance measurement and management have emerged as crucial components for continued viability of businesses. Appropriate performance measurements help managers take a long-term view and devote organizational resources to improve operations. These performance systems ensure that managers adopt appropriate performance metrics (Elgazzar et al., 2019). Supply chain managers regularly compare their operational performance against benchmarks – an important performance measurement activity (Zhao et al., 2023). Nevertheless, modern supply chains are vulnerable to ever-changing business contexts leading to uncertainty and unpredictability.

In this uncertain environment, businesses are shifting their attention away from the development of resources and toward the growth of dynamic skills in order to reduce risks – such as a loss of reputation – and establish competitive advantages (Bag et al., 2020). Managers and researchers place high value on improving SCP, an important factor for fulfilling customer expectations and establishing competitive advantage. Businesses are strongly reliant on their supply networks to help in meeting competitive goals (Rahimi & Alemtabriz, 2022).

## 2 Background

SCP is defined as the degree to which a supply chain fulfills the needs of the end consumer (Carvalho et al., 2012; Hausman, 2005). According to Daneshvar, Hajiagha, Tupėnaitė, and Khoshkheslat (2020), the implementation of a successful strategy for the supply chain has a positive influence on the performance of the supply chain. Through supply chain management (SCM), organizations can support their competitive strategy and maintain competitive advantage (Sutanto & Japutra, 2021).

Companies may collaborate with another to monitor their SCP by using a measurement system with measuring instruments (Fernando et al., 2023). This measurement system measures SCP. Overall firm performance requires performance improvement of each function across the company's supply chain.

SCP refers to extended supply chain actions that fulfill the customer criteria. These activities consist of product availability, on-time delivery, inventories, and the capability of the supply chain to achieve the desired performance in a reactive way (Almatarneh et al., 2022). As part of SCP, organizations devote resources to new technology developments. These technologies support effective channels of communication and cooperative frameworks. This development ensures that information be effectively exchanged (Govindan et al., 2017). Competition across supply chains and maintaining organizational competitive advantage requires achievement and maintenance of SCP.

SCM performance can be separated into financial and nonfinancial indicators. Strategic financial performance measures are required for senior management decisions. Operational measures are required for decisions made by junior management and employees (Saleheen et al., 2018).

SCP should emphasize three distinct kinds of performance measurements: *resource measures*, which include costs, inventory levels, and manpower needs; *output measures* such as responsiveness to customers, and quality; and flexibility measures, which represent a system's adaptability to varying demand levels (Mazzawi & Alawamleh, 2013).

The supply chain operation reference (SCOR) model can be utilized to conduct an evaluation of SCM system performance in relation to customers, companies, and suppliers (Putri et al., 2019). The high-quality value of strong connections between members of the supplier network is directly tied to the successful performance of the supply chain as a whole (Mukhsin et al., 2022).

Since SCP encompasses raw materials, components, and final goods, as well as distribution to customers through a variety of channels, it cuts beyond the boundaries that separate individual companies. In addition, SCP crosses conventional organizational functional boundaries, such as those separating production, distribution, marketing, sales, and research and development (Almatarneh et al., 2022).

## 3 Supply Chain Performance and Resilience

The capacity of supply networks to address unforeseen disruptions is one definition of their resilience. The traditional focus for supply chain design has been to reduce cost or improving service. Recent focus has shifted to emphasize supply chain resilience (SCR) (Carvalho et al., 2012; Christopher & Cristopher, 2011; Hosseini et al., 2019). Resilient supply chain networks make it easier to deal with interruptions – resilience also makes it easier for supply chains to recover quickly. Resilience effects supply chain performance (Piprani et al., 2020).

Building resilience deters disruptive events from happening and contributes to establishing and sustaining acceptable levels of performance. Resilience is currently a critical SCP facilitator (Chowdhury et al., 2019).

When information-processing capability is aligned with the extent of supply chain interruptions, SCR may be favorably correlated with SCP (Belhadi et al., 2021). In order to improve the efficiency and robustness of the supply chain, studies have focused on identifying SCR indicators. Some of these indicators include redundancy and the flexibility of the transport system (Singh et al., 2019a). The effective supply chain resilience benchmark, as outlined by Guoping and Xinqiu (2010), includes the following: a rapid response to unexpected shifts in demand and supply; the ability to adapt to changing market structures and strategies; and the formation of unions among members of the supply chain in order to maximize both their individual benefits and the overall performance of the supply chain as a whole.

## 4 Supply Chain Performance and Sustainability

According to Seuring and Müller (2008), sustainable SCM (SSCM) is defined as: "*the management of material, information, and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental, and social, into account*."

Organizational sustainability is now a strategic endeavor (Gong et al., 2019). Both small and large organizations view environmentally friendly business practice adoption to have positive financial impact, lead to the creation of new income streams, and ultimately boost both consumer and staff satisfaction (Mincer, 2008; Narimissa et al., 2020).

Green supply chain management (GSCM) and SSCM include integrating environmental considerations into SCM activities – including product and design service, procurement, manufacturing processes, distribution, and end-of-life management of the product (Hapsari et al., 2021; Olugu et al., 2011). SSCM helps companies improve their environmental, economic, and operational performance; it is necessary to consider environmental factors when evaluating the past, present, and future performance of companies and their supply chains. This necessity occurs because SSCM contributes to improved company performance in all three of these areas.

As a consequence of this, studies argue that SSCM indicates increases in efficiency that result in cost reductions (Gold et al., 2010). Stakeholder involvement in SSCM helps determine the extent to which it may have an impact (Jermsittiparsert et al., 2019).

The features and practices of SSCM have a significant influence, both positively and adversely, on the performance of the supply chain in terms of environmental sustainability. Social responsibility practices have a significant correlation with environmental performance, and social responsibility activities, such as the design and development of environmentally friendly products, have a positive impact not only on environmental performance but also on social performance and financial performance.

Other social responsibility activities include the design and development of environmentally friendly products (Le, 2020). In a similar vein, a number of studies indicated that interactions with customers, processes and equipment, product design, and connections with suppliers all have a significant influence, both positively and negatively, on sustainable performance (Iranmanesh et al., 2019). Lean culture was found to have a positive relationship to sustainability (Bandehnezhad et al., 2012; Jum'a et al., 2021). The adoption of environmentally friendly methods also comes with a number of important financial advantages (Dubey et al., 2015). These benefits provide a "win-win" scenario for both businesses and the environment (Beckmann et al., 2014).

Green and sustainable activities can save materials and manufacturing costs, transportation and logistics costs, increased product quality, reduced costs for warehousing, and even increased inventiveness (Pagell & Gobeli, 2009). SSCM improves resource efficiency which is directly related to economic success (Cherrafi et al., 2018; Zhang et al., 2012).

Social sustainability indicators and supply chain performance measures include health and safety, as well as expenditure, social policy, workforce, job satisfaction, and ethical behavior on the job. Positive and negative societal repercussions may be determined by looking at factors such as accident rates and the number of employment possibilities available in the service sector (Sreedevi & Saranga, 2017).

In addition to these sustainability measures, ecologically responsible policies foster greater economic and environmental performance across areas (Colicchia et al., 2017; Khan et al., 2020). The improvement of both economic performance and environmental performance through the establishment of long-term buyer–supplier relationships is one of the most important components of SSCM. The provision that suppliers satisfy sustainability performance standards is another important aspect of SSCM (Trivellas et al., 2020).

## 5 Supply Chain Performance and Blockchain Technology

The blockchain (BCT) is a distributed ledger technology that employs features to guarantee the safety, openness, and transparency of a network (Liu et al., 2023). A decentralized structure, a distributed notes and storing system, a consensus method, smart contracts, and asymmetric encryption are some of the elements that are included in this technology.

BCT enables distributed data and storage (Dutta et al., 2020). Since the introduction of industry 4.0, several technologies, such as artificial intelligence, the Internet of Things (IoT), and blockchain, have been implemented more frequently. This implementation has led to an improvement in SCP assessment (Bamakan et al., 2021).

A BCT-enabled supply chain can support building closed supply chain partnerships and improving SCP (Kamble et al., 2021). BCT can provide new and desired directions for supply chains and boost SCP (Hald & Kinra, 2019). The BCT-SCP linkage includes the vertical restructuring of supply chain transactions as well as changes in the resources and capabilities of the businesses (Stranieri et al., 2021). Privacy, auditability, and overall operational efficiency in supply chains can be improved with BCT (Wang et al., 2018).

Manufacturing companies have recently applied blockchain for the purpose of improving SCP (Korpela et al., 2017). BCT has an effect on the resources of organizations and the performance of supply chains (Kamble et al., 2021). BCT is able to improve the level of collaboration that exists between supply chain participants in SCM and can positively influence supply chain costs and efficiencies (Aste et al., 2017).

BCT has to be supplemented by additional activities and procedures to contribute to the improvement of SCP that are more narrowly focused (Kim & Shin, 2019). The degree of openness of the supply chain as well as the degree of transparency offered by the blockchain both have a significant bearing on SCP (Wamba et al., 2020).

Kshetri (2018) provided an explanation of the function of blockchain in relation to the various SCP aspects – speed, dependability, cost flexibility, risk reduction, and sustainability. This structure had the intention of achieving strategic supply chain objectives with appropriate monitoring and increased responsiveness and operational efficiency (Kumar & Pundir, 2020).

BCT importance is growing partially due to it being a facilitator of SCP and for other aspects including trade partner preparation and pressure, information sharing, diffusion, and transparency (Wamba et al., 2020). BCT can help companies achieve improved performance on sales expenses, and ultimately relate to SCP (Figorilli et al., 2018; Wamba et al., 2020).

Businesses and the performance of their supply chains can benefit from BCT, and each benefit may have an effect on the overall economic performance of the organizations (Kamble et al., 2021). According to J. Wang, Wu, Wang, and Shou (2017), a blockchain-enabled application has the potential to improve the procedures that are currently used in SCM by improving data and product flow transparency and traceability. To best achieve these beneficial results, the number of participants should be larger (Abeyratne & Monfared, 2016). BCT has the ability to alter practically all SCM business models, improve supply chain business processes from beginning to finish, and, as a result, provide greater support for SCP (Aste et al., 2017).

## 6 Supply Chain Performance Measurement and ERP

Enterprise resource planning (ERP) systems refer to integrated and adaptable (modular) information systems (Kumar & Van Hillegersberg, 2000). ERP integrates cross-functional business processes and facilitates the communication of information across several divisions and stages both inside and outside the organization (Ghosh & Biswas, 2016).

ERP systems typically have a modularized suite of business software packages that are seamlessly integrated to allow automatic interactions and a common source of data for the performance of a company's supply chain (Jonsson et al., 2007). An ERP system is sometimes referred to as a business information system (BIS) (Forslund, 2010).

Stratman and Roth (2002) define ERP competency as a portfolio of competences that encompasses not just management but also organizational and technical abilities. In order to put these capabilities to use and enhance not just the performance of the company but also the performance of the supply chain, the ERP system has to be reliable from a functional standpoint and able to execute its intended functions (Koh et al., 2014).

ERP systems and SCM offer potential to improve SCP (Su & Yang, 2010). ERP can meet SCM requirements integrating all aspects of the organization and can confer a variety of benefits. ERP can support improved decision-making founded on accurate and updated information. The cumulative impact of all of these factors will result in an improved SCM efficiency (Klaus et al., 2000; Shatat, 2015).

ERP benefits are improved if appropriate partners are part of the SCM performance system especially in complex business environments (Chang et al., 2008). Appropriate partnerships allow organizations to better manage their SCM (Ghosh & Biswas, 2016). ERP can support supply chain operations and analyze its influence on supply chain outputs (Aziz et al., 2018).

Effective ERP deployment can support data alignment and constantly improves the systems. It results in improving supply chain performance (Madapusi & D'Souza, 2012; Santoso et al., 2022). It has been shown that the successful deployment and efficient utilization of ERP systems may assist toward increasing SCM measurement and performance (Shatat & Udin, 2012). ERP software programs throughout a company's supply chain function without any hiccups, allow for the smooth and real-time exchange of data across the supply chain, and facilitate a strong relationship with the company's suppliers and consumers, including SCP (Alazab et al., 2021).

## 7 Supply Chain Performance and Integration

According to Samaranayake (2005), supply chain integration is defined as a "*circumstance in which members of the supply chain interact and work together with the purpose of improving the supply chain's performance and profitability*" (Kumar et al., 2017). When businesses can use each other's resources through an integrated supply chain, the supply chain's performance in meeting consumer needs improves (Som et al., 2019). According to Stank, Keller, and Closs (2001), supply chain integration is the process by which a company aligns its internal business functions with its supply chain partners, with the goal of improving the value provided to customers and the overall performance of the supply chain as a whole for all partners involved (Kumar et al., 2017). Integration of a company's supply chain is one of the strategies that can be used to improve a company's competitiveness and its delivery of performance. These kinds of activities may enhance the supply chain performance measures (Sundram et al., 2016). It is generally accepted that companies pursue integration to obtain advantages such as enhanced quality, reduced manufacturing costs, enhanced SCP, and a competitive edge over other enterprises (Mofokeng & Chinomona, 2019). According to da Silveira and Arkader (2007), the integration of supply chains facilitates the reduction of lead times between processes, the improvement of product availability, and the enhancement of SCP (Sundram et al., 2016). One of the goals of businesses to develop a supply chain integration is to improve the performance measures of their supply chains and to meet industry standards (Youn et al., 2013).

Integration in the supply chain has been shown to improve its performance measures; hence, it is vital to lay out clear cut indications on what they aim to assess in order to accurately evaluate the supply chain. There are various detailed indications such as increased quality, stock-out rates, and improved lead time (Crandall et al., 2009; Kang & Moon, 2016). Integration of supply chains is connected to the business performance and the operational performance of supply networks (Qrunfleh & Tarafdar, 2014). The supply chain integration strategy has a substantial influence on the performance of supply chains, but this influence is exerted only in the capacity of an enhancer of the connection between information integration and SCP (Yawar & Seuring, 2017). Given that supply chain integration has been highlighted as an essential competitive strategy, it is possible to think of SCP as a proper antecedent of supply chain integration (Li & Chen, 2018). Long-term connections have the potential to boost a company's success, and a substantial correlation exists between the integration of logistics and SCP (Prajogo & Olhager, 2012).

## 8 Supply Chain Performance and Data Analytics

Data analytics may be defined as "*the gathering of data, analytical tools, computer algorithms, and procedures in order to draw meaningful insights and patterns from the massive data sets that have been gathered*" (Jeble et al., 2018). The integration of data science with other disciplines, including statistics and computer science, enables the extraction, refinement, storage, and monitoring of valuable data from vast quantities of raw data, with the aim of facilitating informed decision-making (Kamble & Gunasekaran, 2020). According to Janssen, van der Voort, and Wahyudi (2017), adopting and implementing data management systems are imperative for companies to attain optimal supply chain sustainability performance. This scenario arises when there is a notable ambiguity level in the surrounding environment (Bag et al., 2020). Supply Chain Data Analytics is becoming an increasingly important tool for executives working in the supply chain (SC) to use for the management, processing, and analysis of their data. Data analytics has traditionally been portrayed as the primary driving force behind both organizational and supply chain success (Bahrami et al., 2022; Jha et al., 2020). Companies have utilized data analytics to enhance supply chain efficiency and leverage company performance to achieve business optimization via innovation. Industries are under a great deal of pressure to improve the overall performance of the SC in order to get a competitive advantage over their rivals, and this pressure is increasing with time. In a world that is driven by data, businesses may be able to live, breathe, strive, and keep their competitive advantage by inventing and producing innovations that are data-driven (DDI). This is the method that businesses use in order to build and develop data-driven innovations (Gopal et al., 2022).

The incorporation of data analytics into corporate processes and supply chains helps firms to more effectively realize their customers, lower service costs, more effectively regulate risks, and generate new revenue streams that were not previously envisaged (Bahrami et al., 2022; Mishra et al., 2018). Data analytics helps companies improve SCP components. Improvements can be made in areas such as increased flexibility, responsiveness, customer service, and dependability (Cho et al., 2012; Fernando et al., 2018). The strategic value of the DA phenomenon is a significant reason why organizations recognize its substantial contribution toward their goals. Nevertheless, it is necessary to emphasize the significance of strategic planning to the operational effectiveness of businesses, given that this factor contributes to and improves supply chain sustainability performance (Singh et al., 2019b). According to I. J. Chen and Paulraj (2004), SCM focuses on improving the flow of products and materials through a company by exchanging and evaluating data on the activities that take place throughout the supply chain during both internal and external business dealings. This is accomplished by exchanging and evaluating data on the activities that take place throughout the supply chain during both internal and external business dealings (Hallikas et al., 2021).

## 9 Current Concerns

Even though there are many methods and models for measuring SC performance, there are still many obstacles to overcome. These include the need to evaluate vast amounts of data that must first be analyzed, a lack of alignment between tactical, strategic, and operational measures, an absence of clearly defined metrics, and the absence of a balanced approach (El-Baz, 2011; Panayides et al., 2018). Due to increased complexity, we need more powerful tools of performance measurement and evaluation processes (Ramezankhani et al., 2018).

Datta (2017) and Dubey et al. (2020) noted that the research on how supply networks create resilience is still in its infancy and needs to be updated to keep up with the rapid advancements in technology and supply chain dynamics, because the research has not yet matured. This shortcoming has an effect on the performance of the supply chain, which is one of the most essential goals of supply chain management (Belhadi et al., 2021).

Evaluating the success of SCs in terms of sustainability among their multiple members, such as suppliers, manufacturers, distributors, and consumers, is a challenging and demanding task. The extensive array of existing sustainability metrics should be combed through by SC management to select, combine, and form key performance indicators (KPIs). This would make the decision-making process simpler across the board for management (Qorri et al., 2018).

Blockchain is dealing with a lot of severe problems. As a result of the immaturity of the technology, it has some technological challenges. The challenge of ensuring that inter linkages between BC shards are both efficient and consistent may be a demanding one. Furthermore, mining BC transactions may require a significant amount of computer power, and the addition of even a single block to an existing BC may result in a tremendous amount of energy usage. In addition, there is a dearth of human resources that possess the appropriate knowledge and abilities (Jabbar et al., 2021; Rad et al., 2022). When the blockchain is enabling, when it is created with usability and when it is developed with an upgrade logic, only then will it support and increase the capabilities of the supply chain and use the supply chain's talents and intelligence. This shifts organizational processes in new and desirable directions, and it also has the potential to improve SCP over time (Hald & Kinra, 2019).

The supply chain integration literature suggests that integration may influence performance results various ways. Integration, on the other hand, is believed to heighten the level of rivalry between the two companies, and it boosts the competitive advantage of supply chain partners (Li & Chen, 2018; Mofokeng & Chinomona, 2019). Similarly, the quantity of information and data that is available is fast expanding. Retail companies are facing issues such as wasting time in analyzing irrelevant and inaccurate data, as well as challenges such as how to store and access massive amounts of data, etc., which, in turn, decreases the overall performance and efficiency of the SC as well as the profits of the organizations. Retail companies are also facing challenges such as how to access massive amounts of data. This is because the SC has a wealth of information in its storage space (Gopal et al., 2022).

## 10 Emergent Concerns, Outstanding Research, and Future Directions

In today's world, supply chains are implementing innovative ideas, policies, and strategies in an effort to eliminate the insurmountable obstacles associated with their supply chains. In other words, they are looking for a way to find a solution to the problems that cannot be solved. They achieve this goal by making it a priority to identify and implement solutions to the problems that are linked with the various links in their supply chains. Consequently, there is a significant need for a performance assessment system that is both effective and accurate to assist businesses in accomplishing their financial goals by monitoring the implementation of new strategies, because such a system is needed to assist businesses in accomplishing their financial objectives (Jayaram et al., 2014; Ramezankhani et al., 2018).

When businesses work toward environmental sustainability, managers have a responsibility to strengthen environmental practices throughout the entire supply chain. The amount of published material describing environmental management inside the supply chain has been steadily increasing, although it is still relatively limited. Consequently, there is a need to expand the SCP evaluation utilizing a fuzzy logic method to a close loop chain, which is an environmentally friendly supply chain that combines suppliers, manufacturers, distributors, consumers, and reverse logistics (Olugu et al., 2011).

A low data quality would have a severe influence on the overall performance measures of supply chains because of the rising significance of data-driven decision-making in the management of supply networks. It is essential to perform duties such as monitoring, measuring, and controlling the data quality to ensure its accuracy (Arunachalam et al., 2018). Businesses need to construct resilient RSCs through their capabilities in operational and information management to improve their current business performance and achieve sustainability in the postpandemic environment. This will allow the businesses to improve their performance going forward. They will be able to react more quickly to shifts in customer preferences and developments in technical capability as a result of this. This will help businesses improve their corporate performance (Sharma et al., 2021).

## 11 Managerial Implications

This chapter allows policymakers, industry professionals, consumers, and practitioners to identify and assess drivers connected to the adoption of SCP. The research of this chapter may help managers develop strategic policies to progress SCP decision efforts in SCs. The following are implications:

Backing and encouragement from the government in SCP-focused initiatives: It is essential to have governmental support in terms of finances for the implementation of sustainability-focused activities. It may boost the SCP efforts and raise the SCP trends when seen within an SC framework.

Understand the behavior of organizations and markets, as well as create high standards and goals: From the standpoint of SCP, understanding market and organizational behavior and building sustainability into strategic policies are both crucial. This makes setting sustainable development criteria and goals easier for organizations.

The chapter educates customers and people about adopting SCP trends in business. To improve their capacity to embrace sustainable modes of production and consumption, workshops and public awareness campaigns may be organized.

Conduct research on external elements and align the sustainable goals of members of the supply chain: This work enables a better knowledge of external aspects concerning sustainability in business, such as the behavior of the market, the attitude of suppliers, and the preferences of customers.

This effort also assists managers in aligning and streamlining the operations of members and partners of the supply chain in order to achieve SCP trends throughout the SC. Building an SCP-centric system from within an existing SC framework in an organization requires careful synchronization and coordination among all involved parties.

The identified opportunities for both managerial decision-makers and government policymakers play a significant role in making the most of the opportunities in a way that improves SCP and mitigates the impact of the challenges experienced by supply chain. Sustainable SCP requires supply chain managers to adopt reliance, enterprise resource planning (ERP), data analytics, and supply chain integration; and improve the blockchain's enabling powers while minimizing its constraining powers.

## 12 Summary and Conclusion

During the investigation for this chapter, we came across a number of recent developments that are still in the process of gaining momentum. It is anticipated that these trends would provide both theoretical and practical challenges in terms of the performance evaluation process. During the performance management literature review, many research objectives were found, but most addressed current issues. Although each of these problems deserves consideration on its own, taken together they do not provide a perspective of the difficulties involved with performance assessment that is exhaustive, unified, or prospective. This chapter anticipates and draws attention to future performance assessment challenges. Consequently, we have made it possible for the community to develop preventative research projects in order to prepare for the difficulties that lie ahead. The primary shortcoming of the research is that the chapter covers a broad range of topics, analyzing and debating literature from several different aspects of performance assessment, but without delving deeply enough into any one of them. This is so because the chapter touches on so many different topics. On the other hand, we believe that this piece of writing contains an error which also serves as one of its merits. After doing such a comprehensive review of the relevant literature and having a discussion about the findings, we have identified several obstacles to further research which have come to our attention. Henceforth, there is a need to rethink our approach to how we do research in the field of performance evaluation. This came to our attention recently. Indeed, there is a need for research that takes a systems-based, all-encompassing approach to the issue at hand, acknowledging the intertwined nature of the challenges that the industry faces while focusing on a specific issue. The existence of a gap in the existing body of knowledge necessitates this research. As researchers, we may feel driven to concentrate on a certain occurrence and try to get an understanding of it within the context of this complex system. However, practitioners have to live and deal with all of this complexity and the phenomena concurrently; as a direct consequence of this, we have the opportunity to rethink and restructure how we do research on performance evaluation in the future.

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# Performance Measurement: Value Creation

Nathalie Fabbe-Costes

## Contents



**Abstract**

Performance measurement–value creation is a core competence of supply chain management (SCM). It is an important topic for researchers, a key competence for supply chain managers, and an important subject for students. This chapter is

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aimed at both SCM novices and professionals, working in research, teaching or involved in practice, and its purpose is to provide valuable knowledge as well as to motivate readers to think and ask questions about this complex topic. This chapter provides an in-depth analysis of the "performance measurement–value creation" topic in supply chain management (SCM) from the 1970s until now, highlighting the successive issues and key points discussed over time. A general review of this evolution shows the increasing importance of supply chain (SC) performance measurement and value creation, but also points out its complexity in practice. This analysis pinpoints strategic issues as well as difficulties, in particular with regard to SC performance management systems (SCPMSs). The current questions identified by the overall analysis reveal the need for renewed approaches to designing SCPMSs from both the research and practice perspectives. This chapter offers a conceptual basis to address the performance measurement–value creation topic and to think about how to design relevant, useful, and impactful SCPMSs that help SCM to create more value. This chapter looks at under-researched questions and raises important issues for future research. It includes a comprehensive framework that provides guidelines for practice.

**Keywords**

Supply chain performance · Performance in SCM · Value creation · SC/SCM performance measures · Measuring SC/SCM performance · Performance metrics · Performance management system

## 1 Introduction

Supply chains (SCs) and supply chain management (SCM) are recognized as strategic elements of organizations in all economic activities. SCM is meant to improve SC performance and create value. However, this well-acknowledged assumption results in a difficult and endless journey for SC managers and top management of organizations. The assessment of SC performance measurement–value creation is a core, but complex SCM activity and a competence that helps bridge business strategy and operations through tactical and operational strategy (Cavinato, 1992). But, many companies find it hard to develop a clear operational strategy to fit within the broader corporate strategy – making execution difficult (Forbes, 2021; McKinsey, 2019) with this challenge being even more crucial for their supply chains.

Performance measurement and value creation assessment is an essential but challenging interactive process between SC strategy (with expected and effective value creation) and SC operations (with evidence of SC performance). These items and relationships provide evidence of SCM contribution to the organizational success – or failure. Performance measurement and value creation assessment is also a source of learning through the analysis of SC performance and SC outcomes. Implementing refined performance measurement systems and diving into the data to better understand how to improve the management of SCs and their contribution to value creation can be worth the investment. However, building and maintaining a relevant SC performance management system (SCPMS) is more complex than generally acknowledged.

> Performance management is a key ingredient of successful strategy execution. If done ineffectively, this leads to problems such as unclear or missing objectives and targets, wrong use of measures and performance indicators (KPIs), failing resource allocation, or counterproductive incentives. (Forbes, 2021)

SC performance measurement and value assessment is also a time-consuming activity, leading to bureaucratic excess and intrusive monitoring, which exacerbates sensemaking problems both at the strategic and operational levels. It is important not to fall into the "tyranny of metrics" (Muller, 2018). We need a clear understanding of what SCM performance measurement and value creation means, of the difficulties that arise in designing and implementing beneficial SCM performance management systems, and of ways to overcome them. The goal is to benefit from efforts of measuring things that really "count."

This topic, of great importance for practitioners, is a critical area for researchers in SCM. Since the 1970s, logistics and SCM have focused on improving performance, in particular cost-effectiveness and productivity. However, with a better understanding of the strategic power of SCM in companies, the nature of SC performance targets has evolved in connection with value creation. Today, more SCM academics consider that SCs have to fulfil evolving and paradoxical objectives – for example, to be profitable and sustainable. These paradoxical objectives make SC performance measurement and value assessment complex and challenging. It is all the more challenging since SCs themselves have become more complex because of globalization and outsourced activities, made possible by and encouraging specialization, leading to worldwide fragmentation. In the 1990s, SC performance measurement and value creation was a hot topic for researchers. With current challenges – such as climate change and emergent risks and uncertainties – and current SC digitalization efforts it has once again become a critical research topic raising new ontological, epistemological, methodological, and ethical questions.

Therefore, it is of strategic importance to better understand how SCs and SCM can create value – what kind of value and for what kind of stakeholder. It is also important to define and implement a comprehensive SCPMS with useful SC performance measures that make sense for everyone, and to improve the understanding and assessment of the SC performance–value link. These key issues exist for researchers and practitioners facing the need to develop and adapt their SCPMS to address SC strategic sustainability issues and adoption of digital technologies. Students should acquire the conceptual bases to address this topic and to learn to think about how to design and implement relevant, useful, and impactful SCPMSs supporting SCM value creation.

The purpose of this chapter is to explain the importance of measuring SC performance and linking it with SCM value creation. The chapter also describes the current state-of-the-art regarding performance measurement and value creation in SCM and raises important issues for future research. Approaches to overcome difficulties, limitations, pitfalls of performance measurement in SCM, and criticism regarding the phenomenon of "metrics fixation" are also presented.

The chapter offers a solid conceptual basis regarding SCM, SCs, performance, measurement, and value. It also traces the evolution of performance measures related to the evolution of the strategic value that SCs must deliver in line with business strategies – a never-ending story. The paradoxical nature of SC performance and the complexity of measuring it require renewed approaches to designing SCPMS both from the research and practice perspectives. Accordingly, the chapter provides guidelines for designing performance management systems dedicated to SCM aligned with strategy.

The **Background** section provides discussion on origins and evolution of the topic; it is important to understand the beginning in order to assess where it stands now. The **Current concerns** section provides an analysis of the evolution, pointing out the most important aspects to consider today, as a novice or an experienced SC manager or researcher. The **Emergent Concerns, Outstanding Research, and Future Directions** section raises issues, questions, and directions for future research. Finally, the **Managerial implications** section proposes a comprehensive set of guidelines for practice.

## 2 Background: Performance Measurement and Value Creation – Overview of the Evolution of This Topic in the SCM Academic Literature

Performance measurement has always been considered a core logistics and SCM activity and competence. The study of the relationship between SC performance and value creation is a critical research question. An analysis of the academic literature on this topic – which has always been connected to practice – reveals an important evolution that is worth retracing. Table 1 at the end of the section summarizes this evolution.

### 2.1 The Roots of SC Performance and Value Creation: The 1970s and 1980s

An analysis of the academic literature shows that this topic has significant roots in the logistics management literature (e.g., Persson, 1991; Chow et al., 1994). In the 1970s, the management of materials and material flows became a concern. "Logistics tend to become an unavoidable cost factor that at best should be minimized" (Persson, 1991, p. 2). Performance measurement was focused on the cost of stocks, of material flows, and of in-house logistics activities in companies. The link between business strategy and logistics was not studied though, since logistics was considered to be determined by business strategy. Moreover, since logistics activities were

**Table 1** Evolution of the topic and of its main themes

| Period | 1<br>Main SC performance | 2<br>Contribution to strategic objectives | 3<br>Role of SCM in company management | 4<br>Scope of the performance/value analysis | 5<br>Link between SC/SCM and strategy | 6<br>Place of Logistics/SCM in companies |
|---|---|---|---|---|---|---|
| 1970s | Focused on **cost control** and improved productivity of operations | Support to increase organization's **profitability** | Focused on materials flows and logistics management. A basic **compulsory activity** that generates costs.<br>A **support** function to others | Mainly an intra-organizational scope | **Top-down**. Logistics strategy **determined** by the formulation of the business strategy | In-house logistics Activities scattered internally.<br>Little outsourcing |
| 1980s | Focused on **cost reduction** + **performance** of the **logistics service** to customers (quality, rapidity, reliability, etc.)<br>The "golden triangle" (cost, quality, time) | Support for the organization's **competitive strategy**: cost leadership and/or differentiation thanks to logistics service quality | Logistics adds value to products.<br>Helps to respond quickly and efficiently to markets.<br>Becomes a **core activity** in the value chain.<br>Adopts a **profit-center orientation** | Intra-organizational scope + local inter-organizational scope, with direct customers and suppliers whose role is acknowledged | Logistics /SC strategy **more systematically associated** with business strategy.<br>Some stellar logistics/SCM departments able to develop and promote logistics/SC strategies | Integration of material flow processes.<br>Grouping activities under a "Logistics/SC" department umbrella.<br>Outsourcing of transport activities and some related non-core activities |
| 1990s | New **SC performance** indicators related to SC behavior<br>(e.g. Responsiveness, Flexibility, Adaptability). | SC: a source of organizational **competitive advantage**.<br>Differentiation and innovation with | The SC is considered to be a **strategic vector** using time and space.<br>A **proactive** approach to | Toward a wider inter-organizational scope (the "**supply chain**").<br>Measures adapted to the international SC | An **iterative** top-down/bottom-up **dialogue**. SCM able to provide key inputs to strategy formulation. | Greater visibility and power of the logistics/SC department.<br>Outsourcing of more manufacturing and logistics activities. |

(continued)

**Table 1** (continued)

| Period | 1<br>Main SC performance | 2<br>Contribution to strategic objectives | 3<br>Role of SCM in company management | 4<br>Scope of the performance/value analysis | 5<br>Link between SC/SCM and strategy | 6<br>Place of Logistics/ SCM in companies |
|---|---|---|---|---|---|---|
| | Introduction of green SC performance measures | customized products and services | management of flows and processes | arena (seeking **standards**) | Quest for **SC excellence** | Importance of third-party logistics (TPL) |
| 2000s | Additional types of behavioral SC performance gained through IS/IT (Agility, Visibility) | Source of new business development (growth drivers) and more sustainable competitive advantage gained through SC innovations | SCM: a capability for redesigning SCs and their processes with virtual integration of external partners (in line with IT/IS-driven SC innovations, e.g. virtual logistics, omnichannel) | **Extended Supply Chain** (with end-to-end partners). From chain to network, including TPLs and other service providers (e.g. IT).<br>A more **virtual** and **global** arena | SCM able to **dynamically** align business strategy, SC strategy and their environment.<br>SCs are "complex adaptive systems" | Outsourcing of logistics function (a core business for TPLs and 4PL).<br>Giving power to Purchasing and IT departments?<br>An SCM department focusing on SC design and control (thanks to SCPMS) |
| 2010s | Additional types of behavioral SC performance linked to societal impacts and/or crises (Resilience, Sustainability, Social Responsibility) | Again at the center of organizational strategy, but with multiple conflicting roles | The capability to deal with complexity, risks and uncertainty thanks to the redesign of SCs.<br>SCM: dancing with paradoxes.<br>Adopts a **purpose-driven orientation** | SCM **ecosystem**, including other stakeholders (e.g. citizens, politicians).<br>Closed-loop, **circular** SCs.<br>**Inter-SC** synergies | SCM able to **face and cope** with any drastic environmental change.<br>SCM able to **proactively** contribute to sustainable development | SC function gaining ground as a strategic adaptive function (with increasing role of SCPMS).<br>A boundary spanning function and activity with absorptive capacity and scanning capability |

scattered under the responsibility of multiple departments, there was no logistics strategy as such. The objective during that period was to better understand how to control costs and improve the productivity of logistics, presumed to contribute to profitability.

In the 1980s, the nature of competition changed. Cost remained an important issue, and cost reduction was a cornerstone of logistics management. However, quick delivery and reliable quality of products and services were becoming weapons to differentiate from competitors. It became clear that logistics activities could contribute to creating a competitive advantage and that logistics should be linked more systematically to business strategy (Persson, 1991). It was therefore important to measure the performance of the service delivered to customers and to better understand how to improve it.

Although some logistics activities were progressively outsourced, performance metrics were mostly internal in the 1980s and early 1990s (Lambert & Pohlen, 2001). To balance service quality and costs, material flow processes needed to be better integrated and logistics management more consistent, leading to the creation of dedicated departments in charge of the overall management of flows. This formalization paved the way to greater recognition of the strategic significance of logistics and its capacity to create value. The rather negative cost-center view of logistics progressively gave way to a more positive profit-center orientation. Improving the effectiveness and efficiency of logistics and SC processes led companies to recognize the importance of working more closely with direct customers and suppliers, acknowledging that their logistics and SC performance was interwoven with that of their partners.

## 2.2 Toward Excellent Extended SCs: The 1990s – The Rise of SC Performance Metrics Fixation

The end of the 1980s and early 1990s marked a paradigm shift. Logistics became recognized as a core activity in value chains (Porter, 1995) and logistics and SC departments entered into the conversation to formulate business strategy (Fabbe-Costes & Colin, 1994). Logistics performance measurement therefore played a central role in achieving functional excellence and guaranteeing the success of "world-class firms." A study by Fawcett and Cooper (1998) proved that firms were improving their overall measurement capability, which was "one part of their effort to develop world-class logistical capability" (p. 342).

> Four dimensions encompass effective measurement practice at world-class companies: an improved functional measurement capability; a process orientation that facilitates internal integration and external alignment; benchmarking that provides the impetus for continued learning and improvement; the use of partner and supply chain scorecards to evaluate the role and performance of supply chain members and the overall supply chain. (Fawcett & Cooper, 1998, p. 352)

Measurement, which “reflects a firm’s adoption and regular use of internal and external performance metrics” (Goldsby & Stank, 2000, p. 193), is one of the four competencies identified in the “world-class logistics competency model.” Measurement includes three dimensions: Functional Assessment (the development of comprehensive functional performance measurement capability), Process Assessment (the extension of performance measurement systems across internal and external logistical processes), and Benchmarking (the comparison of metrics and processes with best practice performance).

In the early 1990s, the notions of supply chain and SC management (SCM) competed with logistics. Behind the “relabeling or new reality” debate was the need to promote an integrated vision of SCs (Cooper et al., 1997). The competition was increasingly between entire SCs rather than between individual companies. As stated by Lambert and Cooper (2000), “individual organizations can no longer compete as solely autonomous entities, but rather as supply chains.” According to Chow et al. (1994, p. 26), “consideration should be given to assessing the performance of the supply chain, not just that of individual participants.” It was therefore necessary to “move beyond the dyadic relationships to measure the performance of the entire supply chain” (Fawcett & Cooper, 1998, p. 356).

Defining SC metrics to evaluate and align performance across multiple companies in the SC became an issue both for practitioners and researchers (Lambert & Pohlen, 2001). Owing to the development of outsourcing, both for manufacturing and logistics activities, most SC managers considered SC metrics “as a means to increase their ‘line of sight’ over areas they do not directly control, but have a direct impact on their company’s performance” (Lambert & Pohlen, 2001, p. 1). This was even more important because of globalization and the international deployment of SCs.

The 1990s revealed that the competition was not only to deliver the best product or service at the most attractive price, but that companies should develop new products and services, be more responsive to customer demand and work in a more flexible way. Improving the behavior of SCs to produce more customized products and services in a timely manner became a strategic issue that called for new SC performance measures – such as responsiveness and flexibility. To give greater voice to SC departments in the company strategy conversation and justify investments in developing SCM, it was also necessary to clearly demonstrate the contribution of SCM to financial value creation. This justified the introduction of financial measures such as Economic Value Added (EVA) as detailed in Lambert and Pohlen (2001).

Intensified SC competition also led practitioners and researchers to undertake SC performance benchmarking studies. The objective was to compare performance metrics – such as hard, quantitative, if possible, fact-based, key performance indicators or KPIs – and search for best practices in terms of SC performance management systems (SCPMS). In the mid-1990s, the quest for SC excellence (Stewart, 1995) boosted research about SC performance measures and metrics that could help performance assessment and benchmarking in order to identify so-called “best SC practices” (Cohen & Roussel, 2005).

Efforts were directed at defining performance standards to facilitate comparisons, in particular standardized SC benchmarking metrics – such as cash-to-cash cycle time and supply chain response time – with hard indicators that could be linked together in a chain from the supplier of the supplier to the customer of the customer, the SC being inter-organizational. These efforts were supported by the implementation of enterprise resource planning (ERP) systems, promoting the integration of systems and databases in companies, and easing inter-organizational electronic data interchanges (EDI).

Various characteristics evolved during this time, including: geographical extension of SCs; their development in terms of the number of actors involved and the variety of activities; and the multiplicity of different types of performance and value to measure. All these characteristics required more structured SCPMSs that could help to identify trades-off and provide elements for decision-making. Companies developed or adopted balanced metrics frameworks (e.g., in Stewart, 1995) associated with benchmarking initiatives. Consultancies such as PRTM (a subsidiary of Price-Waterhouse Coopers) promoted such combined practices – see Cohen & Roussel, 2005. Adopting the balanced scorecard (Kaplan & Norton, 1992), most SCPMSs used performance metrics to assess the performance of SC processes from three perspectives: customers, shareholders, and internal stakeholders. The popularity of these initiatives led to the formulation and widespread adoption of the supply chain operations reference (SCOR) model (Sürie & Wagner, 2008).

By the end of the 1990s, the development of reverse SCs, the beginning of environmental concerns, and the implementation of more environmentally responsible logistics practices (Goldsby & Stank, 2000), were the impetus for addressing SC green performance. These green performance metrics linked to more general strategic issues related to sustainable development. This evolution led to significant impacts since: “A proactive or ‘value-seeking’ environmental approach calls for major revisions in planning, training, and systems” (Goldsby & Stank, 2000, p. 200).

Measurement systems were revealed to be critical in the incentive programs that reward employees and managers for their involvement in more sustainable logistics and SC activities, and consistent evaluation of environmental performance and environmental auditing were needed to obtain world-class certifications (Goldsby & Stank, 2000). More generally, competence in performance measurement was expected to be conducive to the implementation of any new SC practice.

The 1990s laid the foundations of measurement best practices with normative guidelines for companies. For example, Stewart (1995) suggests establishing and communicating a clear set of regularly measured goals for the company. These goals should include accountability throughout the organization for achieving them. This communication also allows information to be readily accessible and shared throughout the organization – allowing everyone to understand the key metrics and their respective drivers. It also allows for making broad fact-based decisions quickly and consistently. All these characteristics made it was necessary to develop SC performance management capabilities, which entailed collaboration with management accounting (Seal et al., 1999; Dekker & van Goor, 2000).

## 2.3 New Technologies, Increased Digitalization and SCM Innovations: The 2000s

The 2000s marked an important turning point linked to the development and diffusion of information technologies (IT) and information systems (IS) in companies. Alongside IT/IS, the Internet played a key role, opening the door to virtualization and wider digitalization of SCs and SCM. New technologies also offered opportunities to improve the SCPMS and its role in SC control and governance. As a consequence, a significant amount of work has been done in the area of SCPMSs starting in the 2000s (as reported by Balfaqih et al., 2016; Maestrini et al., 2017).

From a strategic point of view, the Internet opened new SCM horizons. It inspired the reengineering of processes: sourcing, manufacturing, retailing, and product returns (end-of-life or returned to repair or resell). The Internet boosted the development of e-commerce: online selling (sometimes combined with physical stores and/or drive-throughs), virtualizing some products and services (doing away with physical flows, e.g., music, books), developing vertical and/or horizontal marketplaces (with suppliers, customers and/or competitors) with new partnership management, and inventing new services based on virtual channels.

Multi- or omni-channel distribution led to more complex distribution networks, with new challenges in terms of stock, asset and flow management, and logistics with last-mile issues. Industry 4.0 technologies also introduced changes in designing, manufacturing, assembling, maintaining, and recycling products and services. The servitization of industries – such as the automotive industry – with new business models also had major impacts on SCs and SCM. These changes expanded the role of end-customers in SCs. They pull on supply chains with online orders specifying the desired characteristics of products or services, last-mile delivery puts them in direct contact with logistics, and they participate directly in the evaluation of products and services. Crowdsourcing strategies call on them to participate in more operations – even logistics ones with crowd logistics. The use of web-based platforms has even led to the development of consumer-to-consumer supply chains.

New technologies and systems combined with SC digitalization has resulted in many intertwined strategic and SCM innovations that had to be translated in the SCPMS, leading companies to include new SC cost and performance measures, as well as new valuable outcomes. The agility and adaptability of SCs became key areas of SC behavioral performance to develop; with SCs increasingly being considered as complex adaptive systems (Choi et al., 2001).

IT/IS, the Internet and other technologies (such as radio-frequency identification – RFID) offered many opportunities to develop SC measurement abilities. New technologies helped to develop close real-time monitoring of activities – such as track-and-trace systems – and automatic data collection. This tracing and data collection included remote actors in the chain, such as the end-consumer. It became easier to share data at a wide inter-organizational level – the extended SC – and to feed data into the SCPMS automatically.

SC managers could dream of extending their SC visible horizon (Carter et al., 2015) and their control over SCs. SC visibility became a desirable performance goal for SCs. But to offer end-to-end SC visibility and to achieve reliable SC performance and value assessment, it was necessary to express cost and performance data in similar terms. The result was a call for harmonization, if not standardization, of measures and systems.

The 2000s were a challenging decade for SCM departments. During this period, more activities were outsourced, giving greater power to purchasing as well as to third-party logistics and emerging fourth party logistics providers. The greater reliance on information systems increased SCM dependence on IT departments and providers.

The strategic contribution of SCM was to design and control the SC, viewed as a complex adaptive system (Choi et al., 2001), to dynamically align business strategy, SC strategy, and their environment. The constant monitoring of remote SC operations and the assessment of SC performance and value creation became a strategic competence and an SCM dynamic capability.

This context resulted in renewed attention to and research on SCPMSs in the mid-2000s. SCPMSs represented a way of improving SC performance and governance. Literature reviews (Gunasekaran et al., 2001; Shepherd & Günter, 2006; Gunasekaran & Kobu, 2007) collected and compiled existing SC performance measures into structured lists or taxonomies. They also levelled certain criticisms at SCPMSs, including: “lack of connection with strategy; focus on cost to the detriment of non-cost indicators; lack of a balanced approach; insufficient focus on customers and competitors; loss of supply chain context, thus encouraging local optimization; and lack of system thinking” (Shepherd & Günter, 2006, p. 247).

The new technologies encouraged companies to introduce additional measures to address new activities or challenges. These new measures’ introduction was the case in the mid-2000s with the development of e-commerce and virtual enterprise environments (Gunasekaran & Kobu, 2007). It was also observed in the need to demonstrate SC compliance with environmental and social responsibility, leading them to develop green performance measures (Shaw et al., 2010).

## 2.4 Toward Complex and Paradoxical Demands with a Wider Scope: From the 2010s Until Now

The 2010s further introduced complexity and uncertainty for SCs with new pressures for SCM and SC managers. A number of crises – natural disasters, economic crises, terrorist attacks, military conflicts, and pandemics – revealed SCs vulnerabilities with greater disruption, but also the need for greater resilience.

In hostile environments and in crisis periods – such as the Covid-19 pandemic – companies and researchers focused on new behaviors and characteristics such as vulnerability, robustness, and resilience. This new focus led to focus on new SC performance measures such as time to respond and to recover. It was becoming necessary to make better use of data with SCPMSs to assess performance with *ex-post* observations and to dynamically monitor supply chains with real-time, fine-tuned monitoring. The additional important dimension was the need for measures to also become predictive to help foresee changes.

The development of risk-sensing tools related to SC measurement was identified as a new strategic necessity. Again, new technologies – such as artificial intelligence with big data, deep learning, or digital twins – were viewed as solutions to improve SCPMSs and increase their usefulness in SCM decision-making. Dynamic dashboarding to anticipate changes and simulations to better forecast risks and estimate their probability of occurrence with potential impacts helped to understand and manage SC resilience and transformation. The successive crises revealed that SCs were embedded in a complex ecosystem. The ecosystem focus supported investigating many understudied stakeholders. It became clear that the behavior of SCs was dependent on many other SCs with inter-SC lock-in effects – which pointed to potential synergies that could be developed.

The 2010s also questioned some hidden assumptions behind the development of contemporary SCs. Globalization, productivism (efficiency and productivity), governance of global value chains such as questioning the role of "voiceless" people (Glover & Touboulic, 2020), and the negative externalities of global SCs.

The need to fulfil sustainable development commitments put new pressures on SC managers and called for new changes in SCM. New performance indicators were also further introduced, including CO2 emissions related to transport and logistics activities. Global warming issues (see GIEC report, 2022), combined with a perceived change in consumer preferences and concerns, led companies to adopt a "purpose-driven orientation" for their business and SC strategies (Gartner, 2021a). The SCPMSs had to support assessment of companies and SCs capacity to meet their sustainability commitments. The SCPMS had to help companies progress toward better SC compliance with environmental and social responsibility and deliver more value to stakeholders.

Since the end of the Cold War, geopolitical issues had regained importance. The era of open globalization and easy international trading, with relatively free positioning of SC assets to seize emerging markets and benefit from low-cost opportunities, has recently been challenged. So-called emerging markets are maturing and want to get the value from the SCs that have been using their resources without compensating them properly. Powerful nations (US, China, and Russia) are using SCs as political and economic weapons – for example China's new Silk Road logistical strategy. Some countries have left trade agreements – such as the UK with Brexit and leaving the EU – to reaffirm their sovereignty, leading to unexpected impacts.

In such a complex and uncertain environment, there is a need to manage multiple and sometimes paradoxical types of SC performance and value. Advanced SCPMSs are expected to contribute to ecosystem sensemaking and improve decision-making in SCs. By assessing performance and value creation throughout the SC and between SCs, they are expected to avoid mismatches in the perception and behaviors of SC actors. These systems are expected to improve collaboration and commitment of organizations while coping with changes, dangers, and disruptions.

# 3 Current Concerns About SC Performance Measurement and Value Creation

Based on the big picture drawn in the previous section, the objective of this section is to identify the current concerns that are important to practitioners, researchers, instructors, and students. It highlights the state-of-the-art in SC performance measurement and value creation. We identify points of consensus, debates, and questions. Some answers to pragmatic questions about performance measurement and value creation assessment in practice are answered. Specifically, questions such as – How should SC managers proceed? What are the key questions to answer? – are addressed in this section.

The evolution of the topic over five decades shows that performance measurement and value creation is both complex and challenging, but that it is necessary to develop this strategic SCM capability. Our overview of the evolution from the 1970s onward shows that each decade has increased the number of performance and value measures, changed the vision of the link between performance and value, and revealed the multiple relevant units of analysis used to study how to improve SC performance and outcomes. Each decade has also revealed the usefulness of SC measurement and SCPMSs, as well as the difficulties in putting them into practice. Table 2 at the end of the section summarizes the evolution on these key points. The key points are of strategic importance for research and practice.

## 3.1 The Need for SC Performance Measurement Capability

Performance measurement is the process of quantifying the effectiveness and efficiency of action (Neely et al., 1995). In the management sciences, there are some well-known maxims: “If you can’t measure it, you can’t manage it.” “No measures, no improvement.” Although critical studies challenge these assumptions, performance measurement has always been considered a vital task in logistics and SCM because it can help to identify problems (e.g., poor quality), monitor progress (e.g., tracking performance improvement), enhance employee motivation (by rewarding progress), and strengthen SC accountability (assessing performance and value).

Performance measurement – or obtaining the performance data from others – has been considered in SCM as a means for gaining control over the entire SC and spotting areas for improvement (Lambert & Pohlen, 2001). Considering that the ultimate objective of improving SC performance is value creation, effective SC measurement has to link value with performance.

There is a clear consensus on the need to develop and improve general measurement capability in SCM. However, it is not easy to determine the types of value to create, the performance measures and metrics, and data acquisition methods. The development and management of SCPMS call on many management competencies and functions – SCM, accounting, IS, purchasing, marketing, and human resources – across many SC partners. The increasing role of IS and IT in SCPMSs, with new information technologies and systems constantly appearing, is a key issue. There is a

**Table 2** Overview of the evolution of SC performance and value measurement: key points

| Period | Performance measures | Value measures | Link between performance and value | Unit of analysis (in coherence with SC scope) | Usefulness of measurement and of SCPMS | Difficulties and risks |
|---|---|---|---|---|---|---|
| 1970s | Cost.<br>Productivity of operations | Profit.<br>Turnover.<br>Asset management | Not studied | Each **operation** (for performance: local optimization) + the **organization** (for profitability) | **Discover** the unknown (and sometimes unthought of) cost of logistics | Lack of data and reference<br>(e.g. average logistics cost = x% of turnover) |
| 1980s | Previous measures + Performance of the logistics service to customers (quality, rapidity, reliability) | Profit.<br>Competitiveness related to cost leadership and/or differentiation thanks to logistics service quality | Logistics costs -> profit.<br>Logistics service performance -> customer satisfaction.<br>Viewed as a trade-off | **The organization** + some direct upstream and downstream **dyads** (partnerships) | **Understand** logistics cost drivers. Look for wasteful, non-value adding activities in the SC.<br>Understand root causes of non-quality (products and services) | Reluctance of partners to share data related to cost drivers.<br>Poor information systems and few electronic data interchanges |
| 1990s | Previous measures + SC behavioral performance measures (e.g., flexibility, responsiveness).<br>Quest for SC **excellence** and **standardized** measures to benchmark | Combine profit + financial outputs, e.g., EVA (for shareholders) and other values (for limited stakeholders) | Integrated view of SC performance and value.<br>Cost + financial and non-financial performance -> value.<br>Need to balance different types of performance and value | **SC** (if possible end-to-end) with a focus on SC processes | **Reduce** total costs throughout the SC.<br>**Understand** how to improve the strategic SC behavior.<br>**Learn** from the comparison with "best-in-class" SCs | Many individual local SCPMSs.<br>Need to structure the SCPMS (many indicators, trade-offs).<br>Are there best measurement practices? |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2000s | Previous measures + New SC behavioral performance measures (Agility)<br>Performance indicators related to logistics and SCM innovations (mainly related to IT, e.g., the Internet) | + Looking for measurable benefits from SC innovations.<br>+ Value for customers, individuals, citizens, the environment | Focus on new (modern) types of performance and value, but studied separately | **Extended SC** (including indirect partners – linked to innovations, e.g., IT companies) | Understand the importance of **intangible** aspects (linked to social networking, knowledge sharing, etc.) | One-size-fits-all KPIs are unable to capture "new" types of performance and value.<br>Difficult to develop inter-organizational data sourcing to feed SCPMS |
| 2010s | New SC capabilities to measure (Resilience, Sustainability, Social Responsibility) | + Compliance with new regulations.<br>+ More global value for society | The challenge of combining multiple types of performance and value, on multiple levels and for multiple time horizons | **SC ecosystem** (including remote "silent" stakeholders) | **Anticipate** changes (prediction), **foresee** crises (risk sensing, detecting weak signals).<br>**Demonstrate** the (non)impact of SCs and SCM on the environment, society, etc. | How to measure the unmeasurable?<br>The technology jungle.<br>Understand the drawbacks and risks of metrics fixation.<br>Adapting the SCPMS to never-ending changes |

goal for improved competence but this goal faces big challenges. The development of this capability is a key point that must be addressed in every firm as well as at the SC level.

### 3.2 Defining Relevant SC Performance Measures and Metrics

As reported in Table 1 (**column 1**), every decade has introduced new SC performance measures, building on previous ones. The relevance of existing (traditional) measures and the need to develop new (modern) ones is an important question (Gunasekaran & Kobu, 2007).

After an initial focus on cost measures – to better control and, if possible, reduce costs – many non-cost measures have been introduced. For example, time, quality, and flexibility were introduced to reflect the SC's ability to deliver better customer service. Efforts to better understand SC behavior also resulted in new measures to reflect the overall SC ability to perform better. These measures include improved integration, responsiveness, and visibility. Additional measures to effectively manage change in demand, supply or in the context of deployment or implementation were also included such as: flexibility, adaptability, agility, robustness, and resilience. Every decade has identified new strategic drivers for future supply chain development, such as sustainability and responsibility.

The most problematic SC performance measures are those concerning SC behaviors that have to be clearly defined before trying to decide how to measure them. New concepts are difficult to measure, especially if these concepts have not been clearly defined (Yao & Fabbe-Costes, 2018). Literature reviews (e.g., Fabbe-Costes & Jahre, 2007, 2008 on SC integration) show that there are many different competing measures that have to be carefully studied before selecting one and that different measures may produce contradictory results.

Another important general question is whether to adopt "hard" measures – such as net income or accounting values that are meant to be objective, or whether there needs to be inclusion of "soft" measures such as customer satisfaction ratings. Usually, soft measures are based on the subjective perception or interpretations of individual actors. These categories of measure have strengths and weaknesses associated with them. Those who promote purely quantitative measures acknowledge the usefulness of qualitative analysis to make sense of them. For example, while benchmarking encourages "quantifying performance improvement opportunities across the entire supply chain," it also calls for "qualitative analysis of best-in-class performance" (Stewart, 1995, p. 40).

The cumulative development of SC performance measures has led to a very large number of individual measures (Shepherd & Günter, 2006; Balfaqih et al., 2016). Measures include quantitative, qualitative, single indicators, or composite measures. Early on in the evolution of SC and SCM, the lists of SC performance measures were rather unstructured (Chow et al., 1994). Categorization efforts from the mid-1990s onwards (Stewart, 1995; Fawcett & Cooper, 1998) resulted in structured lists with many different categories (see Gunasekaran & Kobu, 2007). The content and structure of these lists vary depending on the underlying model – for example some use the SCOR model – or logic used to classify measures and metrics.

From the 2000s, some new or modern categories were developed, broken down into sub-categories with numerous detailed measures – for example green SC performance (Shaw et al., 2010). The result is that there are many SC performance categories; for each performance category several SC performance measures are generally recommended to monitor and manage a variety of SC activities. Each measure has a variety of operational definitions and indicators.

This profusion of measures is challenging for SC managers who have to select suitable SC performance measures and structure them in their SCPMS. There is no consensus about the most appropriate technique for selecting SC performance measures. It is not an easy task since there are different levels of performance. Some measures are operational such as on-time delivery, others are tactical such as service quality, while others are strategic such as SC responsiveness. These multiple levels of measures lead to embedded measures (Cavinato, 1992). The consistency of the overall selection is problematic since some performance measures are interrelated, for example SC collaboration and SC transparency. Other dimensions are independent forming a more global (multi-facets) performance measure. Despite attempts to design standardized measures and SCPMS models in the 1990s, the choice remains open and directly linked to the expected strategic SC outcomes: the type of value to create and for whom (Fabbe-Costes, 2002).

While any single measure or metric may be of interest, no single measure or indicator is sufficient to assess SC performance (Chow et al., 1994). The challenge is to develop a useful set of performance measures, viewed as a system. Challenging managerial questions include: How can we find a balance between exhaustiveness and parsimony? How to choose KPIs that make sense?

The priority is to identify the stakeholders and the types of value to create before deciding on a tactical and operational strategy and a set of SC performance measures and metrics.

## 3.3 Clarifying Value Measures

Compared to SC performance, value measures (Table 1**, column 2**) are far less developed. These measures are described in more general terms such as profit, development, competitivity, and compliance, usually with less precise formulas. The value expected by the company, which is directly linked to its strategy, has also cumulatively increased in its diversity. Value measures have been evolving in keeping with the perception of the strategic value produced by SCs and SCM, as well as with each new strategic issue facing companies and their SC.

In earlier historical time periods of SC, the focus was on financial value creation with quantitative financial measures such as profit, turnover, added value, and EVA. The quest for profitability prioritized shareholder satisfaction. However, to succeed in fierce competitive environments, creating value for the customer rose in priority.

The customer (and customer's customers) satisfaction rapidly became the focus of SCM efforts to build customer loyalty and commitment.

In line with Porter's analysis, an SC could win the competition through cost leadership or through differentiation, leading to new financial value measures related to costs combined with perceived outstanding quality. A consensus emerged on mixing financial and non-financial measures in the SCPMS (Gunasekaran et al., 2001).

In the 1990s, the search for best SC practices revealed the role of strategic processes and strategic resources in creating value, which included human resources. The balanced scorecard (Kaplan & Norton, 1992) introduced inward value related to personnel satisfaction – related to safety, well-being, and rewarding work. There was also development of intangible assets and resources with competence, knowledge, and social network measures. The loyalty, commitment, and efforts of employees working in SC operations were key success factors in competition and proved to be even more strategic in the 2000s for innovation, which included individual creativity. Survival since the 2010s included individual adaptability, robustness, and resilience.

With the recognition of risks and responsibilities, value is not only about intra-SC corporate social responsibility (CSR) value, but also broader societal outcomes. Changes in laws and regulations at the national or international level are a powerful impetus to include new types of value and new measures to prove SC compliance – such as no counterfeiting, no conflict minerals, and no use of illicit products. Seeking credibility, reputation, and trust, companies try to obtain certifications and labels, which guide their selection of value measures. Some international initiatives also provide inspiring frameworks such as the Global Reporting Initiative (GRI) standards, and the UN sustainable development goals (SDGs) to target the most impactful strategic values.

Shareholders are not the only beneficiaries to consider, and financial value is no longer the unique objective. SCM value creation is multi-dimensional, targets multiple stakeholders, and calls for a multi-level assessment (Fabbe-Costes, 2002). SC value creation co-evolves with business strategy, resulting in a system containing both financial and non-financial values to satisfy an increasing number of shareholders and stakeholders. The resulting variety of value creation measures reveals paradoxical issues. A balanced approach is needed and has to evolve dynamically with strategic changes in the SC environment.

## 3.4 Questions Related to the Performance–Value Link

The link between performance and value is key for SCM. As recalled from the introduction of this chapter, there is no success without the coupling of business strategy, SC tactical and operational strategy, and the day-to-day execution of SC operations. However, the evolution of the topic (Table 1**, column 3 and column 5**) explains why it is a complex link to study.

In the early years of SC performance measurement, the link was an expected one, although not studied greatly, it was more a conceptual postulate rather than a demonstrable hypothesis. With the emergence of logistics and SC departments and their participation in the formulation of strategy, it became necessary to provide evidence of the contribution of SC performance to value creation, especially with respect to financial value contribution. The first frameworks for developing supply chain metrics that translated the performance of core SC processes into shareholder value showed the relevance of the approach and its difficulty (see, for example, Lambert & Pohlen, 2001).

Aside from financial value, each new business strategy considered new types of value, generating a distinct analysis of the performance–value link. For example, in the 1980s, cost (C) reduction was related to cost leadership strategies, quality (Q) and time (T) with service differentiation strategies. The links were considered to be mutually conflicting trade-offs.

In the 1990s, integrated views were promoted. An SC that mastered the famous CQT triangle was supposed to win the competition. Balanced scorecards combining four performance perspectives became a best way for capturing the SC performance–value relationship. However, from the 2000s onward, the multiplication of different types of SC performance and value made this picture complex. In-depth studies of the new/modern measures, in particular behavioral performance measures, produced separate evaluations.

However, an in-depth analysis of studies that sought to prove the contribution of specific types of SC behavioral performance to value creation (see Fabbe-Costes & Jahre, 2007, 2008 about SC integration) showed the lack of clear empirical proof of the performance–value link. These studies unveiled some critical issues to consider in research and practice, including: the problem of the conceptual definition of SC performance which contained very diverse definitions; the selection of metrics to measure it that were sometimes inconsistent with the definition; the choice of data source and data type to calculate; and the values impacted.

Considering the many types of value emerging in the 2010s and the challenges facing SCs today, a holistic understanding of the SC performance–value link is necessary. Some types of value are related to short-term objectives, others to longer-term ones. Some types of value are interrelated, others conflicting. The paradoxical nature of some types of performance and value, the difficulty and sometimes futility of identifying clear causal links, the recursive nature of some effects, and the time horizon to observe some of the expected impacts make the SC performance–value link complex.

The systemic and dynamic nature of the interactions in practice calls for specific methodologies and methods. The complexity also varies depending on the SC scope and units of analysis.

## 3.5 Specifying the Units of Analysis

The scope of the performance–value analysis (Table 1**, column 4**) evolved in parallel with the vision and definition of SCM, SC, and the place of SC/SCM in the company structure (Table 1**, column 6**). Studies show that there are many potential units of analysis – corresponding to different scopes. The evolution shows a widening scope, but also a more complex situation. Many questions arise around the definition of SC, its scope, the unit of analysis, and perspective (Cooper et al., 1997). The decision to adopt and at what level and with what lenses along with the scope of measurement such as internal SC or inter-organizational represent some of the multitude of concerns.

The initial focus of these measures was on individual operations that were separately optimized. As the SC department emerged, the unit of analysis rapidly became the firm or the organizational level – which remains the most frequent scope for SC analysis. In the 1980s, inter-organizational units of analysis emerged in order to encompass direct SC partners such as customers and suppliers. Dyads, such as firm-supplier or firm-customer, and triads, a focal firm with a supplier and a customer, also became frequent inter-organizational units of analysis.

The end of the 1990s marked an important turning point regarding efforts to define SC and SCM (Mentzer et al., 2001). This time period led SC managers and researchers to go beyond internal logistics metrics and to demonstrate the strategic role of SCM (Mentzer et al., 2004). They also set to demonstrate SC and SCM value creation. Definitions of SCM always emphasize the importance of key SC processes. Processes are important SCM units of analysis because their execution entails the coordination of multiple actors behaving as if they belonged to a single organization – an SC. Seamless intra- and inter-organizational processes are supposed to deliver better value. The combined analysis of SC process performance and of its perceived value, adopting multiple viewpoints, is a powerful source of improvement. See, for example, the case of the purchasing process in Nollet et al., 2017, 2019.

Since the 2000s, the attempt in both academia and industry to adopt a wider SC scope – such as end-to-end SC, extended SC or the SC ecosystem – revealed additional complexity. The evolving definition of what an SC is or should be has produced a variety of pictures. The measure of SC performance also varied, depending on how companies define their SC. It may be an internal inter-functional chain or process, a dyadic or linear triadic chain, a network centered around a pivotal firm, or a more complex network combining multiple SCs including closed-loops.

Performance can also be measured by considering the output of an organizational SC department or function. It can be measured at the company level, in line with the control it wants to have over its SC. The organization can also try to measure the overall impact of an extended supply chain on its ecosystem.

It is necessary to define the SC, its scope, and the scope of SCM action. It is also necessary to decide if the focus is a single optimization criterion or if the objective is to adopt a systemic approach to performance measurement. The SC scope, units of analysis used to measure SC performance and value, and measurement choices are important to determine for the SCPMS. But before diving into building the SCPMS, it is useful to question its expected usefulness.

### 3.6 Understanding the Usefulness of Measurement and the Supply Chain Performance Measurement System

The history of the SC performance–value topic shows an evolution in the perceived usefulness of performance measurement and value creation assessment in SCM. The overall evolution appears to be a learning process, since every decade has increased SCM knowledge thanks to a better understanding of how to increase the performance of SCs and SCM value creation.

In the early decades of SC evolution, cost-based performance measures offered a view of neglected logistics activities. Production was what added value, not logistics. Therefore, few people cared about this field and it was not really managed. The discovery of logistics costs and of ways to improve productivity opened the door to logistics management.

Lean management and total quality management contributed to continuous improvement based on performance monitoring and empowering employees, so they might find better ways of operating. In a broader perspective, it was acknowledged that "measuring supply chain performance can facilitate a greater understanding of the supply chain, positively influence actors' behavior, and improve its overall performance" (Shepherd & Günter, 2006, p. 243).

The 1980s helped SC managers understand the question of trade-offs between conflicting measures (such as costs and services). One consequence was widespread recognition of the importance of adopting a balanced multicriteria approach to designing the SCPMS, which would better support SCM decision-making than a single SC performance objective.

In the 1990s, the intensity of competition was combined with the underlying assumption that there were indeed SC best practices – a positivist vision of SC practices. There was also a perspective that benchmarking was the most important use of SC performance measurement. The benchmarking literature argues in favor of one-size-fits-all measures that allow for comparisons and identification of best in class SCs. Best in class seeks to identify best practices to dominate the competition or at least survive. This remains a popular approach and an important source of learning for SCM researchers and consulting firms, related to the quest for SC excellence obtained by climbing from one maturity stage to the next, with recognition for the levels achieved (Estampe et al., 2013).

In the 2000s and 2010s, SCM innovation and environmental uncertainties showed that creativity and disruptive models were needed. SCPMS could still be useful to compare value and performance – if the comparison was still relevant – but could be more useful as sensemaking tools to fully understand the overall SC behavior. SCPMS could also be used as sensing tools to detect unexpected evolution or paradigm shifts in the SC ecosystem.

Expanding the "visible horizon" of SC agents (Carter et al., 2015), which has always been a central goal of SCM and of SC performance measurement for various reasons – to get better control, identify risks, perform due diligence – became easier with IS and IT support.

Starting in the 1990s, great hope was placed in new technologies. Information technology supported logistical performance measurement which had been difficult to assess (Fawcett & Cooper, 1998). Data-capturing capability – with real-time tracking systems – coupled with better database technology, provides managers with better decision-making capability in diverse areas (Fawcett & Cooper, 1998). What was more of a dream than a reality in the 1990s is becoming possible not only in companies but on a broad scale for SCs, at many decision levels and on different scales of analysis.

This overview of this section concludes by affirming that useful SCPMSs should balance financial and non-financial measures, adopt a multi-level approach combining strategic, tactical and operational measures, and tries to provide multiple SC views – not limited to internal measures. Despite being rather optimistic, the literature does mention various difficulties and risks to overcome.

## 3.7 Being Aware of Difficulties and Risks

In the 1970s, difficulties were related to the lack of available data and there was no performance–value reference to assess progress. Owing to the infancy of computer systems, automated SC measurement was limited. Inter-organizational SC performance was difficult to measure because of the reluctance to share data. The 1990s marked the development of SCPMSs. Most studies have a positive view of SCPMSs and emphasize their usefulness and contribution to SCM.

Some studies identify the limitations of existing measurement systems:

> They encourage short termism; they lack strategic focus (the measurement system is not aligned correctly with strategic goals, organization culture or reward systems); they encourage local optimization by forcing managers to minimize the variances from standard, rather than seek to improve continually; and, they fail to provide adequate information on what competitors are doing through benchmarking. (Shepherd & Günter, 2006, p. 243)

One of the challenges is to define the type of measure, the type of data, and the sources of reliable data to obtain a reliable measure. The SCPMS needs many types of data, from many sources. Because of the focus on costs, accounting measures – such as cost-based performance measures – are often preferred. As stated by Dekker and Van Goor (2000, p. 52), “accounting measures can be important in supporting SCM decisions, but... they are not sufficient for the success of SCM.”

The SCPMS needs to combine multiple measures coming from SC members or use their data to measure the overall SC performance. How can they select the right source of data to measure an SC performance dimension or source of the measure? Is this source trustworthy, transparent? The measurement base of the SCPMS is an important question.

It is often difficult to obtain an overall SC performance evaluation, especially if a wide scope is selected. The many SCPMSs in the SC and the heterogeneity of the measures and metrics make overall performance evaluation difficult. Standardization efforts are needed.

Some industries such as the automotive industry have tried to develop international standards to facilitate data consolidation and common SC measurement practices. Car manufacturers use such standards to compare supplier performance and audit their SCs (Estampe et al., 2013). Since the 1990s, most SC managers and researchers have considered it important to continually improve supply chain performance using agreed upon metrics (Stewart, 1995). But who decides what metrics to agree upon, or who imposes the SC performance metrics? Who governs these answers has a significant source of power in SCs.

A measurement system that is imposed on one of the partners can conflict with shared destiny principles and thus weakens the long-term health of the relationship. It can influence SC governance and equity in sharing the value created, such as measuring cost reductions and allocating the benefits among the parties.

It is difficult to measure inter-organizational performance. Seal et al. (1999, p. 308) report: "Not only were internal costs measured in an unsatisfactory way, there was also a failure to understand the 'all-in cost' of bought-in supplies." An SCPMS should support SC relationships that deliver tangible and measurable benefits to parties over a long period and allow the sharing of ideas and information.

Another risk in SC performance measurement is to become obsessed with performance improvement and develop what is known as metrics fixation (Mueller, 2018). SC performance needs to be aligned with what matters for SC members, in particular for end-customers, and for SC stakeholders. Metrics fixation is a well-known problem, in particular when adopting ready-made key performance indicators (KPIs). There are more ready-made models with standardized KPIs, such as the SCOR model (Estampe et al., 2013). Sometimes, it can be easier to simply adopt them than to find one's own way of measuring SC performance and value creation with dedicated KPIs. These KPIs can be developed through a participatory approach to better fit what is at stake for the personnel, managers, and decision makers.

Another risk is to design the wrong SCPMS. It is necessary to question the assumptions underlying the way of improving SC performance and value creation – either by creatively seeking one's own way or by adopting existing best practices. It is necessary to choose between a ready-made top-down approach or an ad-hoc dialogic approach to define SC performance measures and metrics. In this field, the technologies and the companies that provide them are not neutral and the IS are so sophisticated that it is difficult to criticize some ready-made tools. How can one be sure that the SCPSM is aligned with what is needed and what counts?

Another difficulty is to maintain SCPMSs over time to remain aligned with dynamic environments and changing strategies. A critical aspect of many SCPMS is that they tend to be static and little attention is paid to their management, resulting in their limited evolution over time (Shepherd & Günter, 2006).

Considering the dynamic nature of SC performance and value creation and the need to keep measures aligned with strategy, the question of how often the SCPMS should be re-evaluated is important. And it is a never-ending complex process that must consider the factors influencing the successful implementation of SCPMSs, the forces shaping their evolution over time, and the problem of their ongoing maintenance. It is important to consider SCPMSs as dynamic entities that must dynamically co-evolve with environmental and strategic changes.

Table 2 summarizes the main points of the evolution.

## 4 Emergent Concerns and Future Research Directions

The performance measurement–value creation topic has remained on top of the organizational research agenda since the 1970s because of changes in companies' business strategy, changes in the SCs themselves and their strategy, and changes in their environment. This situation has led to new business and SC strategies – as well as the adoption of new technologies in SCs, also changing performance measurement management.

Performance measurement and value creation is still an open area of research. Studying the evolution of the topic and identifying key points that need consideration has also revealed under-investigated questions as well as emergent concerns related to digitalization. Moreover, the Covid pandemic experience, combined with sustainable development issues and climate change urgency – made more complex by geopolitical uncertainties – are powerful triggers for further research. This section raises issues, questions, and directions for future research.

The first questions are ontological and epistemological. What is an SC? Does it exist? How does a company (or a researcher) define or view its SC(s)? Is there a best way to manage SCs? Do we need objective ways of measuring SC performance and value? Are there best measures? What are the legitimate points of view to discuss SC performance and value creation?

Depending on the answers, the study of SC performance measurement and value creation (and management) will differ significantly. An analysis of the literature shows a mainly positivist orientation, with few ontological questions. More pluralistic research could improve our understanding of the complexity and offer new answers.

Many underlying hypotheses need to be questioned. Does more SC performance measurement always create value? Do we target the right "beneficiaries" with the right types of value? Are all stakeholders included in the SC scope? Have any relevant stakeholders been omitted? More research is needed to address voiceless stakeholder issues and detect "silent" beneficiaries' needs and values. SC performance and value creation raises ethical questions and issues that have not been sufficiently addressed.

Considering the variety of viewpoints, more research is needed on the capacity of SCPMSs to embrace different perspectives and provide multiple views of SC performance and value creation. This could help us to recognize the diversity of shareholders and stakeholders' expectations and their need to dialogue to navigate the paradoxical nature of SC performance and value creation. The SCPMS could be viewed as a boundary object which could combine different viewpoints that do not have the same objective or culture. How might we design an SCPMS that could operate as a boundary object? In building the SCPMS, KPIs could also be selected using a boundary object perspective.

The SCM literature adopts a very technical approach to the topic, focusing on the rationality of decision-making and viewing SC measurement and value creation assessment as neutral. This vision needs to be balanced with a more sociological approach. There is power in choosing measures and metrics as well as in setting objectives. An SCPMS is not a neutral tool. It says a lot about influence, the "tyranny of metrics" and metrics fixation, which may lead to extremism, particularly in human resources management (e.g., with intrusive monitoring).

There is a need to better connect SC performance with value creation. The literature often studies SC performance alone, disconnected from value creation. Are we measuring what really "counts"? Are we correctly measuring the SC and SCM contribution? Does measuring lead to SCM and SC improvement? Does measuring lead to the improvement of what really matters concerning SC and SCM?

The risk is to create an SCPMS that results in unproductive decisions because of metrics fixation, leading to a loss of meaning and even suffering at work. More generally, studies on SC performance and value creation do not really take humans into account, and the impact of SCPMS on people is insufficiently investigated. There is a need to study the alignment of SCPMSs – which often favor the expectations of the company – with people's expectations and values.

Companies need to improve understanding of the SC performance–value creation link. Most studies assume a causal relationship between SC performance and value creation. This relationship is a simplistic vision, since most relationships are recursive. Studies and practice also often neglect the time horizon for value creation, sometimes focusing on short-term value creation and neglecting the longer term. Sustainability issues and climate change call for a more balanced approach to value creation.

The question of improving SC visibility and transparency thanks to SCPMSs and accountability mechanisms in SCs has been a hot topic in performance measurement and SCM for decades. While there is consensus on the need for more SC accountability and to develop performance assessment in SCs, there is also consensus to acknowledge the complexity of the task and the need to focus on what is worth measuring. Thanks to new technologies and the development of increasingly sophisticated IS, it is possible to gather data to measure more and more types of SC performance and value. Is it possible or necessary to measure everything? Are we sure the measures are relevant? What is best – exhaustiveness or parsimony? How can effective and useful monitoring of the SC be done? There is a risk of relying on precise but out-of-scope metrics, which miss problems.

More research is needed to study how to determine the appropriate scanning scope and how to align this with business and SC strategies. This calls for a dynamic approach to SCPMSs, while most research views them as static.

There is little research on the effective use of SCPMSs and the effect of using SCPMSs. How can the results of the SCPMS be used? Understand? Incentivize? Control? Reward? Monitor activity? Contribute to the implementation of any new SC practice? Develop dialogue, collaboration and SC governance? Foresee changes, risks, or disruptions?

No matter what the intended use of the SCPMS is, it must also contribute to sensemaking and help SCM managers develop and refine their professional judgment. The systemic and dynamic nature of the different interactions at play in the SC calls for specific methodologies such as action research or in-depth case studies.

In the quest for good SC performance and value measures, researchers (and consulting firms) try to define general measures and KPIs. The objective is to

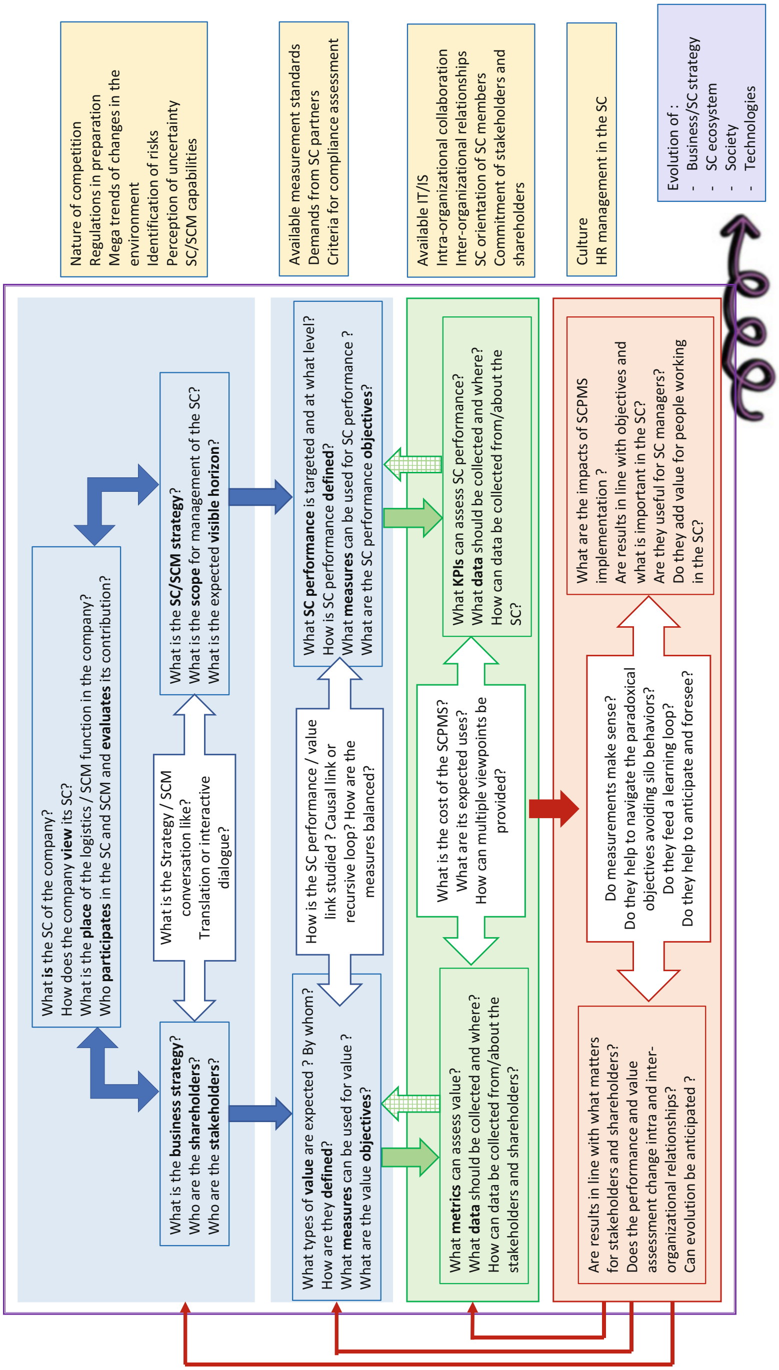


**Fig. 1** The holistic framework of performance measurement – value creation "in practice"

produce comparable and transferrable results that increase the general understanding of the question. Despite this search for standardization, the variety of SC performance measures makes it difficult to draw broad inferences from the literature (e.g., with meta-analysis or aggregating the findings of several studies). Researchers should take care in doing this type of study, making an in-depth analysis of conceptual definitions of measures and the calculation of metrics.

## 5 Managerial Implications

The importance of being recognized as excellent in SCM emerged in the 1990s. It is still important today (see Gartner, 2021b, 2022) even though the criteria for assessing this excellence have changed and will change over time. It is therefore important for SC managers to assess SC performance and value creation. Based on the background to this topic, current key points and in view of the questions raised for further research, this section proposes (see Fig. 1) a comprehensive framework providing guidelines for practice.

The overall approach is dynamic and combines four interrelated groups of questions and decisions. It is not a linear and causal process, but a recursive and endless journey that requires ongoing auditing. It deliberately emphasizes questions more than ready-made solutions and suggests being critical vis-à-vis some mainstream practices (e.g., benchmarking).

## 6 Summary and Conclusion

This chapter provided a detailed analysis of the performance measurement–value creation topic in SCM from the 1970s until now. It highlighted the successive issues and key points discussed over time, showing that – although complex and challenging – performance measurement and value creation is a core competence of SCM. Each decade has increased the number of performance and value measures, changed the vision of the link between performance and value, and revealed the multiple relevant units of analysis used to study how to improve SC performance and outcomes.

Each decade has also demonstrated the usefulness of SC measurement and SCPMSs, as well as the difficulties in putting them into practice. Building and maintaining a relevant and effective SCPMS is more complex than generally acknowledged. The chapter tried to answer pragmatic questions about performance measurement and value creation assessment in practice: How should SC managers proceed? What are the key questions to answer?

Accordingly, the chapter provides a comprehensive set of guidelines for practice. The goal is to benefit from the efforts of measuring things that really "count." Owing to the paradoxical nature of SC performance and the complexity of measuring it, renewed approaches are needed both from the research and practice perspectives.

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# The Inter-play Between Performance and Risk in Supply Chain Management

Sadaf Aman

## Contents




**Abstract**

Risk and performance are inseparable terms, yet how these two influence each other within sustainable supply chain management (SSCM) is still an evolving question. In this chapter, we explore various factors that influence decisions of supply chains considering risk and performance dimensions. We specifically discuss performance measurement (PM) and its characteristics and what role it plays in supply chain risk management (SCRM). The chapter includes an introduction and background of SCRM and how it links to PM. Further, it identifies dimensions of PM and options to integrate it in SCRM. The link will encourage managers to consider PM characteristics in risk management to improve overall sustainability. Emergent concerns and future directions are also presented.



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Performance · Risk management · Sustainable supply chain management · Performance measurement

## 1 Introduction

Risk and performance are old concepts coining its history from the strategic management literature (Miller & Bromiley, 1990). Financial risk was the primary strategic focus and measured through research and development (R&D) intensity, standard deviation of return on asset (ROA), return on equity (ROE), and variance from stock analyst earnings forecasts (Miller & Bromiley, 1990). Negative deviation and variance in performance objectives indicate the presence or absence of certain risks. Early literature tries to identify the causality between the two by implying performance as a driver of risk (Bowman, 1982) and discusses the influence of performance on risk and vice versa (Miller & Bromiley, 1990). This literature suggests an inter-play between performance and risk exists from the beginning of the risk management debate which somewhat builds on the narrative "what is not measured is not managed" (Manuj & Mentzer, 2008, p. 216).

Performance is widely studied as performance measurement (PM) while risk is studied under risk management (RM). Building on this, the following arguments explain how this interplay has evolved with the evolution of the respective domains.

In the literature of risk measurement or assessment has been treated as a subsequent process after risk identification to check the magnitude and probability of the identified risk (Tummala & Schoenherr, 2011). Similarly, RM literature cultivates two broad types of risk management strategies – preventive and reactive (Thun et al., 2011). Gouda and Saranga (2018) contend that "both preventive and reactive risk mitigation strategies are devised before a risk event occurs" (p. 3). The former reduces the effects of risk before its occurrence while latter mitigates the effects after a risk has been occurred.

For preventive strategies, the perceptions regarding risk are formed on the basis of various parameters for example, past experiences, risk preferences, and infrastructural robustness. The conclusion is that the firms need to "track" the actual risk highlighting the need for proper control and monitoring (Gouda & Saranga, 2018). To ensure that the risk management strategies cascade down and lead to concrete actions, a conscious effort in linking PM with risk management strategies is a prerequisite.

A recent shift in current research endeavors to establish a link between performance and risk management by characterizing the former as an antecedent to the latter (Munir et al., 2020). It highlights that less attention has been given to how a company can identify these potential risks or what drives risk management, that is, determining the antecedents of risk management (Fan et al., 2017; Manuj & Mentzer, 2008). PM can support risk control and monitoring allowing managers to detect risk. Therefore, companies with PM can improve their risk visibility by detecting early diversions from the set targets. PM can be viewed as a determinant of risk management. The chapter aims to define the role of PM as both the antecedent and the consequence of risk management in the risk management process.

Furthermore, PM philosophies are convoluted by incorporation of management activities beyond the organizational boundaries. Business today functions as interlinked firms forming networks facilitating the efficient flows of products, capital, and information across the globe. These chains or networks of interconnected firms are referred to as supply chains (SC) in the management related literature (Mentzer et al., 2001). The changing paradigms of today's business necessitates researchers and practitioners to focus on supply chain performance measurement (SCPM). However, the narrative of boundaryless management of associated actors and activities increases complexity and exposes firms to supply chain risks. Therefore, measuring performance for supply chain risk management (SCRM) has become the crucial criteria for firms to become successful.

Moreover, recent studies on financial, environmental, and social performance sustainability into the perspective – also referred to as triple bottom line. Therefore, SCM has also evolved to sustainable supply chain management (SSCM). The concerned literature also suggests that "sustainability performance management is not often due to direct demand enforced by the legal act but because the companies aim to reduce the related risks" (Seuring & Müller, 2008, p. 1703). Example, a focal firm implementing an environment certificate implies that the firm wants to avoid the associated risk of reputational loss, which links PM to risk management. Therefore, understanding that risk is an obscure reality in SSCM and an inseparable concept from performance, where exploring and linking the two is a precursor in minimizing SC problems, hence, the chapter addresses the question:

How can the concepts SCRM and SCPM can be linked under SSCM?

The subsequent sections of the chapter discuss the historical view and practices in SCRM and links it to the SCPM by reviewing studies considering it as an antecedent as well as consequence of RM. Next, SCPM characteristics are presented considering its evolution under (sustainable) supply chain management. Current concerns are highlighted along with emergent concerns, outstanding research, and future directions. Lastly, managerial implications are presented along with the conclusion.

## 2 Background

There are numerous definitions of risk proposed in the literature of supply chain risk management. Most definitions inevitably link performance to risk management. For example, Manuj and Mentzer (2008) define risk as "the distribution of outcomes related to adverse events" (p. 197). Similarly, Tummala and Schoenherr (2011) conceptualize supply chain risk in more detail as "an event that adversely affects supply chain operations and hence its desired performance measures, such as chain-wide service levels and responsiveness, as well as cost" (p. 474). The former definition argues the effect of risk on strategic performance whereas the latter argues its effect on strategic performance through short-term performance measures.

These short-term performance measures are derived based on the managerial strategic choices and decisions for reducing and mitigating risks. For example, disruption risk and proposed measures for two disruption management strategies – flexibility and redundancy – have been linked (Rogerson et al., 2022). In RM, collaboration is a risk reducing strategy (Simangunsong et al., 2012) where trust and trust worthiness are intangible relational performance measures (Aman & Seuring, 2021; Choi et al., 2018; Maestrini et al., 2017). These short-term performance measures are a part of PM initiative, also known as PM metrics, indicators, or measures.

For many years, it has been recognized that PM can affect the successful implementation of company strategy (Laihonen & Pekkola, 2016). It ensures that the company strategies are competently and wholly implemented to sustain organizational growth (Rompho, 2011). A PM must be designed and implemented in accordance with a company's business strategy and must link the strategy to the objectives of functions, groups of people, and individuals (Kaplan & Norton, 1996; Nanni et al., 1992; Neely, 1999; Schneiderman, 1999), as well as to operations (Greatbanks & Boaden, 1998; Lynch & Cross, 1991; Neely et al., 2002). PM further includes tools, systems, instruments, and indicators which are regarded by managers in implementing the risk management strategies. For example, lean operations are a risk reducing strategy incorporating lean six sigma tools devoted to control and measuring quality under two perspectives, either linked to total quality management (i.e., a PM system) or as a continuous improvement approach (Aboelmaged, 2010).

Similarly, lead time management through just-in-time (JIT) modeling usually focuses on the link between changes in different production factors and the corresponding production performance measures (Banker et al., 1993). This perspective discusses the influence of risk on the performance and specifically entails that PM is important in the implementation of SCRM strategies.

PM can enhance SC visibility (Lauras et al., 2010). Visibility is deemed desirable since it increases SC efficiency and decreases SC risk (Nooraie & Parast, 2015). Visibility has been found to be positively related to disruption risk (Brandon-Jones et al., 2014). This finding has also been observed with SC visibility as an antecedent to SCRM capabilities (Yang et al., 2021). Moreover, integration, can be viewed as a performance measure that improves SC visibility and an antecedent to SCRM (Munir et al., 2020). This perspective implies influence of performance on risk and specifically discusses PM as a perspective that improves visibility of the SCs. Therefore, the role of PM in SCRM is twofold. On the one hand, studies consider it a consequence (Tummala & Schoenherr, 2011), and alternatively, it is viewed as an antecedent to SCRM (Munir et al., 2020).

The former conceptualization has been long considered in the SCRM literature (Gouda & Saranga, 2018; Ritchie & Brindley, 2007; Simangunsong et al., 2012); however, less attention has been given to performance as an antecedent of SCRM (Fan & Stevenson, 2018; Fan et al., 2017; Manuj & Mentzer, 2008). This latter conceptualization can further be viewed in the light of chaos theory, which defines systems as complex as opposed to deterministic, in which if the equations describe its behaviors as nonlinear, then the slightest change in the initial conditions can lead to cataclysmic and unpredictable results (Levy, 1994). Chaos theory supports the

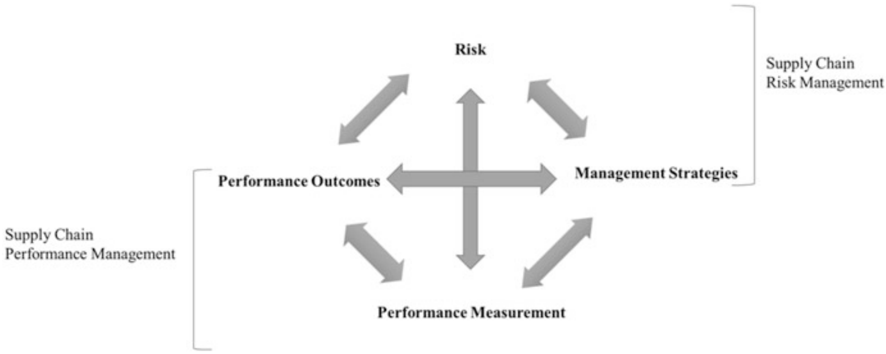


**Fig. 1** Conceptualizing SCPM in risk management

argument of short-term PM to observe change in the initial conditions to timely understand the risks prior to their occurrence (Levy, 1994).

PM facilitates short-term visibility that is necessary for risk management and strategic performance outcomes. It also offers operational or tactical measures for risk management strategies to successfully implement managerial RM strategies. Both former and later explanations are presented in Fig. 1, where the relationship between risk and performance is presented in a loop rather than a linear one. Further, multiple organizational managerial levels are presented in a coherent manner to facilitate the conceptual argumentation of interplay between performance and risk as explained in the previous paragraphs. Figure 1 is further elaborated in Sects. 2.1 and 2.2 which describe SCRM and SCPM, respectively.

## 2.1 Supply Chain Risk Management

Today's market environment is considered fragile and requires swift actions for risk management to control its effects on performance. Risk management involves identifying and assessing risk and devising the strategies accordingly. Once the strategies are devised, concrete actions are required to ensure limiting deviation from the intended outcomes. These considerations demand concrete monitoring of the risk to achieve strategical performance outcomes. One way of managing these considerations is by linking PM with the risk management.

### Sustainability Performance Measurement in Supply Chain Risk Management

SC risk management is broadly divided into three broad steps – identification, assessment, and evaluation, planning and mitigation, and control and monitoring. The identification, assessment, and evaluation of the risks is step one and can identify the probability and magnitude of their occurrence. Once identified and evaluated, related risk management strategies (step two) are devised, which then lead to control and monitoring (step three). To understand the SCRM, all these things need to be explored.

### Step One

The identification, assessment, and evaluation of risk is operationalized into number of potential risks that a firm encounters, including assessing the probability and impact of the risks. Most common and widely discussed risk factors include demand risk, supply risk, distribution risk, transportation risk, delay risk, supplier risk, manufacturing risk, capacity risk, sovereign risk, system risk, and, most recently, disruption risk. Disruption risk is a relative term which has often been discussed with the resilience concept.

### Step Two

Risk planning and mitigation require a set of strategy deployment to mitigate related risks. Risk management is managed at strategic and tactical levels. The strategic level risk is often directed towards the probability of occurrence of a certain event, for which preventive risk strategies could lead to positive outcomes. Practices include product design, shorter planning periods, good decision support systems, collaboration decision policy and procedures, use of information communication and technological (ICT) systems, pricing strategy, and redesign of chain configuration and infrastructure.

These practices can reap long-term strategic benefits as well as protection against risks. The tactical level is linked to the operational level risk and often needs reactive mitigation strategies to reduce their effects on performance. Risk mitigation literature identified reactive mitigation strategies such as postponement, volume and delivery flexibility, process flexibility, customer flexibility, multiple suppliers, strategic stocks, lead time management, financial risk management, and quantitative techniques.

### Step Three

Once top management determines the strategy for risk prevention or mitigation, related action plans need development. This step combines two phases of SCRM: (a) implement and execute and (b) review and adapt (Ha & Tang, 2017). Institutionalizing PM approaches help in addressing the most critical risks, while measuring the amount and need of resources such as information, material, finance, or products. PM facilitates the implementation and execution of risk management strategies by tracking and evaluating the performance measures linked to them (e.g., Blos et al., 2009; Chenhall & Langfield-Smith, 2007; Laihonen & Pekkola, 2016). The risk response actions can be reviewed and adapted according to the priority and the available resources which become visible with performance metrics or indicators measuring them (Lauras et al., 2010).

For example, a strategy such as “postponement” is introduced for managing “capacity risk” and related performance measures such as “cost” linked to postponement can be analyzed. Measuring cost and information throughout the chain can identify the decoupling point to avoid capacity risks. Accordingly, these performance measures or indicators can be proffered by different functional units of an organization (Chenhall & Langfield-Smith, 2007; Laihonen & Pekkola, 2016).

Upstream and downstream suppliers and buyers can also be incorporated to develop the indicators for the entire chain. PM tools can also be incorporated in identifying defects in a firm's operations through continuous auditing and reporting of changes once the risk management strategy has been implemented (Arzu & Erman, 2010). Incorporating sustainability PM efforts as control and monitoring can initially check that the risk management strategies have been cascaded down the organization and reap strategical performance outcomes as intended and further improve visibility to detect early threats of risks and adapt accordingly to ensure that the maximum risk can be avoided. Section 2.2 explains most commonly used PM systems, tools, instruments, and indicators in performance management literature that can be incorporated into the SCRM. It ranges from deciding the measurement tools and instruments to specific indicators.

## 2.2 Supply Chain Performance Measurement

SCPM can be defined as a set of metrics used to assess the efficiency and effectiveness of supply chain processes and relationships, spanning multiple organizational levels and multiple firms. The focus here is on the "metrics" that are used to access efficiency and effectiveness. These PM metrics can be derived from various measurement systems, tools, and instruments (Fig. 2). The literature

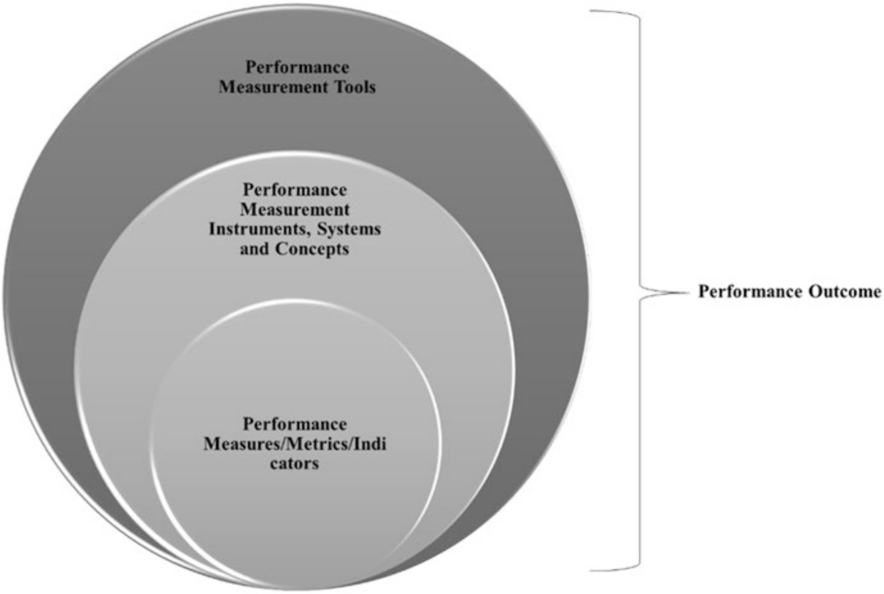


**Fig. 2** Performance measurement attributes

further distinguishes between these tools, systems, and instruments based on their focus. The PM tools can be categorized as instruments, system, or concepts (Beske-Janssen et al., 2015).

Whereas the PM instruments have a narrow focus and can be categorized as indicators, labeling, and reporting (Aman & Seuring, 2021; Beske-Janssen et al., 2015; Schaltegger & Burritt, 2014). Other examples of instruments include benchmarking, auditing, and lead-time reduction etc. These PM instruments are further analyzed through specific performance indicators (PIs) at organizational, operational, and supply chain levels. Therefore, a visual representation is made in Fig. 2 which distinguishes between the terms used in the PM literature and what they entail. Figure 2 explains that these PM terms differ in their scope, where PM tools have a broader scope which includes PM instruments, systems, and concepts as well as PM metrics. Furthermore, what constitutes these terms is explained in upcoming sections.

### Performance Measurement Tools

PM literature comprises various PM tools. Some of the frequently used tools will be defined below:

**Quality Standards (ISO 9001)** International Organization for Standardization (ISO) 9000 is about quality systems and consistency. It aims to give customers confidence in their suppliers by assuring them that the suppliers have the management processes that deliver consistency. It includes a set of standards that encourage organizations to assure product quality (Terziovski et al., 1997).

**Environmental Standards and Certificates** These standards and certificates help companies reach the environmental goals of their business operations using policies and standards for environmental protection (Huber & Bassen, 2018).

**Social Certification** Social certificates are a coordinated and systematic approach to managing health and safety risks by maintaining social standards such as Occupational health and safety (OHS), social accountability (SA) 8000, and Occupational Health and Safety Assessment Series (OHSAS) 18001 (Gold et al., 2010).

**Sustainability Standards** These refer to the standards or rules, procedures, and methods used to systematically assess, measure, audit, and/or communicate the social and environmental behavior and/or performance of firms (Gilbert et al., 2011).

### Performance Measurement Systems

**Quality Management System** A management system which uses the ISO quality certificates for managing the quality of the products (Beske-Janssen et al., 2015).

**Environmental Management System (EMS)** "ISO defines an EMS as 'that part of the overall management system which includes organisational structure, planning, activities, responsibilities, practices, procedures, processes and resources for developing, implementing, achieving, reviewing, and maintaining [the organisation's] environment policy" (ISO, 1996).

**Social Management System** A management system which includes the social ISO certificates for managing the social impact and also includes the occupational health and safety system (OHS) (Beske-Janssen et al., 2015).

**Integrated Management System** A management system which uses integrated managing tools such as Global reporting initiative (GRI) and United Nation (UN) global impact (Beske-Janssen et al., 2015).

## Performance Measurement Concepts

**Corporate Citizenship** "At a minimum, corporate citizenship means the conduct of business in ways that reflect proactive, responsible behaviour in business and dealings with all constituents and with respect to communities, society, and the natural environment more generally" (adapted from Logan et al., 1997, p. 7).

**Stakeholder Dialogue** "In the dialogue with stakeholders (both primary and secondary) opinions are exchanged, (future) interests and expectations are discussed, and standards are developed with respect to business practice" (Kaptein & Van Tulder, 2003, p. 208).

**Sustainability Balanced Scorecard** The well-known four dimensions of the BSC developed by Kaplan and Norton (1992) (i.e., finance, customer, internal business process, learning and growth) are shaped according to the SCM scope, by considering: SCM goals, end-customer benefit, financial benefit, SCM improvement. The idea behind the supply chain balanced score card (SCBSC) is to design a SC strategy coherent with the business strategy, including critical success factors within the four performance dimensions above (Maestrini et al., 2017).

**Supply Chain Operations Reference Model** Set of metrics grouped according to the five distinctive management processes, namely plan, source, make, deliver, and return. These metrics are also classified according to their strategic, tactical, or operational nature (adapted Maestrini et al., 2017).

**Resource, Output, Flexibility (R-O-F) Model** Resources: various dimensions of cost are monitored (e.g., distribution cost, manufacturing cost) with the purpose of fostering efficiency, Output: various dimensions of customer service are reported, Flexibility: it measures the ability to respond to a changing environment. This framework is thought to assess the SCM capabilities of a specific firm and keeps a mainly internal perspective (Maestrini et al., 2017).

## Performance Measurement Instruments

**Life Cycle Assessment** Life cycle assessment is a "cradle-to-grave" approach for assessing industrial systems. LCA evaluates all stages of a product's life from the perspective that they are interdependent, meaning that one operation leads to the next (Scientific Applications International Corporation, 2006).

**Eco-audit** Eco-auditing is a method of describing the state of the environment. It also includes environmental analysis as an approach by the management evaluating to what extent the organization complies with the internal and/or external environmental requirements (Aall, 1999).

**Environmental Benchmarking** Environmental benchmarking is a PM instrument through which companies are given a mark for their actions and achievements.

This enables stakeholders to judge how responsible a specific company is (Graafland et al., 2004).

**Environmental Reporting** "[This is the] process of communicating the environmental effects of organisations' economic actions to particular interest groups within society and society at large" (Nitkin & Brooks, 1998, p. 1499).

**Financial Report** This is an annual report published by companies that tells society at large about the companies' financial situation, including profit or loss for particular periods (Nitkin & Brooks, 1998).

**Social Audit** A social audit attempts to provide a mechanism for decision-makers to evaluate economic and social planning, facilitate popular involvement in economic decisions, and identify the social need as a primary criterion for resource allocation. (Owen et al., 2000). It also assures that the organization is meeting the social requirements.

**Social Benchmarking** It is a set given mark for the companies are for their actions and achievements. It enables stakeholders to judge how socially responsible a specific company is (Graafland et al., 2004, p. 139).

**Social Reporting** This is the process of communicating the social effects of organizations' economic actions to particular interest groups within society and society at large by publishing reports (Nitkin & Brooks, 1998).

**Sustainability Audit and Monitoring** Sustainability auditing refers to characteristics such as suppliers' compliance with the measurable standards that are employed to assess environmental management, the use of a trained audit team, and the organization's release of progress reports.

**Sustainability Monitoring** includes the evaluation of suppliers by auditors vis-à-vis ability to meet measurable standards and improving the flaws by training them (Seuring et al., 2019).

**Sustainability Benchmarking** "Through benchmarking, companies are given a mark for their actions and achievements, which enables stakeholders to judge how responsible a specific company is" (Graafland et al., 2004, p. 139).

**Sustainability Reporting** Sustainability reporting is a process of communicating the companies' initiatives towards environmental and social requirements. One trend that is also apparent in many parts of the world is the tendency of companies to produce separate social and environmental reports. In this context, such reports are generally termed as CSR reports or sustainability reports, depending upon the development of the corporation concerned (Aras & Crowther, 2009).

## Performance Metrics

### Performance Metrics Levels

The performance metrics can be devised for two organizational levels, i.e., strategic and process (Fig. 3). Figure 3 also explains that the process level measures are further divided into output measures and efficiency measures. These subcategories of the process performance measures are explained in further sub sections.

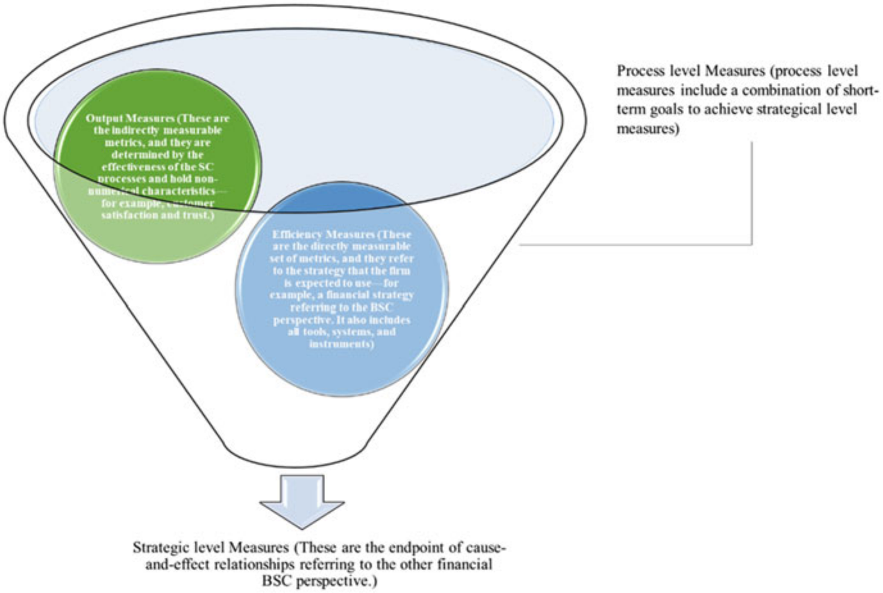


**Fig. 3** Performance metrics

### Strategic Level

A firm's strategic level measures include its final objectives, long-term goals, or outcomes. These strategical level performance measures often considered separately from the PM and are the strategic consequence of management strategies (Aman & Seuring, 2021). Therefore, this level represents the vision of an organization and thus includes long-term goals, for example, sustainability.

**Economics/Business Performance** Financial gains yielded from a business activity – that is, profitability, revenue, and economic growth. The endpoint of the cause-and-effect relationship.

**Sustainable Competitive Advantage** It is achieving and maintaining a competitive advantage as a result of business activity.

**Operational Performance** Cost reduction, speed, time, flexibility, dependability, output quality achieved, new quality product developed.

**Social Performance** Social benefits achieved as a result of a business activity – poverty alleviation, empowerment, inclusiveness, and so on.

**Environmental Performance** Environmental benefit achieved as a result of business activity – that is, energy consumed, waste produced, improved air quality, and so on.

**Sustainability Development** of all three dimensions of sustainability: social, economic, and environment, i.e., not focusing on performance outcome of a single dimension.

### Process Level

A firm's process level measures include a combination of short-term goals which are deployed to achieve strategical level goals. Process level measures further hold tangible or intangible characteristics (Hervani et al., 2005). The tangible measures include greenhouse gas (GHG) emissions and waste production, which are used to observe growth or decline patterns in SC processes. These tangible measures are measured directly (i.e., numerically) and the literature suggests that they should be used to assess the efficiency of SC processes (Beske-Janssen et al., 2015).

The intangible measures are also present in the performance measurement. These performance measures are determined by the effectiveness of SC processes, such as customer satisfaction, trust, and commitment. For example, trust is a non-numerical measure that can determine the reliability of the relationship between two SC actors. Because this relationship cannot be directly assessed, the actors assume trust in each other if they adhere to the standards that they set mutually, such as those required for ISO certification. Therefore, these measures are labeled as output measures, and they hold intangible characteristics. In sum, the efficiency measures have tangible characteristics while output measures hold intangible characteristics.

### Efficiency Measures

These are the directly measurable set of metrics, and they refer to the strategy that the firm is expected to use – for example, a financial strategy referring to the BSC perspective. It also includes all tools, systems, and instruments.

**Financial** The financial perspective indicates whether the transformation of a strategy leads to improved economic success. Financial performance here is defined as a process rather than an end point of the cause-and-effect relationship (Figge et al., 2002).

**Customer** "The customer perspective defines the customer/market segments in which the business competes. By means of appropriate strategic objectives, measures, targets and initiatives the customer value proposition is represented in the customer perspective through which the firm/business unit wants to achieve a competitive advantage in the envisaged market segments" (Figge et al., 2002, p. 271).

**Cycle time** "Cycle time refers to the time it takes from initiation to completion of the purchasing process" (Hult et al., 2002, p. 580).

**Cost** is usually a monetary estimation of effort, material, resources, time and utilities consumed, risks incurred, and opportunity forgone in the production and delivery of a good or service – that is, cost-efficiency (Adegbile & Sarpong, 2018).

**Quality** Quality includes a tangible dimension, i.e., it deals with procedures and specific systems which are established to provide the goods or service.

**Asset** Asset attribute refers to the effectiveness of asset utilization measured in terms of cash-to-cash cycle time, return on fixed assets, and return on working capital (Heuër, 2017).

**Resources** Resource measures include tangible resources, such as capital requirement, inventory levels, and equipment utilization.

**Flexibility** Flexibility refers to how easy it is for an SC to change based on its range of options (Ahrens et al., 2019).

**Gender Diversity** This refers to the consideration of gender diversity in the life cycle of a product. "It is the proportion of males to females in an organisation that can affect the way in which they interact and behave with one another at the workplace, and thereby impact the social and cultural environment" (IGI Global, 2020).

**Human Rights** This refers to the consideration of human rights in the life cycle of a product. Human rights include the right to life and liberty, freedom from slavery and torture, freedom of opinion and expression, the right to work and education, and many more. Everyone is entitled to these rights without discrimination (United Nations, 2020).

**Fair Trade** This is the consideration of fair trade in the life cycle of a product. Fairtrade means that the producers receive prices that cover their average costs of sustainable production, the premium which can be invested in projects that enhance social, economic, and environmental development (Fairtrade International, 2019).

**Fair Labor** This is the consideration of fair labor in the life cycle of a product. "This includes paying less than the minimum wage, employing young children, and working employees for long hours without premium overtime pay" (Goldstein, 1999, p. 1003).

**Child Labor** This is the consideration of child labor in the life cycle of a product. "A child (5–14 years) is defined as economically active if he or she works for wages (cash or in-kind); works on the family farm in the production and processing of primary products; works in family enterprises that are making primary products for the market, barter or own consumption; or is unemployed and looking for these types of work" (Edmonds & Pavcnik, 2005, p. 201).

**Waste Production** This is the consideration of waste production in the life cycle of a product: the production of unwanted materials as a by-product of economic processes (Sustainable Development Indicator Group, 1996).

**Greenhouse Gas (GHG) Emission** This is the consideration of GHG emission in the life cycle of a product for example, $CO_2$, SOx, and NOx. The emission of harmful gases into the air is called air pollution because they alter the chemical composition of the natural atmosphere (adapted from Daly & Zannetti, 2007).

**Noise Pollution** This refers to the consideration of noise pollution in the life cycle of a product. Noise pollution is generally defined as regular exposure to elevated sound levels that may lead to adverse effects in humans or other living organisms (Environmental Pollution Centers, 2019).

**Recycling** This is the consideration of recycling in the life cycle of a product. Recycling means the processing of waste (i.e., unwanted or useless materials) and its (re)introduction back into the material cycle so that contamination of the environment is minimized (Tanskanen, 2013).

**Pollution** This is the consideration of pollution in the life cycle of a product. Pollution is the introduction of harmful materials into the environment which further damage the quality of air, water, and/or land (adapted from Daly & Zannetti, 2007).

**Innovation** Innovation is the setting up of a new production function. This covers the cases of a new commodity and new ventures – that is, an organization or a merger – or the opening of new markets, new relationships, new products, or new marketing infrastructure (Hall et al., 2014).

### Output Measures

These are the indirectly measurable metrics, and they are determined by the effectiveness of the SC processes and hold non-numerical characteristics – for example, customer satisfaction and trust.

**Resources** Resource measures also include intangible resources, such as personnel requirements, relations, and information.

**Quality** Quality also includes an intangible dimension which deals with the interactions among workers and their attitudes and behaviors with customers.

**Customer Satisfaction/Expectation** Various dimensions of customer service are reported. Output measures include customer satisfaction measured through return on the quantity and quality of the products being produced and customer expectation through being more considerate and responsive to customer demand (Viswanathan et al., 2012).

**Local Community Commitment (LCC)** This is the consideration of the local community in the life cycle of a product. LCC means taking the long-term views and embeddedness of firms in local communities into account to deal with the local contestations for survival that filter into the everyday lives of the poor (Ansari et al., 2012) – for example, social inclusion.

**Social Capital** Social capital refers to three broad forms of capital further measure through structural capital, relational capital, and cognitive capital (Nahapiet & Ghoshal, 1998).

**Trust** The degree of reliability enjoyed between the SC partners which also facilitates SC processes (Al-Saa'da et al., 2013).

**Commitment** Commitment may be defined as the relative strength of an individual's identification with and involvement in a particular organization (Steers, 1977).

**Integration** Integrating suppliers, buyer, and intra-firm functional units into the SC processes (Schrader et al., 2012).

**Learning and Growth** The learning and growth output performance measures describes the infrastructure necessary for the achievement of the objectives. It includes information required for new products developed, new markets entered, Research and Development (R&D) spending/sales, training/sales, and investment/total assets/capability development (Figge et al., 2002).

## 3 Current Concerns

PM and SCRM have been separate within the SSCM literature, which highlights a need for exploring the interplay between the two topics. Within the literature, the most commonly used conceptualization includes the strategic level performance measures, that views performance as an ultimate or long-term consequence of SCRM (Simangunsong et al., 2012). This work neglects the role of short-term PM.

Process level measures are also viewed as SCRM antecedents (Munir et al., 2020). PM tools, concepts, and instruments play facilitator or enabler roles. The presence of performance in SCRM has been discussed but the idea of conceptually linking the multiple levels of analysis is relatively new. For example, a container of 500 lithium-ion batteries ordered from company A situated in China by company B in Germany through marine ports. Since the temperature is one of the crucial measures to check the likelihood of getting fire during shipment, company B strives to monitor the temperature during shipment using their PM system. While reaching B, the measurement system showed the company B that the temperature of the container is close to exceeding the set measure thereby indicating a likelihood of disruption risk. Without a proper measurement system or the set PIs, in this case, temperature, how would a company be able to detect a fault?

Taking the same example, suppose the container caught fire, the next step is how to mitigate the risk that has been occurred. The company can check for internal capacity, i.e., use either the social capital, such as alternative suppliers or ad hoc partners, or check the warehouse stock to fulfill the customer demand. Having a measurement system indicating warehouse stock and nearest alternative suppliers can then determine the effectiveness of the company's response to the risk occurred. Therefore, embedding PMs into the risk management – as shown in this example – plays a vital role in reducing and mitigating risk effects. This requires exploring the two concepts in detail and then linking them in such a way that is beneficial for mangers, in particular, and supply chains, in general.

### 3.1 Performance Measurement for Risk Management in Developing Countries

Globalization has caused a greater need for integrating developing regions into supply chains. With the changing paradigms of today's world, measuring performance of supply chain processes and actors in these regions have become important for various reasons. First, increasing focus on sustainability measures put pressure on the companies to ensure sustainability of the entire chain. Upstream performance in developing regions can use related indicators that can curb the sustainability risks. For example, most developing regions are crucial for primary resource-based global supply chains (Silvestre & Neto, 2015). Making sure the practices in these upstream supply chain actors conform to the mission of the company to avoid reputational losses thereby posing financial risks.

Second, offshoring poses a threat of opportunistic behavior which is difficult to determine. Having PMs based on the indicators such as "quality" and "trust" can ensure the integrity of the first and second tier suppliers thereby reducing the probability of risk occurrence. For example, suppose a company is under pressure to quickly start offshoring, primarily due to short-term focus of bonus incentives, can lead to inadequate quality check of second tier suppliers. If not checked, the likelihood of such supplier for suppling defective wires, or other poor practices, is high. These wires are then used by manufacturer and get integrated into a range of appliances. The defective wire then causes the appliances to malfunction. The cost to fix this quality lapse includes replacement of defective appliances, including installation costs, reworking the existing appliances stocked at different levels in the supply chain, and reworking the goods in the three-week long pipeline as they arrived. Therefore, PM for SCRM is an important consideration when organizations devise plans for emerging economies regions.

Considering the "consumer-oriented" and "inclusive business-practices" arguments of the emerging economies literature (Tate et al., 2019), it is evident that measurement of quality and trust play a crucial role in overcoming the risks associated with the two, respectively. Highly uncertain environments of these markets further stress the need for short-term PM which should be well aligned with the risk management strategies of the firms. If considered, it can help in successful implementation of strategies and improve visibility which are two critical components for risk management. Nevertheless, developing countries are important in this context as their market environment is considered highly uncertain and riskier also because of the presence of institutional voids (Parmigiani & Rivera-Santos, 2015). Therefore, it is crucial to devise and incorporate PM for risk management throughout the supply chain.

## 3.2 Sustainable Performance Measurement Through Digitization

Another current concern lies in the enhanced usage of digital platforms, tools, and technologies. The transition towards a digital era brings various performance related concerns such as environmental, social, and financial wellbeing of the organizations. For example, the high-tech firms are highly prone to downsizing the workforce considering them as incompatible for the digital transition. Besides, the environmental hazards embedded in the manufacturing of digital equipment rises the concerns of long-term environmental degradation, unless circular economy concept has been integrated into the system. Here PM improves the visibility and makes organizations more sustainable. For example, using digital scorecards elaborates on the organization's standing on the three dimensions of sustainability.

With advance digital tools one can improve the resource consumption within planetary boundaries, and therefore strive to reduce its consumption footprint and double its circular material use rate. However, it is easier said than done. Using correct PM instrument together with advanced digital tools can circumvent various concerns of today's scholars and organizations. The idea of using digital tool as overall process improvement is further mentioned in the Sect. 4.

## 4 Emergent Concerns, Outstanding Research, and Future Directions

Striving for better performance while successfully managing risks is important for a firm's existence, in particular, and their supply chain, in general. The inter-play between the two topics demands more understanding of the conceptual linkage. It is crucial to explore the literature on PM and SCRM. PM comprises PM tools, systems, concepts, instruments, and indicators which are further categorized based on their focus (Aman & Seuring, 2021; Beske-Janssen et al., 2015; Schaltegger & Burritt, 2014). Within risk management, conceptualization requires details on the risk factors, management practices, and control and monitoring. Furthering the risk management debate is on how PM can influence and be influenced by SCRM is still needed – we have only started the discussion in the chapter, much more is still required.

Various factors have been suggested that can influence decisions that are particular to supply chain risk. The conceptual definition of the performance characteristics has been presented and most common risk and related strategies have been identified. Consideration of their inter-play can affect the strategic outcomes of a firm, and this outcome, through various empirical and case studies, can provide additional insights for future developments.

PM both before and after devising risk management strategies is found critical for risk management. Therefore, understanding this role and its successful implementation can help managers in detecting early diversion from the set performance targets – but can also lay the foundation for long-term strategic competitiveness of firms and their supply chains. How these issues interact needs further study.

There are other directions for discussion and development of the topic especially from scientific, theoretical, and/or research investigation perspective. First, which PM tools, concept, systems and instruments, and indicators are linked to which risk and which risk management strategy? This linkage highly depends on the company's values, competitive priorities, and broadly their vision. Linking the two topics better in such a context require company's managers to consider long-term aims of the company. Consequent strategies and accurately linking them with short-term performance measures ensure that the maximum risk can be avoided. Nevertheless, these PIs for risk management can further be devised for internal, upstream, downstream, and reverse logistic activities as well as actors using the measurement instruments, tools suggested.

Second, the PIs vary from company to company and should be the focus of focal firms. For example, the PIs for food supply chains would be different from the automotive supply chains and that of the apparel supply chains. However, some of the PIs mentioned in the chapter can be applied to all these supply chains and adding more specific indicators based on the company strategic objectives need to be discussed further by the researchers. This industry and contextual difference also mean that the linkage between SCRM and PM may also vary (Negri et al., 2021). These nuances need careful investigation.

Third, there is a question on what behavioral aspects can cause risk and PM problems. There is always a risk of opportunistic behaviors; however, incorporating collaboration as a strategy and relative incorporation of collaboration themed balance scorecard can ensure that the risk can be avoided – or at least studied to determine if this mitigation is likely to occur. Researchers can test this proposition in real world setting. It would be insightful to understand how behavioral aspects relate to various type of risks and how measurement of these indicators minimizes the risk of subsequent negative outcomes. Similarly, what other contingency factors do a company need to consider while linking risk and performance measures? Exploring further contingency factors would help both the practitioners and researchers in understanding the interplay between the two.

Lastly, identifying how digitization facilitates linking risk and PM is a serious and open question. Recent disruption risk faced from COVID-19 enforced the supply chains to incorporate digitization of the existing supply chain activities. Digitization can ease the PM and help in swiftly managing the associated risks. Taking the example of lithium-ion batteries, suppose the company was using sensors in container to check the temperature and a digital assistant to check PIs and upon any diversion, an alarm was set to alert the managers for potential risk of fire in the container. The mangers would quickly try to resolve the related risk such as delay of order by checking the internal capacity of the company through digital assistant.

With the evolution of digitization and digital components such as big data and Internet of Things (IoT), a company can harness web analytics for more informed performance measures to exploit in reaching the performance outcome (Järvinen & Karjaluoto, 2015) as it provides the real-time visibility (Ivanov & Dolgui, 2020). Therefore, digital PM or selection of performance measures from the use of digital components holds several ideas for future studies.

## 5 Managerial Implications

The managers and policy makers can consider these performance and risk factors in strategic decision-making regarding risk management. These factors are also extracted from sustainability perspective, so as to incorporate financial, environmental, and social factors together into their PM. The strategic performance outcomes reflect on the company's vision statement and the process level measures reflect on the mission statement, where PM tools, systems, instruments facilitate the measurement of the latter to monitor and control the risk for the achievement of former. The managerial implications are further elaborated concerning the (1) organizational, (2) technological, and (3) external relationship perspective.

Organizational risk management and PMs not only need to be linked to each other, but also linked to external systems across the supply chain partners. Here the managers need to include SC partners in the early design of the PMs by incorporating suggestions for necessary risk management. Off course this is not an easy thing to do. Considering different SC partners have diverse risks and devising the PMs for each partner can tremendously help the managers for timely risk management.

Besides, schedules of the necessary evaluation based on PM metrics should be included in the initial contract between the parties. This will help the managers to understand which SC partners are prone to more risk and to devise the strategies timely.

Further, managers can use the digital platforms for updating the SC partner's data on the devised PM metrics. A user-friendly interface can even allow for daily visibility of partner's performance making the risk management easy. However, the digital platforms may raise the concerns of reliability when the SC partners are dispersed worldwide, i.e., developing countries. Therefore, strong external relations based on trust are required to work more effectively towards overall risk management.

The managers can use "trust" metrics to measure external relationship with the SC partner, as discussed in section "Performance Metrics", which further can resolve the issue of reliability in measuring the PM metrics digitally. The external relationship can also be built on mutually agreed upon sharing the performance data between managers of two or more SC entities.

## 6 Summary and Conclusion

Building on the notion that there is a dearth of understanding on the interplay between performance and risk, the chapter introduced the current state of performance in SCRM. It further elaborates on this by presenting a comprehensive understanding of the performance considering the PM literature. In doing so, the chapter addresses the previously sought comprehensive view on the antecedent and consequences of SCRM. The role of SCPM within SCRM is presented as a loop which can be explored further by taking individual performance instruments, tools, concepts, or indicators and their role in SCRM. One such example includes role of social capital in SCRM. The chapter concludes that there are many PM constructs that can serve as antecedents and consequence in SCRM which still require future research in its own right.

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# Supply Chain Security

Zachary A. Collier and Shital A. Thekdi

## Contents



**Abstract**

Successful supply chain management involves balancing multiple objectives, such as cost, responsiveness, sustainability, and flexibility. These objectives are dependent upon a secure and functioning information system, especially with the integration of information technology (IT) platforms to perform multiple supply chain management functions. Securing the materials, information, and finances

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transmitted along the supply chain is paramount, as supply chains have become the target of malicious supply chain attacks which can result in costly data breaches, physical impacts, and other compromises. Even the most secure information systems are vulnerable due to information exchanges with third parties, thereby incentivizing malicious parties to often target the weakest links in information-sharing partnerships. In this chapter, we will review the theoretical and methodological approaches to supply chain security, identify emerging challenges across a variety of technological use cases, and provide managerial recommendations for managing risk and ensuring a secure supply chain.

**Keywords**

Security · Cybersecurity · Supply chain management · Risk management

## 1 Introduction

Several high-profile security attacks have plagued supply chain information systems in recent years. For example, the recent JBL ransomware attack disrupted one-fifth of the US meat supply. Another recent ransomware attack resulted in disrupted operations for hundreds of businesses, disrupting abilities to conduct transactions (McMillan, 2021). The SolarWinds attack is particularly notable for its potential to impact the functionality of critical infrastructures (CISA, 2020). The city of Oldsmar, Florida, suffered an attack on their water treatment system in which an attacker remotely increased sodium hydroxide levels in the water to deadly levels (Greenberg, 2021). A casino was attacked through an Internet of things (IoT)-enabled thermometer in a fish tank, enabling access to a database of high rollers (Marks, 2021). *Bloomberg Businessweek* reported on a state-sponsored attack dubbed "the big hack" in which tiny chips, the size of a sharpened pencil tip, were inserted into motherboards during manufacturing by subcontractors in the supply chain. This tiny chip allowed attackers to create a stealth doorway into the networks of the compromised systems (Robertson & Riley, 2018). The global nature of the 5G telecommunications supply chain has raised national security concerns within the federal government (Donahue, 2019).

Societies and economies depend critically upon functional and secure supply chains, particularly within manufacturing, critical infrastructures, and cyber systems. For example, we rely upon secure supply chains for food, ensuring that the food is kept at safe temperatures and free from harmful contaminants (Conrad et al., 2012; Alvarez et al., 2010). Similarly, the supply chain for pharmaceuticals must be free from potentially harmful counterfeit drugs (Outterson & Smith, 2006). As global supply chains grow more complex, coupled with a lack of visibility and an increasing reliance on information technology (IT), supply chains are appealing targets for malicious actors. One such concern is that supply chains may be the target of "supply chain attacks," which according to NIST are defined as "attacks that allow the adversary to utilize implants or other vulnerabilities inserted prior to installation in order to infiltrate data, or manipulate IT hardware, software, operating systems, peripherals (IT products) or services at any point during the life cycle" (NIST, 2021). These attacks are often executed indirectly by exploiting a target's upstream suppliers. According to one study, 56% of companies have experienced a breach caused by one of their vendors (Korolov, 2019).

With the advanced rate of technological progress, supply chain security is becoming a critical component of organizational management. In particular, operations are becoming increasingly automated and interconnected, creating avenues for attacks to impact systems that historically have been managed by humans. These types of attacks have the potential to not only disrupt the movement of goods and services but can also impact physical systems, including the health and well-being of populations. However, an effectively secure supply chain that leverages these new technologies has potential to benefit societies in a variety of ways. Most notably, the increased reliance on artificial intelligence (AI) and automation can drastically improve efficiencies (Manyika & Sneader, 2018; Nunez, 2019) and improve aspects such as health and safety, food security, operational efficiencies, and economic prosperity of nations.

In this chapter, we review the topic of supply chain security. In Sect. 2, we describe the historical and theoretical background of security and risk. In Sect. 3, we summarize current concerns and research efforts, followed by emerging concerns and future research directions in Sect. 4. In Sect. 5, we highlight managerial concerns and implications for supply chain managers. Finally, we offer a summary and concluding discussion in Sect. 6.

## 2 Background

This section will discuss main principles and definitions related to supply chain security and risk.

### 2.1 Supply Chain Security

Closs and McGarrell (2004) defined supply chain security as: "The application of policies, procedures, and technology to protect supply chain assets (product, facilities, equipment, information, and personnel) from theft, damage, or terrorism and to prevent the introduction or unauthorized contraband, people or weapons of mass destruction into the supply chain."

Security-related risks may arise throughout the supply chain, impacting the goods being transported, the factories belonging to the firm and those of outsourced firms, other third-party supply chain vendors, the facilities where supply chain activities are carried out such as warehouses and ports, freight carriers (truck, air, rail, ships), people who have access to the goods and facilities, and information that is transmitted along the supply chain (Sarathy, 2006).

Supply chain security involves the activities of cargo management, facility management, information management, and human resource management (Hintsa et al., 2009). Traditional security measures focus on implementing effective methods, prevention, detection, and reporting of security threats, as well as practices such as background checks on employees and monitoring of facilities via security guards and camera systems (Hintsa et al., 2009). Related to transportation, one example is the routing of hazardous materials along highway systems. Abkowitz et al. (1992) devised five different objective functions for route selection: minimize distance traveled, minimize travel time, minimize accident likelihood, minimize population exposure, and minimize risk (as the product of accident likelihood and population exposure) (Abkowitz et al., 1992).

While security within the context of supply chain management has always been an important topic, it increased in importance in the wake of the September 11th terrorist attacks (Williams et al., 2008). Sheffi (2001) noted that it was not the attacks themselves but rather the government's responses that were disruptive to the supply chain such as border closures and grounding of air traffic. In the post-9/11 world, companies are increasingly focused on managing risk associated with other potential attacks, managing supply chains under increased levels of uncertainty surrounding other types of risk events, managing relationships with the government, and protecting employees, physical assets, and intellectual property (Sheffi, 2001).

Another trend which has accelerated rapidly in recent years is the integration of IT systems supporting supply chain activities. IT systems enable information sharing, communication, and collaboration between supply chain partners, as well as automation of processes like ordering (Subramani, 2004). The use of IT in supply chains typically seeks reduced costs, reduced lead times and cycle times, increased operational capabilities, improved partner relationships, and better decision-making (Nath & Standing, 2010).

Sahay and Gupta (2003) discussed various supply chain software platforms, including enterprise resource planning (ERP) systems with supply chain-related models, as well as more specialized packages for supply chain planning (SCP), order management systems (OMS), warehouse management systems (WMS), manufacturing execution systems (MES), and transportation management systems (TMS). While IT has yielded benefits for supply chains, Spekman and Davis (2016) identified IT systems as a source of risk. Not only do disruptions to IT systems disable and disrupt the firm's operations – in terms of flows of goods, information, and money – but IT systems may inadvertently grant access to proprietary information by an unauthorized party (Spekman & Davis, 2016).

Ransomware is an example of a relevant supply chain disruption. Typically, ransomware is accidentally downloaded onto a computer and encrypts files on the computer and network, requiring a key to unlock the files in exchange for a ransom payment. Within the healthcare field, for example, ransomware has been prevalent, and hospitals incur risks due to medical malpractice which may occur if a patient is affected as a result of the ransomware attack. There are also data privacy concerns, reputational risks, and other costs and expenses associated with ransomware (Spence et al., 2018).

The US National Institute of Standards and Technology (NIST) Special Publication 1500-201 defines a cyber-physical system as follows: "Cyber-physical systems (CPS) are smart systems that include engineered interacting networks of physical and computational components" (NIST, 2017). The IoT, industrial Internet, and "smart" systems such as cities, grids, vehicles, etc., fall into this category. Such systems increasingly play a dual role – they have their own supply chains, which must be secure, and they also support and facilitate the supply chains of other products and services as well. As an example, the supply chain for microelectronics supports the digitally enabled economy. Issues related to counterfeit parts entering into the supply chain and malicious functions inserted into the circuitry result in security issues from degraded functionality to unauthorized remote access to the system and sensitive data (DiMase et al., 2016). Other trends accelerating these concerns within the microelectronics industry include the shift away from in-house manufacturing toward contract manufacturing, increased globalization, and the reuse of intellectual property licensed from third parties (Guin et al., 2016; Polczynski, 2004; Mason et al., 2002). The result is a lack of traceability across the supply chain and opportunities for adversaries to insert malicious code and/or hardware into the final product or system (DiMase et al., 2016).

Therefore, supply chain risk management is an important area of concern for cyber-physical security (DiMase et al., 2015), while the security of the supply chain itself is also important as it represents an entry point for supply chain attacks on downstream partners (Collier & Sarkis, 2021).

## 2.2 Defining Risk

The Society for Risk Analysis (SRA) provides several definitions of risk. Many of these definitions involve uncertainty as it relates to the severity of consequences, involving some aspect that humans value (SRA, 2021). The ISO 31000 standards agree, as it defines risk as the effect of uncertainty on objectives. Kaplan and Garrick (1981) defined risk in terms of the answer to the following questions: "What can happen?" "How likely is it?" "What are the consequences?"

Threats that can impact the functionality of supply chains can take many forms. Natural disasters are often the most visible, taking the form of floods, tornados, hurricanes, earthquakes, wildfires, and others (DHS, 2021). Human-induced threats could include the release of hazardous materials and infrastructure accidents, such as the Deepwater Horizon oil spill. Threats may also be in the form of terrorism, state-based attacks, and cybercrime groups who seek financial gain (e.g., ransomware), information (e.g., trade secrets, intellectual property, information for subsequent attacks), sabotage (e.g., acts of war), and attention (e.g., hacktivism).

The vulnerability of a supply chain can be assessed as the "degree to which a system is affected by a risk source or agent" (SRA, 2021). Modern supply chains are increasingly interconnected, such that the functionality of one firm can have cascading effects on interrelated firms within the supply chain system. Thus, incidents occurring in small or less secure firms can have impacts on larger and more secure partner firms. These types of cyber incidents often result from cyber-vulnerabilities, which can be unknown by the firm – such as *zero-day* threats with previously unknown methods – and attacks can often go undetected.

To manage vulnerability requires active risk management practices that are supported by firm stakeholders. For example, consider the Equifax data breach, which was caused by employees neglecting to install a patch for a known vulnerability (Newman, 2017). This situation can be particularly challenging in times of employee dispersion, as in during the COVID-19 pandemic where workers were required to work remotely using nonsecure connections that bypass physical security controls. Additionally, technologies evolve rapidly, with new devices and software emerging, making it even more difficult to manage vulnerabilities. In times of increasing automation, it is unclear how increased reliance on AI will impact system vulnerabilities, as AI could potentially perform insufficiently in new or surprise situations – where learning typically occurs iteratively.

Cyberattack consequences related to supply chain security can vary. Maintaining *confidentiality*, *integrity*, and *availability* is often the main objective for information security (CISA, 2019). In cases of cyber-physical systems, the consequences can have direct impacts on the health and safety of systems. For example, consider the use of vehicles that are increasingly managed by computer systems – to the extent of being fully autonomous. Attacks on the information systems of those vehicles can cause physical consequences, even for non-autonomous vehicles (Greenberg, 2015).

Once risks have been assessed, the question remains as to how the risks should be managed. This process is often referred to as risk treatment, risk response, or risk control and involves decision-making about what actions to take, which generally fall into four categories – avoidance, transfer, mitigation, and acceptance (Hillson, 1999). Risk *avoidance* activities involve eliminating uncertainty and may include refraining from the activity altogether. Risk *transfer* involves shifting ownership of the risk or liability to a third party. The classic risk transfer mechanism is insurance. The third strategy is risk *mitigation*, in which countermeasures and controls are implemented which bring the residual risk down to an acceptable level. Finally, risk *acceptance* involves moving forward with the activity and devising responses to control and monitor the activity (Hillson, 1999).

Haimes (1991) proposed a series of guiding questions for risk management: "What can be done and what options are available?" "What are the associated trade-offs in terms of all relevant costs, benefits, and risks?" "What are the impacts of current management decisions on future options?"

## 3 Current Concerns in Supply Chain Security

This section discusses current concerns in supply chain security, including legal/regulatory issues, physical safety, and management.

### 3.1 Requirements About Data and Privacy

Data privacy is highly regulated. Organizations that accept or process payment cards are subject to the payment card industry security standards. These standards require organizations to invest heavily in information security, with activities that include maintaining a secure network, managing vulnerabilities, monitoring their networks, and maintaining information security policies (PCI, 2021).

In cases of healthcare-related data, organizations also need to invest heavily in meeting the requirements of the Health Insurance Portability and Accountability Act of 1996. These rules apply to protected health information, which includes medical test results, diagnoses, and treatment information (HIPAA Journal, 2021). The regulation also requires that organizations ensure confidentiality, integrity, and availability of protected data, maintain information security, and certify compliance.

The European Union General Data Protection Regulation (GDPR) of 2018 made a global impact on the practice of data protection. While this regulation applies to the data privacy of people in the EU, the impact is more widespread in cases of multinational outreach efforts. This regulation calls on organizations to minimize the collection and processing of data, limiting the length of time data is stored, and again ensuring security, integrity, and confidentiality of data (GDPR, 2021).

### 3.2 Physical Safety for Supply Chains

IT is increasingly used for critical tasks related to physical systems. For example, consider automation related to infrastructure management, manufacturing, and IoT technologies (IBM, 2021b). Because algorithms and real-time data inform a wide variety of tasks, there is overwhelming potential for increased efficiencies. However, there is also increased potential for risk events that can impact the functionality of these systems. Consider again the example of a cyberattack on a water treatment plant in Oldsmar, Florida, in which an attacker attempted to increase the level of sodium hydroxide in the water to dangerous levels, noting that poisoning from this chemical, known as lye, can cause serious physical health consequences (PEW, 2021).

Similarly, attacks can have serious physical consequences in cases of autonomous vehicles. In the context of infrastructure management, automation of the energy grid may pose serious consequences, for example, recognizing that a functioning energy grid is critical for the operation of essential services, such as security systems, the operations of hospital functionalities such as ICUs, operation of critical traffic signals, and even operation of electric vehicles. Healthcare organizations are frequently targeted by cyberattackers, and these attacks can be serious and deadly (Skahill & West, 2021).

These technology systems can be vulnerable to many types of attacks. The National Security Commission on Artificial Intelligence identifies several AI-related threats, including the presence of automated and stealthy cyberattacks, data poisoning, theft, and bias of AI systems (NSCAI, 2021).

### 3.3 Managing Disruptions to Operations

A current and ongoing concern is managing disruptions to supply chain and other business operations. With the variety of potential disruptions facing firms – such as terrorism, natural disasters, cybercrime, and ransomware – planning and management for business continuity is critical.

ISO 22301:2019 defines business continuity as the "capability of an organization to continue the delivery of products and services within acceptable time frames at predefined capacity during a disruption," while the British Standards Institution defines business continuity management as "A holistic management process that identifies potential threats to an organisation and the impacts to business operations that those threats, if realised, might cause, and which provides a framework for building organisational resilience with the capability for an effective response that safeguards the interests of its key stakeholders, reputation, brand and value-creating activities."

Business continuity management is often associated with other activities such as business continuity planning, crisis response, crisis management, and disaster recovery planning. While there is overlap between these concepts, some have put forward definitions and taxonomies to differentiate between them (e.g., Herbane et al., 2004; Krell, 2006). The use of the term "management" rather than "planning" indicates that there is no start or end to the activity but rather that it is a continuous, dynamic, and proactive process (Smith, 2003).

The strategic contribution of business continuity management is value preservation – the capability of the organization to resist and recover from disruptions and minimize their impacts and losses (Herbane et al., 2004). One of the key activities of business continuity management is business impact analysis (BIA). In BIA, the organization identifies critical business functions, determines the impacts associated with disruptions of those functions, and identifies the resources needed to reestablish critical functions after a disruption (Torabi et al., 2016).

BIA is often compared with risk analysis because they are both associated with identification, analysis, and treatment of risks. But risk analysis typically considers impacts and probabilities of occurrence, while business continuity management typically focuses on impacts and time (Krell, 2006; Torabi et al., 2016). As BIA relates to supply chain management, Suresh et al. (2020) proposed a six-step framework for business continuity management for supply chain resilience, linked to the plan-do-check-act (PDCA) cycle:

1. Examine the organizational context of the supply chain
2. Leadership commitment
3. Prevention (mitigation tactics)
4. Recovery (response tactics)
5. Assessment of plans
6. Continuous improvement

Zsidisin et al. (2005) identified 12 principles for effective supply chain continuity planning:

1. Create internal awareness.
2. Drive awareness into the supply base.
3. Prioritize suppliers and commodities to focus attention.
4. Understand both probability and impact of supply chain disruptions.
5. Eliminate/reduce exposure where feasible; buffer or mitigate where elimination is not feasible.
6. Use multiple information sources to monitor risk.
7. Revisit these issues on a regular basis.
8. Plan for disruptions.
9. Manage the impact of disruptions.
10. Take a continuous improvement view of supply chain continuity planning.
11. Make a post-event audit of supply chain disruptions standard operating procedure.
12. Share knowledge of supply chain continuity planning throughout the organization.

### 3.4 Vendor Risk Management

Another concern within the supply chain is how to effectively manage the risks posed by third parties. In an ongoing effort to enhance competitiveness, companies continue to outsource their noncore business processes to other manufacturers, suppliers, and service providers, creating mutual dependencies within an "extended enterprise" (Spekman & Davis, 2016). The sharing of information and knowledge across supply chain partners builds trust, but the rapid adoption of IT to facilitate information transfer results in an increased attack surface for the firm (Keskin et al., 2021). Target's data breach in 2013 is an example of a supply chain attack in which a third party – a heating, ventilation, and air-conditioning (HVAC) vendor – was the point of entry into Target's systems, ultimately costing the Target company $290 million (Stevens, 2018).

Companies with extended and complex supply chains must implement rigorous third-party risk management practices to mitigate their risk exposure. Much of the guidance on third-party risk management originates from the banking industry – but easily applies to other industries.

The US Office of the Comptroller of the Currency (US OCC, 2013) defines a third-party relationship as "any business arrangement between a bank and another entity, by contract or otherwise" that includes activities like "outsourced products and services, use of independent consultants, networking arrangements, merchant payment processing services, services provided by affiliates and subsidiaries, joint ventures."

Importantly, even though an attack might originate from a third party, the primarily impacted firm tends to hold the responsibility and pay the price of such an attack (Vitunskaite et al., 2019).

The US OCC (2013) summarizes: "A bank's use of third parties does not diminish the responsibility of its board of directors and senior management to ensure that the activity is performed in a safe and sound manner and in compliance with applicable laws." The US Federal Deposit Insurance Corporation (US FDIC, 2008) identified six major categories of risks incurred as a function of third parties: strategic, reputational, operational, transaction, credit, and compliance risk.

The US OCC (2013) introduces a multistep process for third-party risk management, including aspects such as planning, due diligence and third-party selection, contract negotiation, ongoing monitoring, and termination. Specifically, it is suggested that companies engaged with third parties clearly define expectations and responsibilities to limit liability, as well as develop contingency plans to transition outsourced activities in-house (US OCC, 2013). Part of due diligence and vendor selection should include an assessment of the third party's information security program – such as infrastructure and application security, software development practices, vulnerability, and penetration testing – and their management of information systems (US OCC, 2013).

Other risk management practices include the addition of a *right-to-audit* clause to enable monitoring and risk mitigation of third parties (Jackson, 2010). Supplier selection measures should be risk-informed, including consideration of whether the supplier is a sole/single-source, the criticality of the information to which they have access, and whether they are a high-value strategic partner (Wolff et al., 2021).

Firms can partner with third-party suppliers to mitigate risks through cybersecurity education training, maintain oversight of the third party's compliance program, restrict the use of data to hard copies or read-only access, or simply terminate the relationship (Wolff et al., 2021). Following the principle of *least privilege* is another security measure, in which the minimum amount of access privileges is granted to third parties necessary to complete a task (Saltzer & Schroeder, 1975). Finally, organizations must contend with the risks associated with so-called fourth parties, i.e., the outsourced firms contracted by third parties (Bwanya, 2018).

### 3.5 Anti-counterfeiting and Protection of Product Integrity

Another threat to supply chain security is not found in the form of disruptions but through the introduction of counterfeit goods into the supply chain. Many counterfeit products exist, ranging from luxury goods to pharmaceuticals (Outterson & Smith, 2006). Even counterfeit foods exist, which either may be food that has falsified markings on the packaging indicating a misleading brand or origin – such as incorrectly claiming a product was "Made in Italy" – or may be adulterated with different substances not normally found in that type of food (Ministry for Economic Development, 2021). Examples of the latter include documented instances of counterfeit eggs made of various resins and pigments (Boehler, 2012) and cooking oil collected from the sewer, refined, and sold to small restaurants and street vendors (Riggs, 2013).

Another area of concern for counterfeiting is in the semiconductor industry, where electrical, electronic, and electromechanical (EEE) parts are relabeled, refurbished, or repackaged to misrepresent the authenticity of the component (Sood et al., 2011). Guin et al. (2014) developed a taxonomy of counterfeit type, identifying seven main forms of counterfeit electronics – recycled, remarked, over-produced, out of specification/defective, cloned, forged documentation/part substitution, and tampered.

The source of counterfeit electronics is often from collected and recycled electronic waste (e-waste) and resold as new. Consequences of counterfeit electronics include lost revenue, damaged brand reputation, and potential legal liabilities for the firm whose intellectual property has been infringed (Pecht & Tiku, 2006; DiMase & Zulueta, 2009). Moreover, counterfeit electronics are a threat to security, as they may include viruses and malware (sometimes referred to as hardware Trojans) (US Department of Homeland Security, 2020).

Combating counterfeiting within the supply chain is a difficult challenge. When possible, the safest way to procure authentic goods is to purchase directly from the original manufacturer or from an authorized distributor (Livingston, 2007).

Within the defense microelectronics sector, the “Trusted Supplier Program” was created to accredit trusted suppliers of microelectronics for defense applications. In this context, trust is defined as “the confidence in one’s ability to secure national security systems by assessing the integrity of the people and processes used to design, generate, manufacture, and distribute national security critical components” (US Department of Defense, 2004). Specifically, trusted suppliers follow supply chain security practices such as maintaining a chain of custody, mitigating the risks of supply disruptions, preventing modification and tampering, and protecting against reverse engineering (US Department of Defense, 2004).

DiMase et al. (2016) discussed the importance of traceability across the supply chain for ensuring security. Other mitigations include traceability documentation, compliance verification, following good supplier selection practices, and obsolescence management (Livingston, 2007). Additionally, the US government tracks and maintains watch lists of nations and companies suspected of engaging in nefarious trade practices and intellectual property infringement (e.g., Office of the US Trade Representative, 2021; US Department of Commerce, 2020).

## 4 Emergent Concerns, Outstanding Research, and Future Directions

This section will discuss emergent concerns in supply chain security, including developments in AI and technologies. We will also discuss needs for future research and development.

### 4.1 AI

AI is defined by the ability to analyze data and act in ways that mimic the abilities of humans. The data used in AI models can be in the form of text, numbers, or imagery. IBM distinguishes between weak and strong AI. Weak AI involves narrow or specific tasks, as exemplified by personal assistants, robots, and autonomous vehicles. Strong AI involves an intelligence equivalent to humans, in which the system is self-aware and can learn (IBM, 2021a).

Technology including AI has large potential to promote efficiencies in supply chain management. Consider abilities for data sharing that would allow for transparency in information among suppliers. Also, consider vehicle routing using information technologies, which have the potential to reduce costs, emissions, and labor requirements in the transportation sector. For example, Google Maps, which leverages AI, historical data, and real-time data from users (Lau, 2020), identifies the most efficient routes based on user-inputted parameters. AI can also be used to address risk. For example, AI can be used for threat detection in cyber-security applications (Lee et al., 2019).

The movement of goods and services also benefits from the development of smart cities that leverage technology to aid in safety, security, and information sharing. Most notably, these applications can be used for physical security for property throughout the supply chain. For example, AI-based surveillance technologies can be used to not only monitor crime but also to make predictions, allowing supply chain organizations to proactively secure their systems. AI is also used for tasks such as regional traffic monitoring using remote sensing, disaster assessment, and optimization of performance on multimodal transportation infrastructure (Vasudevan et al., 2020).

AI methodologies are used widely in the modern, algorithm-driven economy for applications such as consumer behavior prediction, fraud detection, and making credit decisions (Ozbayoglu et al., 2020). These algorithms often rely upon personally identifiable information. While deidentification methods are often used, this information is still at risk of being reidentified with public information (De Montjoye et al., 2015). Models trained on datasets which have not been deidentified, or only weakly deidentified, can be compromised by various types of algorithmic inference attacks (Gong & Liu, 2018; Shokri et al., 2017).

There are also risks that can emerge from the use of AI. There is unchartered territory from the perspective of addressing biases in activities such as image analysis (Glusac, 2016). These biases have been explored from the perspective of facial recognition software, suggesting that the model accuracy is only as good as the data used for training. As AI-based image detection can be used for managing inventories (Verma et al., 2016), remote sensing and management for infrastructure, and other critical supply chain decision-making activities, biases remain a concern.

Additionally, while AI shows accuracy in typical or as-planned situations, it may not be as accurate in cases of surprises or unforeseen events. Thus, there remains concern about the use of AI from a risk perspective, as these algorithms may lose accuracy during unexpected risk events, times at which the algorithms would be needed the most.

## 4.2 Automation

While self-driving cars have received much attention, it is self-driving trucks that are projected to be revolutionary for supply chains and economies as a whole. Due to their large size, these trucks are able to make more effective use of sensors, leveraging a larger field of view. As these trucks may use more familiar roads, they can operate in less variable environments, making them amenable to automation. Using automated driving, these trucks are more fuel efficient and reduce wear on the truck (Ackerman, 2021).

Drones can be used for monitoring and delivery of goods. The use of drones could potentially decrease congestion on roadways. Of course, there are regulatory issues with implementing drone service, comparable to those faced around autonomous vehicles. Additionally, the use of drones may not result in improved environmental impact, in terms of increased need for warehousing and impact on wildlife (Austin, 2021).

There is also large potential for autonomous robots. The use of these robots can increase productivity and efficiency, reduce error, and improve safety (Fitzgerald & Quasney, 2017) with minimal rest. For example, industrial robots have the capacity to perform redundant and unsafe tasks such as welding, assembly, polishing, and grinding. In cases of food manufacturing, there is potential for robots to detect defects in the production process, which can result in improved food safety and cost. In the case of agriculture, robots and automated systems can perform tasks such as spraying fertilizers and pest control and other laborious and potentially unsafe operations (CMTC, 2021).

Security for these technologies remains a large concern. If these technologies remain reliant on the power grid, their operation would be vulnerable to infrastructure attacks, such as state-sponsored terrorist attacks. These technologies could also be subject to ransomware attacks, which can disrupt operations for extended periods of time. In cases of cyber-intrusions, remote attackers can take control of the technology and use that technology for physical attacks on people and property or reroute those technologies to aid in larger-scale attacks. Attacks could also alter data used by those technologies, which could result in communication loss or inability to perform related business functions. Attacks could also steal data and use that stolen data for activities such as identity theft or sharing of trade secrets. Because these technologies are often connected to other devices, they may also serve as an entry point to other technologies, such as computers and other IoT devices.

There also remain many questions surrounding legal liabilities when automated systems are used, for example, involving industrial robots damaging people or property or accidents involving autonomous vehicles. Consider the case of an autonomous vehicle developed by Uber, which killed a pedestrian in 2018. While Uber did not face criminal liability, the safety driver was charged on grounds of negligent homicide (Conger, 2020).

### 4.3 Zero Trust

One emerging area of research is in the application of "zero trust" principles to the supply chain. The concept of zero trust originated in a series of reports from the IT security field (Kindervag, 2010a, b, 2011). In these reports, it was observed that traditional perimeter-based security approaches were inadequate to deal with modern IT systems, which had porous and amorphous boundaries, with a number of users such as customers, suppliers, and end users accessing the network from within and remotely from cloud platforms. With a large and dynamic attack surface, Kindervag concluded that the paradigm of trusted and untrusted networks no longer applied and that all network traffic should be considered untrusted (Kindervag, 2010a). In a perimeter-based security posture, the goal is to keep attackers out, while in a zero trust security posture, it is assumed that the attacker is already present on the network. Therefore, instead of granting implicit trust, in a zero trust network, access is granted on a per-request, least-privilege basis, ensuring that all network resources are secure and that all network traffic is inspected and logged (Kindervag, 2010a). NIST (2020) published a special publication on zero trust architecture, which summarized the zero trust principles as follows:

> Zero trust security models assume that an attacker is present in the environment and that an enterprise-owned environment is no different—or no more trustworthy—than any nonenterprise-owned environment. In this new paradigm, an enterprise must assume no implicit trust and continually analyze and evaluate the risks to its assets and business functions and then enact protections to mitigate these risks. In zero trust, these protections usually involve minimizing access to resources (such as data and compute resources and applications/services) to only those subjects and assets identified as needing access as well as continually authenticating and authorizing the identity and security posture of each access request. (NIST, 2020)

Recently, there has been interest in applying zero trust principles, originally developed for IT systems, to supply chains. For example, Collier and Sarkis (2021) attempted to draw parallels between zero trust assumptions for IT systems, which are intended to protect information flows, with proposed assumptions for supply chains, which are intended to protect flows of information, materials, and finances.

DiMase et al. (2021) discussed the difficulties of applying zero trust principles to the microelectronics supply chain, noting that IT networks are very different than supply chains, in that the former are highly distributed and redundant, while the latter may have small numbers of suppliers leading to bottlenecks and supply disruptions. In both cases, the application of zero trust to supply chains is an exercise in analogical reasoning. An analogy is when an assertion is made that the relational structure of one domain can be applied in a different domain (Gentner, 1983). In this case, there is not a direct one-to-one mapping of concepts between IT networks and supply chains, meaning that thoughtful translation and application of zero trust principles to supply chains must be conducted and adapted for this new use case. An incomplete or incorrect mapping on concepts could be worse than no mapping at all (DiMase et al., 2021) and therefore requires future research.

### 4.4 Blockchain

Another area of emerging research and application is the role of blockchain technology for supply chains. Blockchains are distributed ledgers which enable decentralized, autonomous, immutable, and trustless record keeping (Chohan, 2019). While there has been much hype about the application of blockchain to supply chains, exactly how they will be implemented is still open to interpretation and development (Saberi, Kouhizadeh, Sarkis, & Shen, 2019b).

Among the drivers for blockchain technology adoption include increases in the need of companies to strengthen their information security and the increased need for information traceability (Saberi, Kouhizadeh, & Sarkis, 2019a). Additional benefits include transparency and component traceability, supply chain visibility, and monitoring of critical assets for auditing, compliance, and security purposes (Mylrea & Gourisetti, 2018). Nandi et al. (2021) speculated that blockchain technology can enhance supply chain redesign efforts around localization, agility, and digitization. Supply chain applications such as asset tracking and paperless order fulfillment have also been proposed (Min, 2019).

As it relates to supply chain security, blockchains can be used to create an immutable record of transactions to provide assurance of a product's authenticity (Hassija et al., 2020). Blockchain technology can facilitate tracking and documentation of product origin, manufacture, raw materials and components, and the intermediaries along the supply chain who handled, transformed, or transported the product (Oliver Wyman, 2017). The tracking of transactions of goods with radio frequency identification (RFID) technology can be integrated with blockchain to provide a record of the chain of custody (Dutta et al., 2020). This provenance can aid in the detection of counterfeit goods, and such transparency in sourcing and distribution can be used to ensure that partners are implementing responsible sourcing practices (Hassija et al., 2020).

However, questions remain about the adoption of blockchain technology within the supply chain (Francisco & Swanson, 2018). Some factors potentially inhibiting adoption include issues with scalability, future legal and regulatory requirements, large amounts of computing power needed, organizational resistance, the need to select the correct technology platform, and lack of organizational expertise (Min, 2019). Saberi, Kouhizadeh, and Sarkis (2019a) further identified barriers such as lack of benchmarking data for technology implementation, lack of supply chain cooperation and coordination, technological immaturity, and market and industry uncertainty about adoption. Further, interoperability of blockchain technology with legacy technologies is a challenge (Linkov et al., 2018). Within organizations and across supply chains, governance structures must be developed to ensure that the use of the technology is consistent with the organization's mission (Linkov et al., 2018).

## 5 Managerial Implications

A managerial implication of supply chain security is organizations needing the ability to effectively assess and manage risk across the supply chain. However, measuring risk for security is particularly difficult. Unlike other fields with plentiful historical data, emerging security threats are difficult to quantify in terms of likelihood and impact. Moreover, these risks are dynamic, especially in the cyber domain, where adaptive adversaries are continuously developing novel attacks (Linkov et al., 2014). Additionally, measuring security is difficult because we cannot test all of the security requirements for complex systems, systems often interact with other systems in unpredictable ways, and cognitive biases about risk skew our perceptions of system security (Pfleeger & Cunningham, 2010).

Managers may focus on a cyber resilience posture. Cyber resilience has been defined as "the ability to anticipate, withstand, recover from, and adapt to adverse conditions, stresses, attacks, or compromises on cyber resources" (Graubart & Bodeau, 2016). Resilience is a system property which describes the ability of a system to plan/prepare for, absorb, recover, and adapt to disruptions in one or more critical system functions across physical, information, cognitive, and social domains (Linkov et al., 2013).

Whereas risk assessment involves the identification of known threats to the system, resilience applies both to known and unknown threats (Linkov et al., 2013). Instead of developing frameworks from scratch, standard work exists to support managers interested in security, risk, and resilience. Managers may leverage industry and government standards to support security- and resilience-based practices, such as NIST Special Publication 800-160 Vol. 2 (NIST, 2019), NIST Cybersecurity Framework (2018), and SAE International's suite of standards from the G-32 Committee on hardware assurance, software assurance, and development of a Cyber-Physical Systems Security Engineering Plan (DiMase et al., 2020).

Given the serious risk concerns, it is imperative for organizations and their supply chain partners to collaboratively invest in risk assessment and management practices. Consider ISO 31000 (ISO, 2021) or Enterprise Risk Management (Moeller, 2007) practices to supplement risk training. However, it is not sufficient to only have a single or few individuals responsible for these risk-based practices. It is important that an effective ERM program include the entire organization in terms of accountability, workforce training, engagement, culture, staying up to date to with new innovations/technologies, and managing legacy systems. Moreover, effective risk management should include one's supply chain partners, since many risks affect the entire network of interrelationships rather than an individual firm in isolation. The impacts experienced by a company can be mitigated (or amplified) by actions taken (or not taken) by others within their supply chain (Ritchie & Brindley, 2007). Noncooperative behavior can be costly and fail to exploit synergistic benefits across supply chain partners, while collaboratively engaging in information sharing and risk management practices can aid in identification of vulnerabilities and managing crises (Kleindorfer & Saad, 2005).

A risk-based strategy is a significant investment for an organization. This strategy needs to consider a variety of stakeholders, including employees, suppliers, shareholders, partners, customers, the environment, and communities. This strategy should also involve the development of a risk culture, in which all employees and key stakeholders are engaged in the risk-based mission. This type of culture can be fostered using communication and transparency. However, communication and transparency are not simple efforts. There is a large literature base for understanding the most effective methods for communicating with various stakeholders (Bier, 2001). The effectiveness of a risk-based strategy is also contingent upon the risk perceptions of those stakeholders which can in turn influence behavior (Sjöberg, 2000). Supplier relationship management is also critical as these practices call for firms to segment suppliers based on criticality to the operation, develop governance policies with those critical suppliers, and actively manage performance and supplier development (Deloitte, 2022).

Two critical managerial questions revolve around how much to spend on security investments and how to justify such spending to management (Rosenquist, 2012). The field of security economics seeks to answer these questions by applying economic theory and tools to the problem of securing the organization (Anderson & Moore, 2006). Spending too little on security can leave the organization exposed to unacceptable levels of risk, while spending too much means that resources are not being allocated optimally (Su, 2006). While technological solutions and business practices are important for cybersecurity, "economics – not technology – determines what security technologies get used" (Schneier, 2003).

One of the prominent models in the field of security economics is the Gordon-Loeb model (Gordon & Loeb, 2012), which seeks to maximize the net benefits of reducing security risk through investments in vulnerability reduction. The model defines an expected loss function which is a function of the monetary consequences of a security breach, the probability of a threat, the baseline vulnerability of the asset or system being protected, and the reduction of vulnerability due to implemented countermeasures (Gordon & Loeb, 2012). Similarly, researchers have attempted to define return on investment metrics for security countermeasures to justify security investment. The return on security investment (ROSI) metric defines returns as costs avoided due to the implementation of security countermeasures, rather than profits (European Network and Information Security Agency, 2012). Additionally, research has been growing in the field of cybersecurity insurance (Romanosky et al., 2019; Eling & Schnell, 2016). Finally, innovative market-based solutions have been proposed such as cyber-vulnerability trading markets and exploit derivatives (Böhme, 2006). More research is needed in this developing field to apply the concepts to the domain of supply chain security.

## 6 Summary and Conclusion

Supply chains are critical to the functioning of modern society, and their security helps to ensure that materials, information, services, and finances flow effectively, efficiently, and safely amidst the complex web of global trade. Physical and cyber threats can disrupt supply chain operations and may be targeted at the organization itself or one of its many third-party vendors. The impacts of supply chain security breaches and disruptions can impact physical safety, cost organizations millions of dollars, and damage their reputation.

Best practices for supply chain security include security strategy assessments, vulnerability scanning and penetration testing, modernization of business practices and technologies, data protection and encryption processes, establishing permissioned controls for access to sensitive information, implementation of blockchain technology, third-party risk management practices, and incident response planning (Ramos, 2020).

Supply chain security investments in areas such as asset visibility and tracking, personnel security, physical security, standards development, supplier selection and investment, transportation and conveyance security, organizational infrastructure awareness and capabilities, collaboration among supply chain partners, proactive technology investments, total quality management (TQM) investments, and voluntary security compliance are all areas impacting supply chain security (Williams et al., 2008).

Supply chain security is a multifaceted and interdisciplinary issue which requires collaboration between multiple functional roles within the organization as well as with supply chain partners. Good supply chain security practices require sound risk management to identify risks and direct resources to those risks which are the highest for the organization. Moreover, ongoing training and education is needed as threats continue to evolve to prepare the next generation of supply chain security professionals.

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# Supply Chain Mapping for "Visilience": Role of Blockchain-Driven Supply Chain Management

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## Contents



**Abstract**

Supply chain visibility and resilience – cotermed as *visilience* – have emerged as major areas requiring significant improvement. Practitioners have put forward supply chain mapping as one of the effective strategies for supporting supply chain *visilience*. Since supply chain mapping is a complex process, involving various entities, it is essential to determine how supply chain mapping could be achieved. In this chapter, we put forward blockchain-based supply chain management as a major enabler of supply chain mapping. We also argue that blockchain-based supply chain management will help a firm to attain effective supply chain mapping, which will improve its overall *visilience*. A few of the issues related to blockchain adoption have also been highlighted. This chapter offers some background and insights to researchers, students, and practitioners.

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Supply chain mapping · Visibility · Resilience · Visilience · Blockchain · Enablers

## 1 Introduction

Current supply chains are complex and extended, consisting of multiple geographically dispersed organizations collaborating to serve customers globally (Choi et al., 2020; Mubarik et al., 2021, 2022). The extended nature of supply chains characterized by diverse cultures, customer pressures, and varying human behaviors make sharing of the right information to the right entity at the right time – *information sharing and evaluation* – highly challenging (Ivanov et al., 2019).

The need for information-sharing evaluation is increasing as the failure to do so may raise the transaction cost, pilferage, and fraud, further leading to trust deficit. Often incidences of altering information about the provenance of high-value products or their losses have been reported by supply chain (SC) partners (Maurer, 2017). In this context, traceability, verifiability, and transparent information sharing appear as the cornerstone supply chain capabilities in any industry (Maurer, 2017).

Lower transparency of any product flow impedes organizations from evaluating and validating the actual value of that product. Further, the cost of intermediaries, their dependability, and their clarity make traceability even complicated. These risks, coupled with poor transparency, may cause supply chain disruption and reputational risks. Such risks are high in conventional supply chains since they heavily rely upon centralized, in some cases heterogeneous and stand-alone, information management systems. In such a situation, supply chain partners need a higher level of trust to rely upon a single firm or agent to store their valuable, strategic, and sensitive information.

Similarly, a conventional centralized system may be exposed to the "single point failure," putting the whole system at the mercy of hackers, errors, and attacks (Dong et al., 2017). There is a serious question on existing supply chain information management systems' ability to provide the required relevant information in a basic, robust, secured, transparent, and trustworthy manner. This situation demands a system of the supply chain where information visualization, traceability, and verifiability of information.

A number of studies (e.g., Fabbe-Costes et al., 2020; Khan et al., 2021; Kusi-Sarpong et al., 2022; Mubarik et al., 2023) consider SC mapping as a major source to improve the traceability and visualization of the value chain processes. SC mapping can play a breakthrough role in improving a firm's supply chain visibility, traceability, and verifiability (Mubarik et al., 2023). It also offers companies flexibility by monitoring threats and avoiding or minimizing the effects of possible disruption (Fragapane et al., 2022).

According to Choi et al. (2020), *"[companies] have better visibility into the structure of their supply chains. Instead of scrambling at the last minute, they have a* *lot of information at their fingertips within minutes of potential disruption. They know exactly which suppliers, sites, parts, and products are at risk, which allows them to put themselves first in line to secure constrained inventory and capacity at alternate sites*."

Ironically, conventional supply chains have limited ability to map supply chain processes to deal with traceability, verifiability, and visualization (Saveen & Radmehr, 2016). It is critical to know how SC mapping can be put into practice to improve the SC visibility, traceability, and verifiability. Blockchain-based supply chain management (BCSCM) can be a solution to this issue. We argue that blockchain-driven supply chains have ability to drastically improve supply chain mapping.

Blockchain provides better economically and technologically viable solutions as this technology has a decentralized "trustless" database (Abeyratne & Monfared, 2016). This characteristic allows the execution of large-scale transactions globally and permits decentralization and process disintermediation among multiple supply chain entities (Crosby et al., 2016). Anecdotal evidence on the use of blockchain technologies in managing various aspects of supply chains demonstrates its ability to support traceability, verifiability, and mapping of supply chains.

Literature on BCSCM has increased in the past few years; however, concrete studies are missing concerning whether BCSCM is improving supply chain mapping (Mubarik et al., 2021, 2023; Yli-Huumo et al., 2016). This chapter is devoted to exploring the role of BCSCM in improving the supply chain mapping of a firm which can be instrumental in channeling the effect of BCSCM toward supply chain performance.

The remainder of this chapter begins with Sect. 2, where the background covering supply chain mapping and BCSCM are presented. Discussion on how supply chain mapping can be improved through BCSCM is presented in Sect. 3. In Sect. 4, the managerial implications of the literature are presented. A chapter summary and conclusion with relevant recommendations and future directions are presented in Sect. 5.

## 2 Background

### 2.1 Supply Chain Mapping

Supply chain mapping could be traced back to the early 1980s, when a few studies emphasized supply chain maps to better understand the nature and processes of a supply chain (Mubarik et al., 2021). These earlier studies on the supply chain focused on physical mapping of the processes, using conventional map-building techniques. These maps were expected to work as the stand-in of the actual supply chain and were used to understand the overall design of the supply chain (Farris, 2010; Gardner & Cooper, 2003). However, these supply chain maps had a major flaw: lack of dynamism.

The maps were able to illustrate the supply chain positions at a certain point in time. Any changes taking place after those maps would not be addressed. Hence, the reliability in using these initial supply chain maps for decision-making was limited.

Supply chain mapping includes documenting a company's supply chain from the very initial stage till the last stage (Fabbe-Costes et al., 2020; Mubarik et al., 2023). This concept resurfaced in 2020, during COVID-19, when a lack of supply chain mapping made the supply chains response poor and unorganized (Ali et al., 2021; Choi et al., 2020; Khan et al., 2022; Kusi-Sarpong et al., 2022; Mubarik et al., 2021, 2023, 2022).

The empirical evidence supporting the need for supply chain mapping appeared from various parts of the world. They also provided a brand-new definition of supply chain mapping, which was an extension of the earlier concept. They defined SC mapping as the process of recording information from suppliers to manufacturers to consumers and everyone in between, so that it creates an overall map of the supply network compiled in a single data platform for easy analysis (Mubarik et al., 2023). This information includes, but is not limited to, the sources of suppliers, routes of shipments, manufacturing facilities, warehouse networks, and other useful information that might help stakeholders involved to better understand the supply network and make well-informed decisions accordingly (Mubarik et al., 2021).

Since the concept of SC mapping is in its nascent phase, we have only the study of Mubarik et al. (2023) that offers a measure of supply chain mapping. Mubarik et al. (2023) stipulate that SC mapping has three subdimensions (upstream mapping, midstream mapping, and downstream mapping) and 25 items.

The next section sheds light on as to why supply chain mapping could be a strategic weapon to combat disruptions.

## 2.2 Why Supply Chain Mapping?

Some of the many benefits of supply chain mapping include the following:

- Distinguishing where in the supply chain network value is added or lost. For example, whether the means of transportation to carry raw materials to production facility might be slowing down the manufacturing speed.
- Moderating and identifying risks earlier than their occurrence. For example, how might the company's supply chain be affected by a natural disaster such as flooding?
- Reinforcing the whole supply chain. By supporting connections through clear correspondence between organizations linked to your company, you assist them to better understand their position in the supply chain network, along with your expectations and objectives.
- Aligning processes and increasing speed. In reviewing a supply chain map, companies can identify processes that are slowed or bottlenecks and take necessary corrective action. For example, a company has a supplier who provides raw material 10 days later than the agreed upon delivery date which in turn slows

down production and distribution. Organizational decision makers can identify this delay with the help of a supply chain map – they can request the supplier to fix delivery durations or opt for a more reliable supplier.

- Identifying the main points affecting a company's cash flow. For example, a supplier might want cash in advance before materials delivery. In this case, the company's decision makers can either agree on alternate payment terms with the supplier or find another supplier that agrees to work on credit.

Supply chain mapping helps a company avoid risks in general. For example, if a company has the entire supply network mapped, it is easy for them to track a lost shipment or find an alternate supplier if any issue arises. If there is a sudden increase in demand or even if something like a pandemic occurs, a focal company can put strategies in place thanks to supply chain mapping to counter such situations. A company can also assess situations like climate change, global shortage of certain raw materials, or any other natural occurrences to determine supply chain and business process impacts and can address concerns in a timely manner.

Supply chain professionals and companies have significant interest in supply chain mapping as the current pandemic suddenly disrupted global supply chain processes and left companies and individuals in hazardous situations. More studies are taking place to better understand the supply chain mapping dynamics, approaches, and solutions to the problems arising while mapping the supply chain. Some of these studies are reviewed below to understand some of these aspects.

## 2.3 Blockchain-Driven Supply Chains

Blockchain technology (BC) has emerged as a disruptive digital technology that can transform conventional ways of doing business. Equipped features such as decentralized databases, immutability of data, and higher traceability provide an agile and secure way of executing business transactions.

BCSCM can also help improve supply chain transparency at multiple stages from producers to consumers. These sets of relationships and their governance can be completed through smart contracts. Further, digitally signed messages ensure that the message received by the receiver is from the claimed sender and there is no alteration being done during the transit. This process does not allow for modification in message due to technical reasons as limits or stops malicious modifications, that is, data is immutable. Digital signatures depend on hashing functions, cryptography, and public key. Interconnection between lower and higher blockchain could be established through serial number (Kawaguchi, 2019). Due to these benefits, blockchain technology is being implemented in supply chains. A number of firms are in the pursuit of blockchain-driven supply chains across various sectors.

One of the key sectors in developing countries is agriculture. In the agriculture sector, information shared is not symmetric, the price of crops is altered at every step as each and every supply chain stage takes additional profit resulting in a smaller share for farmers. BC can resolve these issues by uniting – and disintermediating some – parties having trust issues on a single platform while keeping security and verifiability. The main entities involved in implementation of blockchain in the agriculture sector are *data, process,* and *stakeholders*.

Blockchain data may comprise various forms of information such as climate and environmental data, farmers, soil moisture content, seed quality, harvest yield, and sale price of crops as well as demand of crops. BC-driven agro-supply chains, utilizing the features of traceability and smart contracts, help execute these transactions in a secure, agile, and efficient manner. BCSCM integrates all the agro supply chain stakeholders including users (wholesalers, farmers, retailers, and customers), regulators (assessors, surveyors), and agencies (insurance companies, banks).

Within the agricultural industry, AgriOnBlock is a specific blockchain example. With this blockchain system, retailer submits their requirements on AgriOnBlock and credential details to bank. Once the bank verifies credentials on AgriOnBlock, then the BC instructs warehouse to process shipments. Warehouse determines the validity of transactions on AgriOnBlock after which the transaction is considered to be complete. Further, insurance claims raised by farmers are communicated to AgriOnBlock, which is further communicated to an insurance company and surveyor for verification of a claim. After due verification of a claim by surveyor, the insurance company intimates bank to make the payment. After payment, transaction is committed once it has been communicated to AgriOnBlock.

Farmers may request pickup of crops to a shipping company and further submits invoices to retailers. Once, the retailer confirms the invoice, the shipping company picks up the crop from the farmer's site and delivers it to the retailer, the transaction is updated on AgriOnBlock, and BC system then makes payment to farmers. The retailer further transfers the crops to a distributor or wholesaler through a shipping company. Once the crops are shipped to a distributor or wholesaler, the bank makes payment to the retailer from the wholesaler or distributor account and the transaction is committed. The entire chain of transaction is recorded on a block present in a blockchain network (Patel & Shrimali, 2021). Many times, this type of approach will shorten the supply chain as some levels may not be needed as more direct communication has likely occurred among upstream and downstream supply chain partners.

Besides the agriculture sector, implementation of BCSCM has occurred across many other sectors. The World Trade Forum estimated that effectively managing key supply chain aspects (e.g., transportation management, procurement, global trade logistics, track & trace, and customs collaboration) could help increase global trade by 15%. The aspects of these issues could be well managed by using blockchain-driven supply chain. The following discussion provides a few examples, illustrating the use of BC in managing supply chain processes of various industries.

(a) ***Blockchain in the textile industry***: An industry facing volatile demand from customers, rising competition, and product counterfeits is the textile and clothing industry. The textile industry has been subjected to severe criticism due to lack of transparency and unfair practices in supply chain processes. Since the textile supply chain network can be spread broadly across various geographical regions, it is often difficult for companies to keep track on all the suppliers, subsuppliers, and contractors. This situation reduces transparency in supply chain processes – a situation that can be addressed to help stakeholders get a chance of maximizing profits while reducing costs from difficult to manageable situations such as an unethical practices. These issues can be solved by establishing traceability through blockchain technology.

Traceability in textiles is necessary for identification, history tracking, and distribution as well as identification of product location. All the desired features of traceability could be achieved through BCSCM implementation – further establishing an information trail. Information could be shared in a secured manner supporting improved product quality, operational monitoring control, data-acquisition, in addition to visibility throughout the supply chain.

In the textile supply chain, it is the retailer who is responsible for maintaining and initiating the blockchain network. The retailer has to interact with upstream suppliers forming a cluster. Each cluster can be connected with one or more channels. Each cluster includes the subsupplier network from a fiber manufacturer to apparel manufacturing unit. There may exist a separate blockchain for each channel which stores a set of transactions. One or a set of channels can be connected to a cluster of upstream suppliers – dealing in a specific product – depending on the type of transactions. This process divides the main network into subnetworks having its own smart contract, shared ledger, and common rules over the network, defining access rights of partners involved as well as the interaction they could make over the network (Agrawal et al., 2021).

(b) ***Blockchain in the Retail Sector***: As an example of a successful retail chain, WALMART worked with IBM on a blockchain food safety solution to make the decentralized food supply ecosystem more transparent by digitizing the food supply chain process. They created a food traceability system based on Hyperledger Fabric, the open-source accounting technology. Blockchain makes it possible to make the process more transparent and traceable to a specific location. They worked with the Barcode and Labeling Standards Authority to define the attributes of the data to be uploaded to the blockchain. IBM then wrote the code for the chain.

The providers used new tags and uploaded their data via a web-based interface. To test the system, IBM partnered with WALMART used two proof-of-concepts one in the USA and other in China, and the system is proven effective in both the cases. In the USA, it took a week to trace an origin of an item. The new system helped reduce the time to 2.2 Seconds. The good news is that suppliers do not have to be blockchain experts to benefit from the system; they just need to know how to upload data to the blockchain application. After the successful implementation of phase 1 in 2016, WALMART later shifted over 25 of its products and its stock keeping units (SKUs) on the hyperledger system (Network, 2020).

(c) ***Blockchain in the Manufacturing Sector***: Mitsubishi Heavy Industry (MHI) partnered with IBM to develop a blockchain solution to control carbon emissions through tracking and making captured carbon dioxide more reusable. The system is called CO2NEX. Mitsubishi provided all the necessary infrastructural support to capture carbon emissions in its manufacturing, and IBM was responsible for providing the digitalized platform. According to Nikkei, MHI planned to create a buyer-seller market to test in 2022.

Capturing carbon dioxide emissions at the emissions point of electricity or cement production is significantly cheaper than removing carbon dioxide from the atmosphere. The United Nations estimates the cost of capture to be between $ 10 and $ 100 per ton of carbon dioxide, but that does not include transportation and storage. By 2050, 1030 gigatons of carbon dioxide could be removed annually, although the capacity for this is currently not available. With the use of blockchain, CO2NEX follows the collection and distribution of carbon dioxide, which provides transparency. The test of IBM product had been conducted earlier in May, and now trading market platforms are developed parallel to Mitsubishi equipment. Now the use of blockchain is becoming the new normal, and many organizations are in plan to accelerate the projects in carbon marketplaces globally (Insights, 2021).

(d) ***Blockchain in the shipping industry***: MAERSK and IBM collaborated to establish a blockchain technology for transparency and cost-effective procedures with paperless system. The platform will provide benefits not only to MAERSK but also to all its partners as it provides the platform to all partners to access the data and extract the values out of it. It aims to bring the industry together at an open blockchain platform that offers digital products and services integration.

The shipping industry's cost of global trade is around 1.8 trillion dollars; the blockchain network will help to enhance the process and will support to save up to 10% of the costs – representing billions of dollars in savings. The shipping industry consist of a global network of interconnected shipping corridors connecting ports and terminals, customs authorities, shipping companies, third-party logistics (3PL), land transport, freight forwarders, and other concerned authorities, all together. The two most important functions at launch address transparency and documentation challenges. The end-to-end process transparency will be increased which enables all the stakeholders in global transactions to exchange the shipments more efficiently. Digitized and automatically filled documents stamped and approved for trade by enabling end user to submit it securely globally (White, 2018).

(e) ***Blockchain in the healthcare industry***: Blockchain in healthcare can aid the field of medical sciences. BC can help to ensure transparency in recordkeeping, while maintaining privacy, of individuals and broader populations via smart contracts through an Ethereum blockchain. The Medrec Model is an example system that helps to restore the comprehensive patient directory on healthcare information.

MedRec's smart contract structure serves as a model for a "Directory of Healthcare and Resource Location" that is protected with public key cryptography and equipped with crucial data integrity and provenance properties. It provides a proof-of-concept system demonstrating how the principles of decentralization and blockchain architectures could contribute to secure and interoperable systems by using Ethereum smart contracts to establish a content access system on separate storage and orchestrate provider sites.

MedRec's authentication register regulates access to medical records and at the same time offers patients a comprehensive review of records, verifiability of care, and data exchange. These systems can be integrated with existing provider systems, prioritizing open APIs and transparency of the network structure (Azaria et al., 2016).

In this section, we illustrated how and why firms across the various sectors are adopting blockchain technologies to improve their supply chain processes. The adoption of blockchain is especially expected to improve the end-to-end traceability of supply chains, improve integration (from suppliers to customers), and make processes more transparent, secure, and visible. Thus, key benefits expected from blockchain are improved traceability and visibility of supply chains. Anecdotal evidence supports this supposition – that blockchain improves a firm's visibility, traceability, verifiability, and security through supply chain mapping. It implies that blockchain can greatly benefit a firm's supply chain mapping, which provides its visibility, transparency, integration, and security. In the following section, we explain this association in the light of various published literature.

## 3 Improving Supply Chain Mapping Through Blockchain

Supply chain mapping supports effective delivering of goods or services in a supply chain. Actors and relationships are mapped to enable traceability, visibility, and verifiability of activities and transactions along the supply chain (Mubarik et al., 2022, 2023). It improves the visibility of the processes by providing real-time data from across various interfaces and helps to ensure trust exists among the supply chain partners since information shared are verifiable (Ivanov & Dolgui, 2020; Kusi-Sarpong et al., 2022; Mubarik et al., 2021).

To operationalize supply chain mapping, there is the need to integrate the mapped processes using technologies (Kusi-Sarpong et al., 2022). BCSCM – the integration of blockchain technology within the supply chain – can enable and improve supply chain mapping of organizations. BCSCM will enable organizations to accurately map their supply chains helping them to visualize their suppliers, their locations, and their contributions to the supply base, materials flows, finance, and information (Soto-Viruet et al., 2013).

Supply chain partners can have decentralized and mutual records, where every validated transaction made by SC partner is placed into a block. These transactional blocks from individual SC partners are connected and collectively blocked to generate an irreversible record in the SC. Any modification effected by any of the

SC partners will be notified to all SC participants, thereby providing a map for every transaction (Khan et al., 2022).

The integration of radio-frequency identification (RFID) and Internet of Things (IoT), as a part of a BCSCM, do offer the opportunity for mapping process for entering real-time data such as stock issuances or purchases into blocks. This system does provide a very important means to improve SC traceability, visibility, and verifiability which leads to transparency and enhances SCM and aid a positive effect in digitally mapping the supply chain (Ali et al., 2021; Ivanov & Dolgui, 2021; Khan et al., 2022).

As an example, organizations that can transition their traditional supply chain to a digital supply chain (Khan et al., 2021) using a blockchain system are able to trace their operational raw materials or components from their origins or suppliers through to their production and the finished products to their customers. This structure will enable these organizations to be able to map their processes that are involved in moving the raw materials from the source or origin through to the focal firms and to their customers, creating visibility and becoming resilient – such as organizations' preparedness, flexibility, and responsiveness, to deal with any demand fluctuations or supply disruptions (Mubarik et al., 2021).

However, should organizations fail to connect their SC partners via digital technologies, they can significantly reduce the level of information shared by and with their SC partners impeding visibility which can result in difficulties in managing and predicting SC disruptions. Thus, should they identify any issues with any raw materials or components along their supply chains, it may be extremely challenging for them to identify the origins or sources of the problems and eradicate them. An example framework is shown in Fig. 1.

Figure 1 exhibits the role of BCSCM in improving supply chain mapping, visibility, and resilience. It shows how BCSCM directly contributes to SC mapping. It helps see the overall structure of an end-to-end map supply chain of a firm, resulting a seamless integration and flow of information from tier 2 suppliers to tier 2 customers. Effective supply chain mapping uplifts a firm's supply chain visibility. Likewise, it also improves a firm's supply chain readiness, response, and recovery, in a combined way affecting its supply chain resilience. The framework

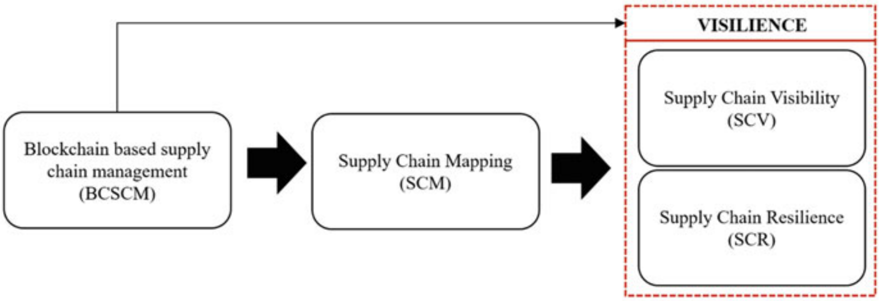


**Fig. 1** BCSCM-led mapping and "visilience"

depicted in Fig. 1 also highlights a direct impact of BCSCM on supply chain visibility and resilience of a firm. Putting together, a firm can yield threefold benefits by adopting BCSCM: Supply chain mapping, visibility, and resilience. Based on the above discussion, we present a few managerial implications to offer in the next section.

## 4 Managerial Implications

There are a number of implications regarding the improvement of supply chain visibility and resilience ("visilience"). COVID-19 unveiled two essential supply chain capabilities when encountering supply chain disruptions. These capacities are supply chain visibility and supply chain resilience. Supply chain visibility represents the ability of a supply chain to visualize the changes at various supply chain stages – upstream, downstream, and midstream. This visualization helps firms proactively plan to address any unforeseen abnormal situations. For example, during COVID-19, a number of firms in China were not able to keep their supply chains afloat and serve their customers. These firms happened to be tier 3 or tier 4 suppliers of a number of firms located outside China. Since these firms were not aware of what was happening in their upstream supply chain, they were caught off guard once those effects occurred in downstream supply chains. This lack of visibility resulted into a subtle, unorganized, and weak response of the firms to SC disruptions further resulting into massive supply chain losses.

Likewise, supply chain resilience – *characterized by a firm's ability to prepare, respond, and bounce back supply chain disruption* – has appeared as the other important supply chain capability essential for firm survival. Supply chain visibility and resilience go hand-in-hand. Visibility helps a firm to be more resilient, hence the term "visilience," an essential capability for survival and growth of any firm and their supply chains.

Supply chain mapping strategies can effectively improve these twin supply chain capabilities. Based on the framework derived in this chapter (see Fig. 1), supply chain mapping – defined as the extent to which a firm has mapped its upstream, downstream, and midstream supply chain processes so that these provide real-time information about the supply chain entities – appears to be instrumental for "visilience."

Supply chain mapping allows a firm to look beyond the immediate supplier through mapping the processes of suppliers and subsuppliers across multiple tiers. Likewise, mapping allows a firm to have real-time information about its downstream supply chain, reaching down the line to multiple tiers down to the ultimate customers. In other words, mapping not only provides the real-time information about the various players in supply chain – such as physical location, financial stability, and process sustainability – but also allows for real-time flow of goods and funds visibility across the supply chain. This ability of a supply chain not only improves its visibility but also builds its resilience. Our findings suggest that managers need to address supply chain mapping-led visilience.

The proposed framework reflects that blockchain-based supply chain can be a single important strategy, which can simultaneously cater the issues of mapping, visibility, and resilience. Our framework suggests that BCSCM not only helps firms to significantly map their supply chain processes across the three streams (upstream, midstream, and downstream) but it also directly improves the "visilience" of a firm.

One of the prominent features of BCSCM is its ability to trace the products to its point of origin with immutable records. It allows managers to not only visualize the various SC processes but also see the source of any transaction. BCSCM allows to not only map the supply chain processes but also to thoroughly look into the supply chain processes to identify any waste. BCSCM-led supply chain mapping can also allow firms to control supply chain issues like the horsemeat scandal in Europe.

BCSCM can provide multidimensional information about the various facets of supply chain, thus making supply chain planning process – and the necessary performance management of these systems – more robust, and resilient. For example, as noted by Gaur and Gaiha (2020, p.1), "Execution errors—such as mistakes in inventory data, missing shipments, and duplicate payments—are often impossible to detect in real time. Even when a problem is discovered after the fact, it is difficult and expensive to pinpoint its source or fix it by tracing the sequence of activities recorded in available ledger entries and documents."

Such execution errors greatly compromise the "visilience" of a supply chain. BCSCM has the ability to effectively cater for such errors by clearly exposing the origin of the transactions.

Although organizations and managers can benefit from BCSCM, some concerns do arise; these issues include the following:

(a) Blockchain platform selection: There are various blockchain platforms available, having varying degrees of conformance to various blockchain features. It is tricky for firms to choose the appropriate platform as wrong selection of platform can cause harm to the whole business and supply chain partners.
(b) The linkage of blockchain with upstream and downstream supply chain partners requires care and is challenging. Adoption of blockchain requires building relationships with other entities in supply chain (suppliers, customers, regulators, etc.), which may be challenging if the SC partners have heterogonous technologies and goals.
(c) The cost of blockchain adoption can be significant. Since blockchain is required to be implemented across the organization and linked to other stakeholders in the supply chain, it may be capital intensive.
(d) Regulations related to blockchain are currently in the nascent stage. Hence, in case of any legal issue, firm may face some serious challenges. As noted by Eliacik (2022), "Many businesses today operate under the constraints of legislation. Their customers put their trust in them with important information. However, if all of this data is kept on a public ledger, it will not be truly private."
(e) The use of consensus algorithms is highly energy intensive and may increase the average usage of energy of an organization. Sustainability considerations play an important role in blockchain operations.

(f) Cyberattacks can hurt multiple stakeholders and processes: Although blockchain is much more secured than other peer systems, open blockchain can have issues of security. According to Eliacik (2022), "Some are more secure than others. The decentralized blockchain, for example, are more vulnerable to 51% attacks than the centralized ones."

## 5 Summary and Conclusion

In this chapter, we identified factors that can improve the supply chain visibility and resilience, termed as "visilience" of a firm. A comprehensive review of the literature reveals that firms faced challenging situation due to lack of "visilience." Many firms could not survive due to poor "visilience," and many were struggling to keep their supply chain afloat – especially from the aftereffects of the COVID-19 crisis.

In order to build these twin supply chain capabilities, we put forward supply chain mapping and blockchain-based supply chain as the major precursors. Execution of BCSCM significantly minimizes traceability, verifiability, and coordination issues, thus improving the resilience of a firm. The framework offered in this chapter depicts that BCSCM is a viable way of pursuing supply chain mapping and "visilience" simultaneously. It shows that organizations with an end-to-end mapping of the supply chain can not only have a much better visibility and capability to respond to any disruptions or unpredictable occurrences but also bounce back much quickly and stronger. The blockchain-based supply chain can help the organizations to be prepared by creating visibility and enabling them to be able to manage this situation with ease.

Conclusively, there exists a significant gap to improve SCs in context of visibility, and resilience. BCSCM appears to be a powerful strategy to address these deficiencies. This is the right time for supply chain managers and other relevant stakeholders to come forward and plan as to how BCSCM can be executed to uplift the performance of their supply chains.

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# Resilience in the Supply Chain

E. Revilla, B. Acero, and M. J. Sáenz

## Contents



**Abstract**

Supply chain resilience is vital to long-term viability of firms. Supply chain design and operation conditions will influence their survival during major crises. While most firms have focused on how to quickly recover from disruptions, resilience is more than quickly overcoming a natural disaster that destroyed part of their facilities. Resilient firms are also capable of adapting to new operating contexts as a result of unexpected changes or disruptions. Supply chain resilience

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is better defined by the integration of two main historical approaches: engineering resilience and social-ecological resilience. Traditional resilience practices with a focus on mitigating disruption impact seem insufficient in the current landscape. This chapter presents a comprehensive understanding of supply chain resilience. We introduce supply chain disruption definitions and discuss why these unexpected events are central to the current operating environment. The understanding of resilience in the current context leads to the development of a framework that integrates the necessity of both proactive designs and reactive deployments of supply chain elements. The chapter categorizes and details a set of practices that companies should holistically implement to deal with unexpected events. The concepts presented are reinforced with numerous practical examples, so they are easy to understand for professionals and students with different backgrounds.

**Keywords**

Supply chain disruptions · Resilience · Resilience framework

## 1 Supply Chain Disruptions

Early in 2020, shortages of masks, ventilators, and adequate protective gear to respond to the COVID-19 pandemic triggered unprecedented shifts in demand of diverse products such as toilet paper, printers, exercise equipment, or baking-related gadgets such as stand mixers. This situation put incredible pressure on *well-oiled* supply chains that had accustomed us to get whatever we desired at our doorstep within days and, in some cases, within hours. Suddenly, consumers had to wait weeks, if not months, to buy furniture or electronic gadgets for the newly installed home offices, and companies had to compromise their selections because goods were stranded in ports for an unknown period of time.

After this crisis – with several developed countries functionally declaring an end to the pandemic – virtually every single industry is still affected to some extent by shortages and delays. Skyrocketing energy and fuel prices, inflation, new pandemic-related shutdowns in China, and the invasion of Ukraine, with subsequent economic sanctions on Russia, mean more chaos to an already fragile supply chain situation.

Construction and chemical industries are suffering from limited availability of raw materials and shipping containers; technological and automotive companies are struggling to meet the demand due to a serious microchip shortage; China's energy crisis occurring since 2021 is restricting factory production; and the list just keeps growing. It does not seem that the problem will end soon. In particular, for the chip shortage will only get worse as conflicts continue, Ukraine for example is a major exporter in neon, a crucial component in chips manufacturing. Additionally, automakers, cosmetics, or food manufacturers have started to suffer the shortages of raw material imported from Russia and Ukraine. Predictions on food and energy disruptions are such that Egypt devalued its currency in an attempt to contain the impact (Dodd, 2022).

These geo-political disruptions, in addition to longer term concerns such as climate change, are likely to continue this situation for global supply chains.

Disruptions, which are defined as an unexpected breakdown in the production or distribution of goods of the supply chain (Ivanov, 2021), have become so important in our daily lives that even the popular media has given it a name, *the Great Supply Chain Disruption* (Goodman & Bradsher, 2021). The US White House has designated a dedicated special task force team to address the existing supply chain discontinuities (TheWhiteHouse, 2022).

Although disruptions have always been present in supply chains, we have reached a point in which the previous scenario of smoothly run supply chains suffering isolated interruptions has now transformed into a continuous struggle to cope with disruptions that are stretched in time. But today's disruptions are not just Covid-related. Companies are facing more recurrent cyberattacks to access storage data or to create an interruption in the operations – a more integrated system from Industry 4.0 efforts becomes more common (ENISA, 2021). Public pressure on sustainability and human rights are disrupting the operations of companies whose manufacturing or suppliers are located in areas with relaxed or unethical environmental and labor regulations (Villena & Gioia, 2020). And overall, companies, whether operating in global or more local context, are suffering the consequences of geopolitical instability due to armed conflicts, border closures, or regional trade and tariff policies.

Disruptions in supply chains impact the stability of companies related to operational, financial, and reputational aspects (Katsaliaki et al., 2021). First, operational consequences impact day-to-day business and may include an increase in the lead times, poor asset utilization, increase in the production costs, or unbalances in the inventory levels (Chopra & Sodhi, 2014). We can find a recent example in the blockage of the Suez Canal in 2021 that during a week exacerbated the already existing congestion on ports and the container shortage caused by Covid-19 imbalances in demand predictions.

Second, disruptions also affect the financial stability of firms. Persisting disruptions can take a serious toll on the financial health of companies. They can lead to poor performance of supply chains, which in turn can translate into loss of revenue, sales, and even reduced market shares. In fact, regardless of the size of the company, disruptions have been linked to a reduction of stock returns of nearly 40% and an increase of equity risk of around 13.5%, both lasting up to a year after the disruption occurs (Hendricks & Singhal, 2005).

Third, depending on the type of disruption, companies can suffer significant losses in their reputation and credibility. Reputational damage relates to the loss of credibility due to damage in the perception that stakeholders and society have on firm image, status, and popularity (Alfarsi et al., 2019; Rhee & Haunschild, 2006). A loss in the goodwill of the company as well as corporate embarrassment can have severe damaging effects on its viability. Reputational consequences are specially challenging to manage and can escalate tremendously. That was the case of Samsung that saw its reputation among consumers plummet after the firm had to issue a global recall on over 2.5 million Galaxy Note 7 smartphone devices due to a high risk of their batteries exploding (Rahim, 2017).

### 1.1 Supply Chain Fragility and Its Search for Efficiency

The catastrophic consequences of disruptions have revealed the fragility of supply chains and how efficient systems can easily break external, unpredicted, and, in appearance, even unrelated – to the supply chain – events (Pettit et al., 2019). During the past few decades, we have witnessed how companies have searched for efficiency by means of globalization and adoption of lean practices, allowing firms to be more competitive while opening new markets (Reeves & Whitaker, 2020). Lean management's objective of minimizing costs and increasing profits caused companies to embrace practices that eliminate redundancies through just-in-time or lean inventory management approaches. Following those principles, companies mainly rely on one supplier for a critical component; workforce is optimized to minimum and relies on overtime if needed; processes are streamlined and highly standardized, and inventories and safety stocks are kept low.

In a well-oiled system, slight fluctuations, either from the demand or supply side, can be easily absorbed with minor adjustments on production while maintaining lean practices and limited inventory; however, as the pandemic has shown, major delays and shortages on components can severely impact production (Goodman & Chokshi, 2021). Many automotive and general appliance companies had to reduce and even temporarily halt production because their suppliers were not able to deliver their required parts on time. Their inventory levels could not make up for such delays and reduction on the quantities received. Globalization has amplified this scenario due to global interconnection of economies, firms, and suppliers (Sheffi, 2020).

Globalization has facilitated trade and increased efficiency. With the help of digital tools and flexible trade agreements, companies have opened to new and distant markets; what in the past was cheap and reliable sea transportation facilitated the location of manufacturing plants in distant countries with much lower labor cost. However, globalization has considerably increased the interdependence of supply chain activities. Even the smallest manufacturing or service firm will depend to some extent on components produced in distant parts of the world.

Supply chain risks are exponentially escalated as complexity increases (Pettit et al., 2019). Lead times are impacted by customs delays and lack of adequate transportation. Quality may not be up to the expected standards due to difficulties with distant (sub-)suppliers. Ensuring compliance with social and safety rules may not be easy to achieve in complex networks. Political instability may cause difficultly in sourcing a given product or commodity. Fluctuations in exchange rates may impact the economic outcomes. The disruption risk list is extensive. Each risk makes supply chains more vulnerable and more exposed to suffer unwanted, and sometimes catastrophic, consequences.

Globalization and lean management practices have historically given companies a competitive edge, but at the expense of creating vulnerable unbalanced supply chains that have to face multiple risks that arise from numerous sources (Purvis et al., 2016). As a consequence, when a disruption hits, this global and efficiency-oriented supply chain configuration has proven to be too rigid to adapt to the newly disruptive operating and environmental context. Therefore, there is a need for change and for developing supply chains that can resist during turmoil and transform adverse situations to their advantage. Companies need to be resilient and develop mechanisms that will keep them afloat during disruptions. Supply chain resilience is the key to navigate disruptions while maintaining and even increasing their competitive advantage (Pires Ribeiro & Barbosa-Povoa, 2018; Purvis et al., 2016).

## 2 Understanding Supply Chain Resilience

The discussion about resilient supply chains has been occurring for decades – examples include major natural disasters temporarily halting operations in well-known global companies. Disasters like Katrina in 2004, the volcanic eruption in Iceland in 2010, or the earthquake and tsunami in Japan in 2011 initially expounded the vulnerability of global supply chains (Pettit et al., 2013; Purvis et al., 2016).

However, as the impact of such disruptions were mostly contained to a limited number of companies, few firms seriously considered investing in supply chain resilience strategies to be prepared for the next disruption (Sáenz et al., 2018). This perception has changed with cascading disruptions generated by the Covid-19 pandemic, bringing to light the importance of being prepared for the worst through the development of resilient supply chains (Alicke et al., 2020). By furthering resilience in supply chains, leading companies are trying to neutralize the risks originated by globalization and the prioritization of efficiency (W. Shih, 2020a). To that end, firms are developing new approaches and strategies to create supply chains that are both capable of minimizing the impact of disruptions and recover their functionality once the disruption has occurred (Fig. 1).

Even though resilience is increasingly appearing on the agenda of supply chain executives as a key enabler of operations and business continuity, as success, and as


**Fig. 1** Balancing supply chain risks

a long-lasting competitiveness enabler, there is still no consensus on how to successfully develop resilient supply chains or what does it mean for a firm to be resilient (Sáenz et al., 2018; Wieland & Durach, 2021). For that reason, it is necessary to understand what being resilient means and its analysis across different fields beyond the traditional supply chain risk management-focused approach. Resilience has been widely researched in the engineering and socioecological fields, with former discipline exerting a wider influence resilience definition (Ponomarov & Holcomb, 2009; Wieland & Durach, 2021).

## 2.1 Resilience from an Engineering Perspective

The engineering approach to resilience is rooted in the original conception of supply chain which conceptualizes them as engineerable systems whose different parts (suppliers, warehouses, distribution centers, and production facilities) are to be designed, optimized, and controlled to maintain a stable status (Wieland & Durach, 2021). Although, this approach is outdated and no manager would doubt the complex interactions that global supply chains face beyond their own components, the engineering approach to resilience still prevails.

A widely accepted conception of resilience revolves around the optimization of two engineering concepts: the time-to-recovery (TTR) and the time-to-survive (TTS) (Simchi-Levi et al., 2014). These concepts measure the time the system would need to recover after a disruption and the maximum time that service levels could be guaranteed after such disruption and before recovering the previously defined equilibrium. These mechanisms aim to create a robust supply chain capable of both resisting disruptions and maintaining their stable and optimized functioning (Simchi-Levi et al., 2018).

Robust supply chains share two distinctive features: anticipation and preparedness for disruptions (Wieland & Wallenburg, 2013). Through investment in processes and capabilities, robust supply chains improve their capacity to anticipate disruptions that can later have a negative impact on the operations and profitability of the company (Brandon-Jones et al., 2014). To that end, it is important for firms to proactively revisit previously defined signals that can provide hints about upcoming disruptions (Sáenz et al., 2018). Robustness enables the deployment of a series of mitigating mechanisms that allow supply chains to continue their normal operations during turbulent times. By anticipating disruptions and being prepared to face their consequences, robust supply chains are capable of retaining the stable status that they had prior to a crisis without having to make any adjustments to their organizational or operational structures (Purvis et al., 2016).

Firms deploying an engineering approach to resilience design their operations through a careful analysis of what can go wrong. For this approach, firms initially seek to understand the supply chain vulnerabilities (Sáenz et al., 2018). However, global supply chains are so complex that controlling all the possible risks at any given point in the supply chain becomes unrealistic. Take, for example, the case of Boeing, the airplane manufacturer. In just 1 year the company procures 783 million parts in 5400 factories distributed globally. Listing the risks associated with these

783 million parts, the risks from each factory, their different suppliers, and sub-suppliers is virtually impossible (BOEING, 2013). Not all risks can be accounted for or controlled.

When the Rana Plaza garments factory complex collapsed in 2013 killing over 1100 people in Bangladesh, many companies ignored that they were affected. That was the case for Walmart that 1 year earlier had banned the only supplier the company had working in the Rana Plaza complex. However, that same supplier was later subcontracted by another – this time authorized – Walmart supplier. Well-known global retailers – such as Walmart – were affected by this incident, and each of them saw damage to their reputation (Sheffi, 2015).

Adopting a pure engineering approach to resilience may not return the desired results in every disruptive situation firms face (Wieland & Durach, 2021). Traditional engineering conception of resilience revolves around the principle of a recovery to the previous equilibrium or state. Such recovery stabilization may never occur. Multiple companies have been experiencing this situation since the pandemic outbreak. This situation has forced firms to adapt to a new equilibrium or "new normal" if they want to survive. Firms have been forced to adapt to new ways of consumption, shifts in demands, and struggles with shortages to keep afloat. In these cases, a pure engineering approach seems insufficient as the survival of the firm requires adaptation and reconfiguration to achieve a new stable status.

### 2.2 Resilience from a Social-Ecological Perspective

In the current global economies, supply chains have become complex entities with multiple echelons that do not operate in isolation but with a series of interdependencies and connections with their operating, economic, and social environment. This situation is more like an ecosystem where a network of organizations, resources, information, and social actors align their work to achieve a common goal (Ponomarov & Holcomb, 2009). In this context, it makes sense to delve into the origins of resilience from ecological and social studies.

Ecological resilience is defined as the ability of a system to absorb changes that will facilitate reaching an equilibrium (Pettit et al., 2013). The difference from the engineering approach is that it is not a preestablished predisruption equilibrium but one that the system has reached after reconfiguring itself so it can continue its operations via an adaptation to new circumstances. As such, the ecological approach to resilience highlights the system's adaptive capability by assuming changes due to disruptions are inevitable, and that resilience is reached via adaptation to new conditions (Wieland & Durach, 2021).

The system capacity to reconfigure itself to reach a new equilibrium requires a well-orchestrated combination of all the available resources, capabilities, and strengths of the organization, together with the different channel partners and stakeholders. Incorporating social and human factors to the equation activates a learning capacity (Ponomarov & Holcomb, 2009). In this way, the system can pick up from previous disasters and deploy adaptive and transformative strategies to better react to future undesirable events, highlighting supply chain agility.

Agility focuses on rapid system reconfiguration in the face of unforeseeable changes (Kamalahmadi & Parast, 2016). It is the ability to rapidly respond to undesirable events by adjusting to a new disrupted environment. The multiple definitions of agility highlight the reactive and transformative nature of supply chains in which they have developed the capability for a quick reaction, response, or reconfiguration of its resources in order to maintain productivity levels (Bakshi & Kleindorfer, 2009). However, a fast reaction to disruptions is only possible if the supply chain has the resources and capabilities to perceive crises happening not only inside the supply chain but also in its operating context, in its environment, and even in adjacent industries. This situation creates awareness and facilitates a fast reaction to changes or disruptions. Fast reaction is a crucial element in supply chain redesign. It is important for firms to anticipate disruptions in firms to successfully and rapidly reconfigure their resources to meet these disruptions (Kamalahmadi & Parast, 2016; Wieland & Wallenburg, 2013).

Adopting the socioecological perspective of resilience allows supply chains to embrace disruptions in two different ways. First, when a disruption threatens a given equilibrium, supply chains are capable to effectively reorganize themselves and adapt to the new conditions for continued operations (Wieland & Durach, 2021). Second, resilient supply chains can exploit adverse situations with a goal of converting them into opportunities. They learn from the past and adapt their organizations and operations to face similar disruptions in the future.

Resilient supply chains are better prepared to maintain a competitive advantage during disruptions. This response is what happened during the covid-19 pandemic. Multiple companies, driven by a mix of community responsibility and necessity to survive, adapted their operations to manufacture medical or protective-related material. Demcon, a Dutch manufacturer of high-technological products in aerospace, food, and health industry rapidly adapted their supply chain processes of traditional blowers to design and manufacture their first hospital respiratory ventilation systems (B. Acero & Revilla, 2021).

Transformation and adaptation are also about foreseeing upcoming disruptions. The electric car industry is a clear example. The boom in electric vehicles is expected to cause serious environmental problems regarding the disposal of lithium-ion based batteries as well as sourcing scarcity of some of the metals required to manufacture them (Domonoske, 2021). As such, leading automotive companies have foreseen such disruptions and are already investing in adapting recycling technology and research pilot projects to avoid them (Nicola, 2021) (Table 1).

## 2.3 The Concept of Supply Chain Resilience

An analysis of two different approaches to supply chain resilience suggests that not all disruptions can be dealt in the same way. *Engineering resilience* facilitates resistance to turbulent changes and speeds-up the return to the previously defined equilibrium. *Socioecological resilience* allows supply chains to rapidly react to undesirable events and adapt operations and organizational structures to the new disruption-created scenarios, whether temporary or permanent.

**Table 1** Features of the resilience approaches

| Resilience | |
|---|---|
| Engineering approach | Social-ecological approach |
| Resist to disruptions | Reacts to disruptions |
| Return to a predisruption equilibrium | Adapts to a “new normal” equilibrium |
| Anticipates disruptions | Senses disruptions through visibility |
| The supply chain is prepared to deal with disruptions | The supply chain deploys a speedup recovery process |

For companies to survive in existing global and disruptive scenarios, it requires that organizations remain unaffected by disruptions and to continuously adapt to new situations. Adopting a combination of social-ecological and engineering resilience perspectives facilitates a holistic approach to supply chain risks and vulnerabilities (Wieland & Durach, 2021) – whether these disruptions are anticipated or not.

As an example, the engineering approach hinges on the robustness dimension of resilience allowing the supply chain to anticipate something such as a winter storm that may temporarily affect the production and distribution of a given product. A social-ecological approach rests on the agility dimension of resilience and prepares firms to efficiently react and adapt to unexpected events that may affect the normal operations of the supply chain for an unknown period of time (Wieland & Durach, 2021). An example of this latter situation is a shortage of critical components such as microchips. Supply chains need to be simultaneously robust and agile (Wieland & Wallenburg, 2013). Robustness facilitates the supply chain to retain the same stable configuration prior the disruption, while agility prepares it to respond to disruptions by adapting to a new stable condition through a reconfiguration of resources (Purvis et al., 2016).

Capturing both dimensions – agility and robustness – of resilience implies the ability to anticipate and respond efficiently to disruptions and unforeseen, unknown, or unquantifiable risks. It also means the ability to restore equilibrium to a more desirable state of operations as soon as possible to ensure high operational performance. Resilient firms are less vulnerable and more capable of dealing with all types of disruptions. Based on the definition provided by Wieland and Durach (2021, p. 2), we understand supply chain resilience as the capacity to persist, adapt, or transform in the face of *unexpected* changes.

*Supply chain resilience is the capacity to persist, adapt, or transform in the face of unexpected changes*

## 3 Developing a Resilient Supply Chain

Supply chain leaders are becoming aware of the need to build more resilient enterprises. Firms have started to adopt a series of practices to ensure supply chain resilience in times of disruptions.

Resilience is not an easy endeavor. Traditionally, firms have developed a series of risk management approaches including deploying a series of mitigation strategies for identified risks (Sáenz et al., 2018). While this technique, if done in a diligent way, can help in the avoidance and mitigation of risks from known sources – risks that can be identified and measured – a global, interconnected, and complex environment in which today supply chains operate is packed with risks that are impossible or extremely difficult to foresee, unknown risks (W. Shih, 2020a).

Analyzing how leading global companies are dealing with disruptions highlights how supply chain resilience cannot be achieved just by developing a couple of isolated practices. It requires a holistic approach through a set of practices that can be categorized as proactive or reactive mechanisms (Sáenz et al., 2018). Proactiveness assumes that disruptions will eventually happen and prepare the firm to deal with them by working at the core of the supply chain itself: the design of the supply chain, its products, and its processes. Reactive practices are deployed once the disruption hits the supply chain to contain or mitigate its negative consequences. These two complementary mechanisms and how successful companies are implementing them are further explored in the following subsections (Fig. 2).

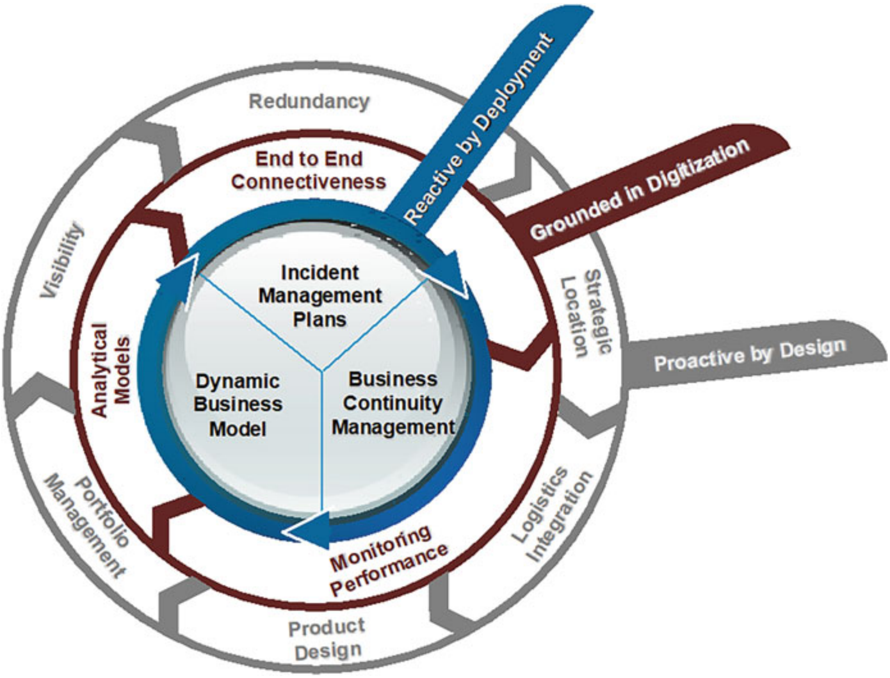


**Fig. 2** The resilience framework. (Adapted from Sáenz et al. (2018))

## 3.1 Proactive by Design

Companies anticipate disruptions by planning resilience based on the supply chain and product design. The design of supply chains has traditionally taken into consideration the idiosyncrasies of their operating industries and a series of efficiency and cost objectives (Sáenz et al., 2018). However, as it has been highlighted in previous sections, efficiency goals make supply chains fragile and operating around a unique equilibrium point that is difficult to maintain during tumultuous situations. For that reason, supply chains that are designed find a balanced trade-off between their operational procedures and resilient capabilities outperform their competitors in difficult times.

We summarize seven leading practices that companies should take into consideration when designing a resilient supply chain.

### Redundancy

Supply chain redundancy relates to the design of the supply chain using series of backup resources so that operations can continue during failures of critical parts. Such redundancies involve three main practices: holding extra inventory, securing alternative suppliers, or designing production lines to accommodate additional extra capacity (Reeves & Whitaker, 2020).

Traditionally, the most conservative way to secure operations continuity has been holding extra inventory and the safety stock in line with the company's "time-to-recovery" and "time-to-survive" strategy. This robustness practice may not suit every supply chain, like those with short-life span or highly perishable products, but it can be an advantage in times of disruption. For example, during the massive lockdowns of 2020 the demand for some type of foods drastically increased. Kellogg's, the giant food manufacturer, successfully dealt with the high demand rise of cereals, snack, and noodles thanks in part to their large inventory holding of grains and quick shift to a previously identified local provider of cardboard. Their robustness, through a redundant design, paid off during the pandemic disruption by buying them time to quickly reorganize their supply chain to the new situation (Silver, 2021).

But, holding extra inventory could be a costly practice as every dollar invested in extra stock beyond what is considered strictly necessary for normal operations is not a dollar spent in the company's R&D, investment on new assets, payment of dividends to shareholders, or bonuses to executives. In fact, a recent analysis highlights how in the past 40 years companies around the world have been reducing their inventories while rebuying their own stocks (Goodman & Chokshi, 2021). While this approach has largely benefited their shareholders during stable times, it has proven greatly damaging when demand suddenly becomes unpredictable or when shortages of key components are sustained in time. For that reason, it seems necessary to identify alternative redundancy practices that would increase the resilience of the supply chain without compromising the efficiency of operations or the commitment with shareholders and employees.

A different way to create redundancies is qualifying alternative suppliers or sourcing the same component from different suppliers. Through this policy, firms can enhance the resilience of their supply chain as if one of the suppliers becomes disrupted, the company can still secure the product (Lund et al., 2020). For example, Apple gradually shifted part of its primary contract manufacturer to alternative qualified firms (Rapoza, 2020). Other companies, motivated by geopolitical disputes like the US-China trade war or Brexit, have opted for a "plus one" strategy. They do this by moving part of their production to other countries, qualifying extra suppliers from other regional areas and nourishing the relationship with these alternative suppliers in order to adapt to the new context and minimize the consequences of the political instability. This type of practice may not be feasible for some supply chains, especially ones where companies rely on suppliers with sophisticated technology or "know-how." This situation is the case of a vast number of car manufacturers given that some of the required automotive parts imply high levels of investment that having second sources becomes extremely expensive (Geriant, 2014).

A third way of increasing supply chain redundancy is by diversifying what is manufactured in each production plant. In this way, if a plant is shut down or its production is halted due to, for example, inclement weather or labor strikes, other plants can absorb part of the missing production. Companies that are aware of the impact of a disrupted facility on their revenues and market share build redundant manufacturing lines for the most important products of their portfolio. This is how Procter & Gamble designs its supply chain to increase its resilience. This approach was successfully tested when a tornado badly damaged the only production facility of Pringles chips in the USA and the firm managed to mitigate its impact by diverting production to another plant in Belgium (Sheffi, 2005).

**Strategic Location**

The location of suppliers, distribution centers, and production plants conditions how the supply chain reacts during a disruption. Location is of critical importance, because it can affect the time it takes to notice that something is wrong. Location also dictates the reaction time once a disruption is identified. The farther apart different elements of the supply chain are, the longer it will take to react. Global location of manufacturing facilities and suppliers and the extreme dependency of global supply chains on Asia was a major issue during the recent global pandemic. Yet, there were already globalization concerns with trade protectionism sentiment of previous years already causing global supply chains to rethink their previous configurations (Rojas et al., 2022; Schwartz, 2022).

Searching for low-cost and optimized supply chains saw companies from all around the world move part or their entire production to Asia. Later, that work was simply overtaken by external suppliers located in these low-cost labor markets. Europe and the USA are now paying a high price as their economies and supply chains have become highly dependent on Asia. This issue has expanded beyond textiles, technology, or automobiles. Around 80% of the active pharmaceutical ingredients (API) used in the European Union come from India and China. Just these two countries account for 90% of the penicillin, 60% of the paracetamol, and 50% of the ibuprofen world production (EUParliament, 2022).

Dependency is global and has serious consequences. As of March 2022, the US Food and Drug Administration was listing shortages of over 100 basic drugs (FDA, 2022). To avoid future disruptions, the EU is providing economic incentives of API producers to locate in Europe, which will increase the robustness of their supply chains (EUParliament, 2022). Similarly, movements to reshore and regionalize strategic value chain activities are being developed globally to create supply chains that can reconfigure themselves to adapt to the new operating environment.

A drastic reshoring may not be a wise decision. With the risk of stagflation in some major economies, producing in higher-cost countries may not be feasible for firm survival, although the introduction of new technology such as automation and robotization can significantly lower production costs (Burke et al., 2021). Companies should reevaluate their production practices to balance profit and efficiency maximization with disruption minimization or avoidance due to overreliance on remote sourcing (Hartman et al., 2017; Lynch, 2021).

As an example, if a given company has some of their suppliers concentrated in one geographical area, it might be wise to think about moving part of the production closer. This becomes especially pertinent if political circumstances show signals of instability. Nearshoring certain manufacturing capabilities and critical suppliers contributes greater supply chain control, reduces lead times, and facilitates adaptation to demand fluctuations. When combined with the current practices of relying on low-cost locations, this locational diversification increases supply chain resilience by facilitating the procurement of materials and parts from different sources depending on the situation, and by setting the foundations to adapt to new operating contexts.

### Logistics Integration

Traditional supply chain design has, in many cases, left aside the role of transportation and logistics providers (Acero et al., 2022). A resilient supply chain should account for logistics diversification to ensure that goods can be delivered on time during disruptive times. Previous disruptions such as the Icelandic Volcano in 2010 or port strikes in 2012 highlighted the resilient role of supply chain transportation. However, these disruptions were temporary, and companies did not seem to pay much attention to transportation once the situation returned to normal. The interruption of ports' activities due to lockdowns, the global shortage of sea containers, and the lack of air freight capacity seem to have changed this idea, and it has irrevocably revealed the need to include logistics in the resilient design of supply chains.

More recently, sanctions on Russia are causing a nightmare to the already fragile global logistics system. Cargo that was shipped by rail between China and Europe can no longer transit Russian territory. There are not many alternatives as sea and airfreight capacity is limited with exorbitantly high fares.

The creation of a resilient supply chain will require collaboration between transportation and logistics providers when designing the supply chain (Revilla & Acero, 2021). A joint assessment of the vulnerabilities and "what-can-go-wrong" scenarios can contribute toward the robustness and agility of the supply chain. This collaboration can completely avoid disruptions or adapt to a new operating situation such as a long-term reduction of shipping capacity or inability to use the predefined transportation model.

It is important to develop agreements with strategic logistics partners that will secure capacity and service during periods of disruption. As new business models that prioritize e-commerce and omnichannels emerge, transportation partners that integrate real-time information and multimodal shifts become critical players. As a bonus, transportation and logistics may significantly contribute toward achieving the sustainability targets of supply chain through multimodal promotion and partial freight shifts toward railway and waterways (McKinnon, 2018).

### Product Design

Integrating a resilient product design can help companies to quickly adapt their operations in times of disruptions (Sáenz et al., 2018). Products should be designed for adaptation to different potential uses or configurations that arise from adverse events. Flexibility in product design includes modularity and postponement. By standardizing components and interfaces between components, modularity avoids the failure of one part affecting the entire system. A modular product design embeds coordination and loose coupling, while reducing cost and improving response time (Revilla & Acero, 2021). This approach is especially suitable for companies that rely on single sourcing for key components or whose main suppliers are concentrated in a particular geographical area. A flexible product design facilitates the adaptation to new requirements imposed by disruptions. Finally, understanding the design of the products creates awareness of the risks associated to each step, which promotes the development of mitigating strategies and may even lead to rethink some of the process' stages (Sáenz et al., 2018).

A second flexible product design practice, postponement, is based on designing a group or family of products with a core element that can later be easily customized to produce different products. This practice, successfully developed by leading companies such as DELL, allows companies to benefit from offshore outsourcing of the core component to reduce costs while the final stages of the manufacturing can be done in closer locations to the final consumer (Sheffi, 2005). This way, production is finalized once the customer orders are received, avoiding forecasting uncertainty associated with volatile markets and the overstocking of final goods. Therefore, flexibility through postponement can enhance the resilience of the supply chain as production of goods is mostly guaranteed by tailoring the offered products to sudden changes in the demand or supply side (Tukamuhabwa et al., 2015).

### Portfolio Management

Product portfolios refer to the number of products that a given organization manufactures. How this portfolio is designed will directly affect the extent to which certain occurring challenges impact the supply chain. Supply chain managers could believe that providing a large variety of product options (type and size) may increase their resiliency to disruptions. However, companies should be aware of the trade-offs between product variety and resilience (W. C. Shih, 2020b).

With companies offering multiple varieties of the same base product, it becomes harder to adjust to demand, and shifting among production lines may not always be possible. Furthermore, in times of disruption a large variety can work against firm operational efficiency. Limiting the options provided streamlines production facilities and reduces logistics downtime, and it ultimately helps to maintain a satisfied customer base.

Companies such as Coca-Cola, Mondelez, or Procter & Gamble have historically provided plenty of options to customers and are now reevaluating their product portfolio, so they can simplify their supply chain. Simultaneously they are investing in flexibility to increase their agility to adapt their products and processes during future disruptions (Cosgrove, 2020). However, product portfolio simplification should go beyond a mere reduction of the products offered or just keeping the "best-sellers." It requires of a careful review of the current product strategy and alignment with current and future potential trends through a flexible planning, so production can be adapted to foreseeable changes or existing disruptive events (Sheffi, 2020).

Flexible planning sets the stage for agile reactions during disruptions by taking into consideration the needs for manufacturing equipment with different production rates as well as the staff requirements to operate in such a flexible environment. That was the case of some automotive companies that in absence of microchips focused its constrained resources in producing those cars with the highest revenue margins, which help to maintain the firms' financial solvency in highly unpredictable and disruptive times (Yergin & Fini, 2021).

### Visibility

Introducing end-to-end visibility in supply chain designs creates awareness of vulnerabilities in both the supply chain and its operating context. It also facilitates continuous monitoring that triggers the signals of an imminent disruption (Sáenz et al., 2018). To this end, firms need to have access to accurate, timely, and useful information of what is happening in every node and link of the supply chain (Brandon-Jones et al., 2014).

Visibility in supply chains can help identify its actors through an exhaustive mapping of its suppliers. Mapping has proven to be a useful tool in the identification of risks and preparation of the company to face the consequences of the materialization of such risks. However, the traditional mapping exercise performed by companies is mostly limited to the identification of tier-one suppliers, underestimating how a disruption on tier-2 or tier-3 suppliers can impact the normal operations of their own supply chains. For example, the recent trade restrictions on Russia have revealed the existence of over 7.6 million tier-2 relationships with Russian entities all around the globe, which may have a tremendous impact for global supply chains (D & B, 2022).

Visibility is more than a deep knowledge of where each component required for the manufacturing process is being produced or sourced. Complementing the identification of subtier suppliers with a real-time evaluation of critical performance variables – such as supplier inventory status, production schedules, shipment information, or supplier disruptions – can improve supply chain performance and decision-making (Caridi et al., 2014).

For supply chain resilience, firms should also assess the origin and criticality of supplied components. This tracing requires recurrent monitoring of direct suppliers in terms of financial and operational viability. For example, corporate restructuring or lawsuits in suppliers may trigger new risks. By integrating supply chain monitoring with the supplier data, companies can have a comprehensive and holistic view of risks, which will increase the robustness of the supply chain.

Finally, a visible supply chain requires understanding of the operating context in terms of both industry competitors and adjacent industries. For example, in the initial months of the pandemic, as a result of a sharp decline on fuel demand, the production of gasoline plummeted and so did the production of one of its by-products: ethanol. This by-product is a key component in $CO_2$ generation and required for carbonation of soft drinks and beers. The result of such decline increased CO2 prices by 25% (Baertlein & Kelly, 2020).

## 3.2 Reactive by Deployment

Proactive resilient practices need to be complemented with reactive disruption responses. Once a disruptive event happens, firms need to quickly react and deploy a series of mitigating tools to minimize the negative disruption impact. The deployment of reactive approaches is of critical relevance, especially when disruptions persist and require adjustments to a new context. Two main reactive practices stand out among the analysis of best practices deployed by leading companies: risk management plans in the form of business continuity and incident management plans, and adaptation to new business models.

### Risk Management Practices

Risk management practices are a formal response to deal with disruptions. With disruptions happening more frequently and companies having an increased awareness of devastating consequences of being exposed to risks, risk management has become a formal responsibility in supply chain management. It includes new job roles, job titles, and entire departments dedicated to risk management.

Effective risk management approaches incorporate multidisciplinary teams from different functions of the supply chain that tailor responses based on the nature and impact of the disruption (Sáenz et al., 2018). They identify disruption signals and implement reactive mitigation measures through four steps or stages: risk identification, risk assessment, risk treatment, and risk monitoring and review (Dittman, 2014).

The first step consists of the identification of possible risks completed by mapping out nodes and links within a supply chain. Identified risks should then be categorized based on how its materialization would impact the normal operations, the probability of such materialization, and if the company is prepared to deal with such disruption. This second step allows risks managers to prioritize mitigation measures and may eventually lead to changes in the design of the supply chain. In the third stage, each of the risks identified is matched with a series of mitigating practices and response plans that would be developed to respond to the disruption caused by such risk. Finally, an effective approach to risk management needs to include continuous monitoring of the risks identified. The dedicated risk management teams may use different signals to detect potential disruption, for example, using control towers or other visibility platforms, and if something is detected that may trigger the deployment of contingency measures.

### Business Continuity Plans

Companies have traditionally embarked on risk management practices through Business Continuity Plans (BCP). These plans seek to deal with disruptions by ensuring a continuation of the operations with minimum interruptions (Sáenz et al., 2018). Therefore, when an unexpected crisis impacts the supply chain, a series of contingency measures are deployed to keep operating with the available resources.

BCP provides a roadmap to follow during a potential disruption. Such potential disruptions could include interruption of operations due to extreme weather events, extensive physical damage to a critical facility, cybersecurity breach, or power outage. For years now, CISCO Systems Inc. has enforced its Business Continuity Plan, which has proven successful in critical events such as the Tohoku earthquake. A dedicated team closely monitors each critical supply chain node information. In this way, when a disaster or unexpected event occurs, the company can automatically assess the extent of the disruption impact and implement previously developed corrective actions (Sáenz & Revilla, 2014). All these measures, once deployed, aim at mitigating the negative consequences of a materialized disruption.

### Incident Management Plans

Another widely used risk management practice is Incident Management Plans (IMP). IMP are developed to create an awareness culture of what may trigger a disruption and react if these disruptions materialize. Even though it may seem similar to BCP, there is a substantial difference between the two of them. BCP imply that a disruption has materialized and is causing an interruption to the operations. However, IMP are deployed to address and minimize the impacts of incidents by quickly detecting signals of disruptions. However, such disruptions may not necessarily cause an interruption of the operations.

As an example, Starbucks anticipates disruptions through a series of pre-established signals, and if needed its center of excellence activates the required mitigation strategies which are tailored to each specific disruption (Sáenz et al., 2018). While the existence of these risk management practices will not fully avoid the impact of a global crisis, previous experience indicates that only those companies with mature approaches to risk management can react to disruption faster and adapt their operations in a more favorable way.

### Dynamic Business Models

Depending on the type of disruption, it may not be possible to continue with the original operating model. Therefore, to be resilient it is necessary to design the firm's business model thinking that it is in a state of perpetual evolution, in which disruptions are seen as opportunities to exploit new markets.

We have seen plenty of successful and unsuccessful examples of agile adaptation triggered by the Covid-19 pandemic. We will continue to see them as the consequences of new lockdowns in China, such as the one in Shanghai in March 2022, or the economic implications and raw material shortages derived from the Ukrainian armed conflict. There will be other events to cause similar disruptions.

Before the pandemic, passenger aircraft were providing around 50% of the airfreight cargo capacity; with traffic down by 90% and tariffs increasing by more than 200%, some passenger companies saw an opportunity with new business opportunities and stayed afloat at the same time. This was the case of Wamos Air, a Spanish airline whose main business revenues came from transporting passengers to cruises in the Caribbean. With tourism virtually nonexistent during the Covid crisis, the company worked fast to react to the new circumstances. They adapted to the new demand by quickly converting 70% of their fleet into cargo planes. Wamos Air was the first Spanish operator, in June 2020, to get an exemption from the Civil Aviation Authority of Spain (AESA) to remove the seats from some of its A330s and carry cargo, reacting to the clear cargo demand in the market. Furthermore, as a consequence of this situation, the company has developed the ability to transform aircraft in just 2 days from cargo to passenger thanks to having its own Part 145 maintenance party.

A dynamic business model to adapt to new disruptive contexts can only be achieved if its workforce is also ready to adapt. To that end, it is important to develop a culture of permanent reskilling of the people and develop a collaborative framework with the latest digital tools and edge technology.

## 3.3 Grounded in Digitization

Building supply chain resilience requires two complementary approaches mentioned above (proactive and reactive). The supply chain risk is reduced through its design, and a series of particular mechanisms can be reactively deployed when a disruption materializes.

Supply chain managers have to aim clear and dynamic representations of supply chain tracks to be able to link both approaches. They need to do this while designing the supply chain structure and the product configuration. Digital technology and rich data can expand end-to-end in the supply chain, for digitization of supply chain processes, connected along with a combination of flexible alternatives.

End-to end data allow the connection between demand and supply being flexible in how to configure the product with complementary components. This visibility provides the representation of real time flows of supply chains that enhance the necessary awareness of risks, implement risk mitigations practices, and minimize its negative impacts.

### End-to-End Connectivity

Building end-to-end (E2E) connectivity facilitates the development of supply chain visibility, integrating it in the deployment of risk mitigation practices. To achieve this, E2E connectivity multiple sources of data must be accessed and integrated depending on the particular scenario of the disruption risks. Storing and sharing data through data lakes and data hubs requires access to the most traditional sources of data in supply chain settings. This situation would include historical formal data from forecasting systems, sales and operations integrated, inventory positions of the multiple parts, and final products, combined within the Enterprise Resource Planning Systems (ERPs), Warehouse and Transportation Management Systems. By integrating data with modern computing architecture, decision-making can be made on more solid inputs and reaction times can be substantially reduced.

Building supply chain resilience also requires the contextualization of real-time disruption risks and the learning after analyzing the potential threats behind. This implies access to sources of real-time data anywhere along the supply chain which represents the real context that the supply chain has to face as well as some threats to the operations. Examples of these sources of information are trade bodies, currency exchanges rates, web crawlers showing the dynamism of prices, behavior of competitors, online product reviews by customers, social media reactions, seasonal and weather forecast, threats of political instability, and reputational status of supply chain partners, among others.

### Monitoring Performance

One of the critical elements of successful resilient supply chains is the orientation to a value-driven supply chain that is enhanced by digitization, in which specific value propositions are guiding how to deploy the operational flows (Saenz et al., 2022). For this purpose, stablishing specific organizational and supply chain goals will help to navigate the creation of supply chain resilience. The establishment of these goals will facilitate a balance in the trade-offs eluded in this chapter such as resilience and efficiency or redundancies and cost-savings, among others.

Digitizing supply chain processes will create the availability of insightful data to better connect with the ecosystem of supply chain partners, suppliers, retailers, and customers, as well as key players such as logistics service providers. With the main aim of monitoring the creation of resilience, cohesive panels of comparable and comprehensive metrics are required. Key performance indicators should be created to align the two approaches mentioned before, while proactively designing the supply chain and monitoring the deployment and variation of that capability when a real disruption is threatening operations. Monitoring and visualizing this dynamic performance in real time will facilitate a setting for informed decisions. Every supply chain and business have to specify their way of measuring performance. Examples of the key performance indicators to monitor supply chain resilience are included in Table 2.

**Table 2** Resilience indicators

| Metric | Definition | How it is created |
|---|---|---|
| *Time to Recovery (TTR)* | TTR measures the time the system would need to recover after an unexpected event | TTR can be composed by multiple categories that can be weighted depending on the supply chain goals, the vulnerabilities exposed, and their importance on building resilience. This might include TTR at the level of supply chain nodes, in terms of components in product portfolio, suppliers, manufacturing facilities, or test equipment. A continuous learning loop when the TTR metric is assessed based on the supply chain design is monitored when a real disruption happens |
| *Time to Survive (TTS)* | Complementary to TTR, it assesses the duration of a supply chain satisfying demand with the current supply chain structure, especially after a disruption strikes | In a proactive approach, diverse scenarios can be developed and tested. The implications about cost-to-serve can be assessed in all those scenarios together with sensitivity analysis |
| *Value at Risk (VaR)* | VaR measures the potential economic or financial losses given a potential disruptive scenario | This metric is assessed using a risk exposure index, that is built based on the probability of a disruption, combined with real-time information that contextualize a particular facility, location, or flow. Unbiased measure of disruption risk complemented with the quantification of parameters of value, in terms, for example, of inventory hold, expected value of loss, investment made, or the opportunity cost of losing that facility if a disruption happens |

## Analytical Models

Once the key goals are defined and the sources of information are assessed and data is available, it is time to create the necessary insights to operate a resilient supply chain. Various analytical models can be created depending on the particular goals. For example, they can help to map business and supply chain processes as well as their interdependencies. They can detect vulnerabilities because some supply chain nodes do not have enough capacity to absorb disruptions or because they cannot adapt to new unexpected circumstances (defined by proactive by design mechanisms) or because the supply chain needs to deploy certain reactive practices when a disruption happens. In any case, both proactive and reactive mechanisms need to be closely monitored through a continuous collection of key data so as to ensure that the resilience creation mechanisms are aligned with the operating needs and external context.

Analytical models can be replicas of, for example, consumers and market behavior, geo-strategic models, value at risk of supply chain infrastructure and assets, industry behavior, or macroindicators that signal forward-looking trends in certain regions.

The engine that puts these models into action includes different analytics techniques, such as predictive, prescriptive analytics, or more advanced techniques based on machine learning and artificial intelligence (Gesing et al., 2018). These last two techniques are used in the context of supply chain risk management in order to actively learn from past experiences and project such learning in the day-to-day supply chain operation. Artificial intelligence emulates some cognitive functions associated with human minds such as perceiving the sources of vulnerability and uncertainty, interacts with the environment in real time with devices and users who can define or quantify the uncertain context, and learns as information changes, and as goals and requirements evolve. On the other hand, machine learning refers to systems that learn from the data they are given, drawing inferences after an evaluation and categorization of the received data. Both artificial intelligence and machine learning can augment the visibility and awareness of the supply chain, facilitating the monitoring of complex networks, sensing what is happening in the supply chain and its environment in real time, and even predicting disruptions (Gesing et al., 2018). Overall facilitating supply chain resilience.

## 4 Conclusion

In this chapter, we present the need for firms to integrate the development of supply chain resilience into their operational and business strategies to ensure their long-term viability. Resilient firms are more capable of developing supply chains with the capacity to persist, adapt, or transform in the face of disruptions. To effectively absorb and/or adapt to changes, supply chains need to embrace two different but complementary capabilities: robustness and agility, each of them coming from two different research field areas – engineering and ecology, respectively. Supply chain robustness facilitates, through anticipation, an efficient respond to disruptions, while agility prepares the supply chain to adapt operations so as to ensure a new desirable equilibrium.

Using these two complementary dimensions of resilience, we have created a comprehensive framework that facilitates a step-by-step resilience creation integrating the necessity of both proactive designs and reactive deployments of the supply chain elements. Overall, the framework presented in this chapter highlights a set of practices (redundancy, strategic location, logistics integration, product design, portfolio management, visibility, E2E connectiveness, monitoring performance, analytical models, incident management plans, business continuity management, and dynamic models) that companies should holistically implement to deal with unexpected events and achieve the much-desired supply chain resilience.

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# Conflict in Supply Chain Relationships: A Review, Conceptualization, and Future Research Agenda

Meriem Bouazzaoui, Brian Squire, Michael A. Lewis, and Jens K. Roehrich

## Contents




### Abstract

Conflict in buyer–supplier relationships is a regular occurrence and, therefore, understanding its emergence, consequences, management, and resolution is a vital area for academics and managers alike. In recent times, studies have given more consideration to whether and how conflict in these relationships leads to (dys-)functional outcomes, but plenty of questions remain unanswered. Based on an analysis of 124 papers, and drawing upon core assumptions that underpin



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supply chain relationships, we present descriptive and thematic analyses and synthesis to highlight what has been explored to date. Building on these analyses, we position a future research agenda by outlining key research avenues by which to advance our understanding of and insights into conflicts in supply chain relationships. We focus on four key themes: (i) conflict conceptualization; (ii) conflict antecedents; (iii) conflict management and resolution; and (iv) conflict outcomes. For each theme, gaps in prior study are outlined before identifying the opportunities for future research that will serve to address these lacunas in our knowledge and practice. Thus, we articulate fruitful research questions for each of these themes and discuss the significant managerial implications of current and future research.

**Keywords**

Conflict · Conflict resolution · Conflict management · Supply chain relationships · Interorganizational relationships · Buyer–supplier relationships · Future research · Research agenda · Literature review

## 1 Introduction

Conflict, defined as "the process that begins when one party perceives that its goal attainment is being impeded by another, with stress or tension the result" (Gaski, 1984: 11), is an inherent characteristic of buyer–supplier relationships. Companies face a variety of major challenges, such as digitalization, global competitiveness, supply chain uncertainty, and shortened time to market, and these provide a ripe environment for conflicts to emerge, as well as impacting the way companies resolve them (Eshghi & Ray, 2021).

Scholars have argued that conflict has a double-edged nature in that it can act as a cohesive force that brings partners closer, or as a disruptive force that threatens the stability of the relationship. Researchers have demonstrated that conflicts among supply chain partners can disrupt their interaction, block their ability to gain the resources that are necessary to advance their goals, and may increase product development time and costs (Lam & Chin, 2004; Leonidou et al., 2006). Contrarily, researchers have also reported that a certain degree of conflict between parties in a relationship may intensify value-creation efforts, provide an opportunity to refine the ongoing relationship, and enhance future purchase intentions (Skarmeas, 2006).

The predominance of conflict in buyer–supplier relationships and the mixed findings regarding its impact require deeper exploration and synthesis of existing knowledge in order to understand the key factors involved in conflict emergence and management. Yet, prior studies largely lack any systematic review of conflict literature. An exception is the study by Lumineau et al. (2015), which provided a narrative review of the conflict literature, focusing particularly on the difference between conflict at the intra- and interorganizational levels. Yet, as the authors clearly stated, "our intent is not to conduct an exhaustive review of the literature, but rather highlight key studies of inter-organizational conflict" (Lumineau et al., 2015: 45). In addition, Johnsen and Lacoste (2016) developed a systematic review of conflict, power, and dependence, but only examined the downside of these constructs, largely ignoring the more positive aspects of conflict including the stream of prior studies concerned with "conflict management," considered a crucial component of conflict research.

In order to address this shortfall, this chapter synthesizes and extends understanding of the evolution of conflict within supply chain relationships by considering the following: (i) *What is the current state of buyer–supplier conflict research?* (ii) *What are the outstanding conceptual and empirical concerns in buyer–supplier conflict research?* (iii) *What can organizations and managers learn from prior conflict research when seeking to address conflicts in their supply chains?*

To address these questions, we draw on a synthesis of 124 conflict-related articles focusing on interorganizational relationships. We examine key theoretical, methodological, and empirical aspects of existing research, and build on core assumptions of supply chain relationships (Lumineau & Oliveira, 2018) to propose areas for research that will help in building, testing, and elaborating theoretical advances, and informing practice, when it comes to conflict. This chapter seeks to serve as a source of reference for future research and engagement, to position the avenues for this future research from a theoretical perspective, and to guide managerial decision-making.

The remainder of the chapter is organized as follows: first, we describe the methodology used for the review of the literature and the descriptive analysis of the papers identified; we then present our synthesis and thematic analysis, before concluding the chapter with a discussion of the managerial implications of our results.

## 2 Systematic Review Methodology and Descriptive Analysis

### 2.1 Methodology

The domain for the research synthesis consists of empirical (both qualitative and quantitative) and conceptual papers that examine conflict in supply chain relationships. The substantive relevance of the selected papers was ensured by requiring the presence of the terms "conflict," "disagreement," "tension" (De Wit et al., 2012), "conflict management," "conflict handling," and "conflict strategy" in the "Topic" category in the ISI Web of Knowledge, combined with at least one of the following terms in the articles' titles: "cooperat*," "interfirm/inter-firm," "inter-organizational/interorganizational/inter-organisational/interorganisational," "supply chain," "buyer," and "supplier." Further, because some supply chain conflict research was initially conducted in a distribution channel context, the term "distribution channel" was also incorporated to fully embrace interorganizational conflict. Given these elements, more detailed inclusion and exclusion criteria were discussed and agreed among the author team.

Overall, we reviewed 319 abstracts and only retained papers where conflict was the main subject, or where conflict/conflict management had been used as a variable to predict certain attitudinal and behavioral outcomes in supply chain relationships. Articles placed out of scope included mathematical modeling and operational research papers dealing with internal channel conflict, and those concerned with conflicts involving organizational or cross-functional teams, financial decision-making, and dispute management (litigation). The final data set consisted of 124 papers, which was then analyzed through both descriptive and thematic methods.

## 2.2 Descriptive Analysis

On the basis of our comprehensive analysis and synthesis, this section draws out key observations in relation to our data set of conflict studies.

In terms of distribution over time, the rate of journal publication has been increasing, which illustrates the growing importance of this research area among scholars and practitioners. Two major periods can be distinguished: 1969–2002 and 2003–2021. Forty of our papers were published in the first of these (over 33 years), with the number increasing by more than 50% in the latter period (just 18 years). The resurgence of interest in the field from 2003 onwards can be explained by the refinement of the conceptualization of the conflict construct, and the emergence of two paradigms for handling conflict: (i) as a problem to be eliminated; and (ii) as a resource for improvement (Samaha et al., 2011). This conceptual clarification encouraged a vigorous and renewed attention to the study of the underlying psychological, structural, and environmental factors that induce, support, and diminish conflict.

In terms of the research methods used in prior conflict studies, surveys were the dominant form (75%; see Fig. 1). Within the specific context of interorganizational conflicts, survey research provided insights into antecedents that might explain variance in the amount of conflict within a dyad, as well as conflict outcomes, in a wide range of industrial and national contexts. However, the practicalities of a survey-based

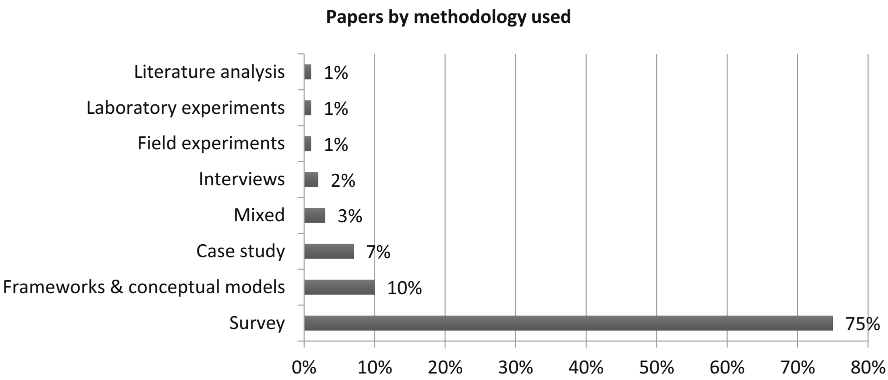


**Fig. 1** Publications by methodology

methodology also mean that dynamics are overlooked. Thus, surveys provide little insight as to how and why conflict levels change, and do not illustrate how firms make decisions in the course of the conflict resolution process. Moreover, surveys do not indicate the sequence of events, making it impossible to infer causality (Krafft et al., 2015). Case study methods were employed in just 7% of the empirical papers yet, given that conflict is defined as a process, are particularly valuable in substantiating the evolving nature of conflict and unraveling the complexities inherent in its resolution, including the why, what, when, and how. The confidentiality issues that researchers encounter when investigating a sensitive phenomenon such as conflict (Lumineau et al., 2015) may have inhibited the wider use of case studies within this context.

Although conflict in buyer–supplier relationships is a dyadic phenomenon, most empirical papers describe studies in which researchers examined the subject from the perspective of a focal company (80%) within the dyad, with the perspective of both sides of the dyad (matched dyads 16%; unmatched dyads 4%) studied to a much lesser extent. This is consistent with the results of Krafft et al. (2015), who found that, in a sample of 362 studies in marketing channels, dyadic empirical research was low in comparison to non-dyadic studies. Dyadic research designs enable researchers to measure both the magnitude of the phenomenon across the dyad and the (a)symmetry in partner perceptions (Liu et al., 2012).

The dyadic studies reviewed in this chapter used dyadic data either for triangulation purposes in understanding different perspectives (e.g., how the position in the dyad impacts the hypothesized relationship), or for determining magnitude by measuring the mean value score from paired dyads (Luo et al., 2009; Liu et al., 2017). This situation means that *conflict asymmetry* has been significantly understudied. The advancement of conflict research must move beyond the perspective of a single actor because conflict episodes involve partners with different perceptions, in which symmetry is not a typical state (Hingley, 2001).

Of the selected papers, only 37 explicitly referred to theories, meaning that most articles are not grounded in theory. This result is surprising because the need for extensive use of theory in operations and supply chain management research has long been advocated (Harland & Roehrich, 2022). Analysis of theory frequencies indicates that social exchange theory (SET) and transaction cost economics (TCE) provide the dominant theoretical perspectives, which is unsurprising because these two theories have been fundamental in explicating the nature of buyer–supplier relationships.

## 3 Synthesis and Thematic Analysis: Emergent Concerns and Gaps in Prior Studies

In order to clarify the state of the art of knowledge on conflict in supply chain relationships, and pave the way for future research efforts and managerial insights and implications, this section provides a synthesis of and critical reflection on the key themes and research gaps identified by the review and analyses. Thus, we categorize our analysis and synthesis according to four themes, discussed in turn below: (i) conflict conceptualization; (ii) conflict antecedents; (iii) conflict management and resolution; and (iv) conflict outcomes. A final subsection brings together other observations from prior conflict studies to support the synthesis.

### 3.1 Conflict Conceptualization

As conflict gained importance as a research area over the last three decades, scholars have sought to refine its conceptualization (Jehn, 1995). Two types of conflict emerged initially, namely task conflict and relationship conflict. Task conflict refers to "disagreements among group members about the content of the tasks being performed, including differences in viewpoints, ideas, and opinions" (Jehn, 1995: 258); relationship conflict, on the other hand, refers to "personal incompatibilities among group members, which typically includes tension, animosity, and annoyance among members within a group" (Jehn, 1995: 258).

Although this categorization has gained resonance in the organizational behavior literature over the last two decades (De Wit et al., 2012), the supply chain conflict literature showed a vast majority of studies still considering conflict as a single construct in which factors pertaining to both task and relationship conflicts were combined. A handful of prior studies have explicitly considered either task conflict or relationship conflict, while others have included both conflict types in one study. Thus, a significant gap exists in this respect, because the conceptualization of different conflict types has been recognized as constituting a critical theoretical distinction in several meta-analyses (e.g., De Dreu & Weingart, 2003) because they have differential impacts on conflict outcomes.

Further refinement of the conflict construct has resulted in the addition of a third type of conflict, referred to as process conflict and defined as "controversies about aspects of how task accomplishment will proceed (. . .) pertains to issues of duty and resource delegation, such as who should do what and how much responsibility different people should get" (Jehn & Mannix, 2001, 239). However, to date, this type of conflict has been largely neglected in empirical studies on supply chain conflict. An exception is the recent study by Cai et al. (2020), investigating how the three conflict types impact green supplier integration. In essence, prior studies have failed to obtain discriminant validity because of the strong overlap between task conflict and process conflict, intercorrelation of which is high, ranging from 0.44 to 0.90 (e.g., Jehn & Mannix, 2001). Accordingly, researchers have argued that process conflict is merely one kind of task conflict (Barki & Hartwick, 2004), and it is the dual distinction, task versus relationship, that has formed the basis of much of the prior conflict research in relation to management.

### 3.2 Conflict Antecedents

A considerable amount of literature has been published on conflict antecedents in order to highlight the causes of conflict occurrence, with the *power* antecedent being the most investigated. The relationship between power and conflict was reported in the first studies by Lusch (1976), who found that coercion tends to increase the frequency of conflict, whereas noncoercive power leads to fewer disagreements, although these findings were not consistent across subsequent studies. Inconsistencies in results emerged from differing approaches to measurement of the conflict construct, which could be based on frequency (Lee, 2001), intensity (Zhang & Zhang, 2013), or a combination of frequency and importance (Schul & Babakus, 1988).

Scholars have also studied how buyer–supplier governance mechanisms are associated with conflict, with researchers starting to examine contracts and contract types as conflict antecedents. For instance, when an output-based contract governs the buyer–supplier exchange, a buyer has minimal involvement in the supplier's processes, which in turn reduces conflict over how to perform the cooperative task. Conversely, the use of behavior-based contracts generates conflict, because buyers are given increased power to legitimately monitor a supplier's operations, which may in some instances be considered inappropriate and lead to conflict (Bai et al., 2016). You et al. (2019) investigated how governance mechanisms are linked to different types of conflicts, and other antecedents that have been investigated include opportunism (Skarmeas, 2006) and environmental dynamism (Cai et al., 2017).

Further research should continue to investigate conflicts and the role and impact of, for instance, different types of contracts (e.g., performance-based contracts), contract clauses (e.g., control vs. coordination), specific boundary objects in the contract (e.g., timelines), and phases of the contracting process (e.g., Roehrich et al., 2021; Karaba et al., 2022), as well as wider market dynamics, and economic, social, and political disruption and change (e.g., BREXIT, the COVID-19 pandemic, natural disasters, climate change, carbon emissions – Phillips et al., 2022a, b). These factors could variously suppress or support the emergence of conflict in supply chain relationships.

Overall, three major limitations can be distinguished in the stream of antecedent research: the predominance of factors associated with relationship conflict, a tendency to consider each level of analysis in isolation, and a lack of replication across studies. First, conflict involves mechanisms from other levels of analysis besides those at relationship level (Lumineau et al., 2015). By focusing on just one level of analysis, researchers only provide a partial picture of conflict. Moreover, by considering each level separately, conflict researchers neglect the interaction between levels, and may attribute effects from the dimensions of one level to those of another level, thereby creating a cross-level fallacy (Rousseau, 1985). Accordingly, a multilevel theoretical lens that encompasses the dynamic interplay across levels should provide a more insightful description of the conflict phenomenon. Finally, few replication studies have been published. Yet, replication is essential to the extent that it enables researchers to confirm past findings and to examine a phenomenon from various points of reference – such as different contexts, timing, and/or perspectives – and thereby grant original theories greater legitimacy.

## 3.3 Conflict Management and Resolution

Conflict management refers to the approaches and strategies used by parties to reduce and manage the tension. Researchers have attempted to classify these strategies, and hence various models have emerged. These frameworks differ in the terms used to describe the strategies, but their classifications are broadly based on two dimensions, which reflect people's concerns for their own interests, and their concerns for those of the other party. Figure 2 illustrates these dimensions and the classifications of the strategies identified in prior studies.

In general terms, five distinct conflict management strategies have been identified, as shown in the figure: (1) *accommodating*, which implies offering help and acceding to the desires of the other party; (2) *collaborating*, which is oriented toward achieving maximum satisfaction of both parties' concerns through high levels of cooperation; (3) *compromising*, which presumes a mutual give and take so as to at least gain partial fulfillment of one's desires; (4) *avoiding*, which involves ignoring the associated concerns and downplaying the importance of the issue; and (5) *forcing*, which involves imposing one's will on the other party.

Conflict management has not been sufficiently investigated. Of the 124 papers we reviewed, only 27 recognized conflict management strategies as part of their theoretical framework. Of these 27, the vast majority (73%) explored the direct relationship between strategies and outcomes, followed by a group that incorporated conflict (as a single construct) into their strategy models (19%), and only a few studies that combined conflict management strategies with specific conflict types (8%). This represents a significant limitation, and the nature and level of conflict may account for as much variance in outcomes as the conflict management process and strategies.

Studies related to conflict management strategies cover a variety of theoretical domains. Prior research suggests that various factors have a bearing on the use of any

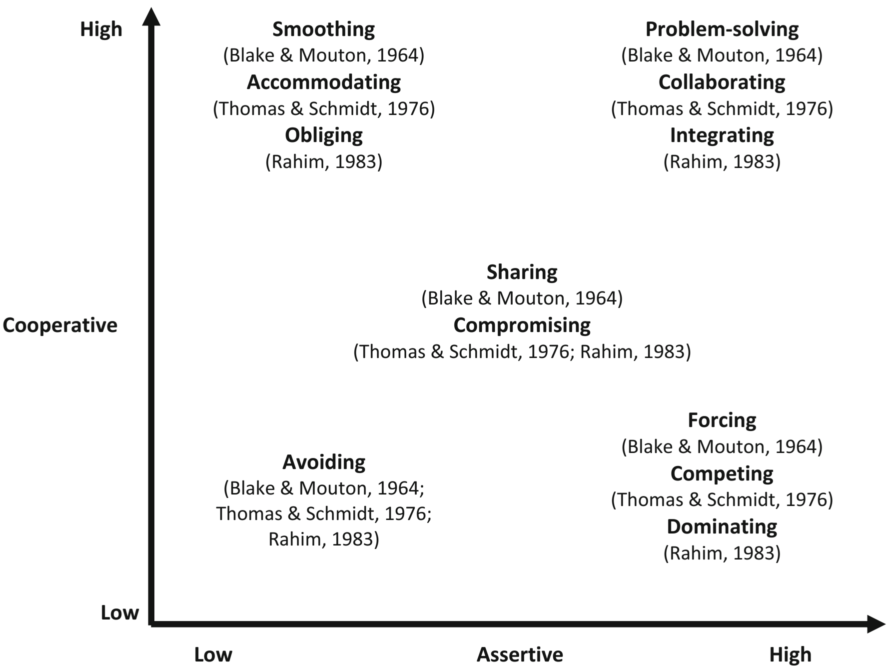


**Fig. 2** Conflict management strategies and some representative studies

given conflict strategy, with determinants including relational aspects such as power (Lam & Chin, 2004), fairness (Strutton et al., 1993), governance mechanisms (Shahzad et al., 2020), and project-related aspects such as product technological complexity (Lam & Chin, 2004).

Another stream of research explores the effectiveness of conflict management strategies through the investigation of their positive or negative outcomes (e.g., Ndubisi, 2011), particularly in terms of relationships. With the exception of a collaborative management strategy that was positively related to relationship outcomes in every such study, the results for other strategies were inconsistent or singular. For instance, while Bobot (2011) reported a negative relationship between *accommodation* and trust and commitment, Ndubisi (2011) demonstrated a positive relationship. Bobot (2011) also reported a negative relationship between a *forcing* strategy and trust and commitment.

Hypotheses concerning the effectiveness of an *avoiding* strategy were not supported in any of the associated studies, which might be explained by the fact that an avoidance strategy fails to address the root causes of a conflict, with the conflict problem persisting if parties choose to ignore it (Le Nguyen et al., 2016). Moreover, this strategy tends to undermine a relationship's goal of mutual gain and thus seems inconsistent with the norms and values advocated in supply chain relationships (Mohr & Spekman, 1994).

Other factors involved in the process of conflict management were investigated without testing the direct relationship of a conflict management strategy. For instance, Pulles and Loohuis (2020) examined how buyer openness and directness impact a supplier's willingness to adapt during a conflict episode.

Although this body of research has provided insights into conflict management, several limitations can be noted. First, few studies investigated the conditions (moderators) that might influence the relationship between a conflict management strategy and conflict outcomes. Similarly, few papers considered conflict types in conjunction with conflict management strategies, even though a small number of studies provided strong evidence of the necessity to combine them in order to understand conflict outcomes. For instance, Bobot (2011) found that when retailers use collaboration, rather than confrontation, the relationship between task conflict and relationship quality is amplified. One further limitation of existing studies is their cross-sectional nature, which largely overlooks changes in conflict intensity and the consequent changes required in conflict management. Finally, while a *strategic* approach to conflict can be useful, recent studies have criticized its applicability in practice and have advocated the use of a more fine-grained approach based on specific tactics oriented toward conflict resolution (Carton & Tewfik, 2016).

## 3.4 Conflict Outcomes

Researchers distinguish between the functional outcomes of conflict, which are the positive performance results that conflict generates, and dysfunctional ones, which are adverse effects on the performance of partners and are the more evident. Murfield et al. (2016) found that conflict is associated with the perception of lower levels of relationship quality on the part of suppliers, with a reduced motivation to accommodate buyers' request in the future. Other detrimental effects of conflict include relational betrayal (Leonidou et al., 2017), lack of cooperation and flexibility (Samaha et al., 2011), decreased relational investment (Luo et al., 2009), and reduced trust and commitment (Leonidou et al., 2006). Conversely, a few studies have shown that a certain degree of conflict between parties in a relationship may strengthen partner efforts toward value-creation, provide an opportunity to refine the ongoing relationship, and decrease switching intentions (Skarmeas, 2006).

Following analysis of conflict outcomes in the extant literature, two main observations can be made: (1) the predominance of conflict dysfunctionality; and (2) the focus on firm or dyadic outcomes. Empirical evidence about the benefits of conflict in supply chains is limited, and this could be explained by the conceptualization of the conflict construct. Researchers typically used a unidimensional conceptualization incorporating "conflict," "incompatibilities," and "tensions," which tend to be interpreted negatively by respondents (O'Neill et al., 2015). These conceptualizations are not only indicative of a degree of conflict between partners but also imply dysfunctional outcomes. Moreover, a one-dimensional conceptualization of conflict fails to capture the true effect of conflict on relationship outcomes (Ren et al., 2009). In addition, prior studies have very often theorized the conflict–outcome link as linear, and hence there has been little investigation of the mechanisms through which conflict gives rise to (dys)functional outcomes (mediating variables), and of the contextual factors that could moderate these relationships.

Lastly, conflict outcome measures considered in existing research focus largely on firm or dyadic outcomes. However, as previously discussed, supply chain relationships are nested in other relationships involving a variety of levels (e.g., individual, dyad, network), and conflict outcomes could very well pertain to interorganizational issues, and to other levels, lower and higher.

## 3.5 Other Observations from Prior Conflict Studies

Figure 3 summarizes the key research themes discussed in the preceding sections. We also derived three other observations from our analysis, concerning: (1) time insensitivity; (2) lack of cross-level analysis; and (3) focus on a single point of view.

First, the majority of supply chain conflict research is time-insensitive. This means that prior studies appear to consider conflict episodes to be invariant over time, particularly in their use of cross-sectional surveys. Despite the long-term nature of interorganizational relationships, and the importance of investigating conflict dynamics over time, few publications apply a longitudinal or a processual perspective to the subject. However, "if we want to acknowledge the dynamic nature of conflict, our theorization must allow for time and not ignore it" (Mikkelsen & Clegg, 2017: 9).

Second, supply chain conflicts are considered to be inherently cross-level phenomena (Lumineau et al., 2015). Therefore, a more comprehensive understanding of [conflict] dynamics may further add to our current understanding and mitigate

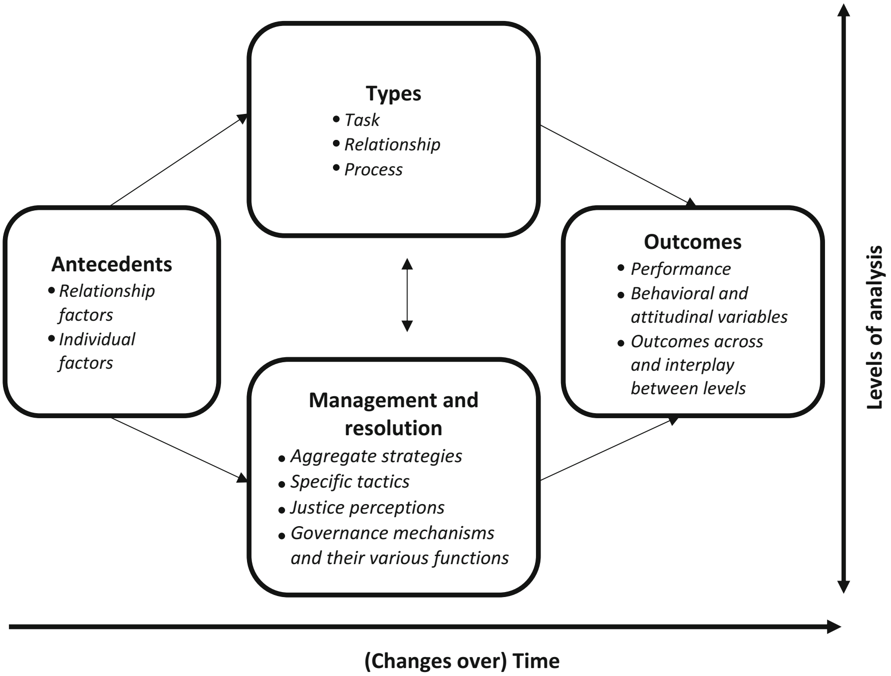


**Fig. 3** Conflict research – summary of key research themes and their relationships

against "cross-level fallacy" (Rousseau, 1985). However, prior studies have largely ignored more than one level of analysis when investigating relationship conflicts.

Third, supply chain relationships "undergo a continual balancing act where symmetry is not a typical state" (Hingley, 2001: 850). Yet, most of the empirical papers included in this review represent studies in which researchers examined the perspective of one focal company (80%) within a dyad and, to a far lesser extent, the perspective of both sides of a dyad (matched dyads 16%; unmatched dyads 4%). Typically, exchange partners exhibit asymmetry in their perceptions of various relational constructs such as trust, dependence, justice, and knowledge, and these asymmetries have been argued to be significant determinants of the behaviors of relationship partners (Gundlach & Cadotte, 1994).

## 4 Emerging Research Directions

Through our descriptive and thematic analyses, we identified and categorized gaps in terms of the major assumptions underlying conflict research in supply chain relationships. The following subsections outline the most significant areas in need of further investigation, setting the foundations for a research agenda to support advances in our understanding of and insight into such conflict. These emerging research directions are presented according to the same four key themes previously identified: (i) conflict conceptualization and the evolution and interplay of conflict types; (ii) conflict antecedents; (iii) conflict management and resolution; and (iv) conflict outcomes.

## 4.1 Conceptualization and the Evolution and Interplay of Conflict Types

Existing conflict research has demonstrated that conflict types are interrelated. However, their patterns of temporal change have not yet been investigated. One approach to investigating conflict type patterns is to use the concept of *velocity*. Velocity represents the rate and direction of change over a specified period of time. While the rate of change refers to the amount of change, the direction of change refers to its degree of continuity/discontinuity, where continuity reflects an extension of past change, and discontinuity represents a shift in direction (McCarthy et al., 2010).

Building on the multidimensional conceptualization of conflict and on the concept of velocity, each type of conflict could exhibit a particular velocity at a specific point in time. Accordingly, scholars could study the differences and relationships between *task* and *relationship conflict velocities*. Researchers could follow McCarthy et al. (2010) and study three dimensions of velocity: velocity homology – the similarity between the rate and direction of change of conflict types; velocity coupling – the extent to which the velocities of conflict types are causally connected; and velocity regimes – the various patterns that emerge from differences in velocity homology and velocity coupling.

Integrating a temporal perspective would enable understanding of periods of time in a conflict situation when task and relationship conflicts prevail and those when they do not occur simultaneously. These patterns could be linked to particular mechanisms throughout the conflict process. Examining changes in conflict types will advance our understanding of how these types emerge in supply chain relationships and how they evolve – either singularly, in parallel, or interactively – during the conflict episode. It would also inform conflict theory by explicating the direction and rate of change in conflict types in temporal terms, which could eventually lead to a better understanding of (dys)functional outcomes.

## 4.2 Conflict Antecedents

Human agency plays a major role in explaining idiosyncratic behaviors in buyer–supplier relationships, specifically in terms of developing trust, exercising power, reducing opportunism, and preventing relationship dissolution. For instance, Tangpong et al. (2010) found that the interaction of agent cooperativeness (an individual personality trait) and relationship norms (an organizational-level factor) mitigates opportunism in buyer–supplier relationships. These findings demonstrate that individuals at the interfaces of supply chain relationships can have an essential impact on conflict. A study by Cai et al. (2017) demonstrated how guanxi between boundary-spanners mitigates interorganizational conflict through the reciprocal exchange of favors between exchange partners. Besides the impacts of such interpersonal relationships, another fertile research opportunity relates to the characteristics of individuals and their impact on the conflict management process. For example, by applying personality trait theory (Weiss & Adler, 1984), conflict scholars could investigate how different traits or characteristics that explain behavioral difference among individuals – for example, cooperativeness, temporal orientation, attitude toward risk – interact with other interorganizational factors to mitigate or amplify conflict.

A further research opportunity is to theorize the role of the relationship network in dyadic conflict. For instance, in the context of multinational corporations (MNCs) with centralized purchasing and sales centers, relationships in a given country are embedded within the relationship between the regional offices. An interesting research avenue is therefore to investigate how multiple ties operate and constrain relationship management in general, and conflict in particular. Team conflict research has embraced such reasoning. For instance, Ren (2008) demonstrated that network bridging ties act as a buffer against conflict. Along similar lines, Li and Hambrick (2005) investigated international joint-venture groups and found that parent company affiliations can generate fault lines – dividing lines that can split a group into subgroups – that lead to relationship conflict. Apart from the embeddedness of relationships in a wider network, the nature of the product/service being procured – such as its complexity or servitization (Johnson et al., 2021) – may have an impact on how conflicts emerge and are subsequently managed.

Finally, relationships are influenced by the external environment, including institutional, political, economic, cultural, environmental, and historical contexts (Lumineau et al., 2015; Zhu & Sarkis, 2007). Therefore, the study of conflict between organizations should take into consideration the environment in which the relationship is embedded. An exemplary study by Bai et al. (2016) integrated the macro-level (institutional environment: legal enforceability and government support), with the interorganizational level (contract structure) to provide a more refined picture of the impact of contracts on conflict, thereby circumventing the single-level-of-analysis limitation. The researchers found that interorganizational control grounded in an output-based contract was negatively related to buyer–supplier conflict when legal enforceability was high but not when it was low. An extension of this research would consider other institutional characteristics, including stringency of environmental control, regulatory ambiguity, and regulatory interference (Luo et al., 2009) such as experienced in public–private partnerships and/or other relationships with public sector involvement. Relationships between public and private organizations may be particularly subject to conflict and coordination failures as a result of, for instance, divergent objectives, values, and aims (Roehrich et al., 2014; Caldwell et al., 2017; Kalra et al., 2021; Roehrich & Kivleniece, 2022).

In addition, future research might also explore how the characteristics of a competitive business environment, including complexity and dynamism, impact conflict in supply chain relationships.

### 4.3 Conflict Management and Resolution

As already discussed, conflict management and resolution has mainly been researched from the perspective of strategies. Although enlightening, this approach is limited in not offering tangible tactics that can be used in practice. To circumvent this limitation, researchers could employ a justice theory lens (Bouazzaoui et al., 2020). Four justice dimensions have been identified in the existing literature (Liu et al., 2012): *distributive* justice ensures that parties to an exchange receive benefits that are commensurate with their inputs into the relationship; *procedural* justice refers to the process of resource allocation and is evaluated on the basis of six rules covering consistency, bias-suppression, accuracy, correctability, representativeness, and ethicality; *interpersonal* justice refers to the interpersonal treatment received during the enactment of procedures; finally, *informational* justice is concerned with the accuracy and adequacy of the information provided. Future conflict studies could investigate how perceptions of justice drive the conflict management process – such as the efficacy of tactics associated with each justice dimension in relation to the intensity and type(s) of conflict.

Conflict management and resolution could also be investigated from a governance perspective. Scholars distinguish between relational (e.g., trust) and contractual mechanisms (Roehrich et al., 2020). While a few prior studies have started to investigate how both mechanisms prevent or trigger conflict – see the preceding subsection on *antecedents* – how governance mechanisms are used when conflict emerges requires further investigation. Shazad et al. (2020) found that contract completeness is positively associated with problem-solving and legalistic conflict management strategies and inversely related to a compromising strategy. Moreover, the investigators found that when trust exists between partnering organizations, they tend to adopt problem-solving and compromising strategies rather than legalistic ones. A further exploration of governance mechanisms could involve the use of contractual functions (coordination vs. control) when invoking or managing conflict.

Future conflict research should consider conflict episodes as being embedded in a relationship context. Accounting for the simultaneous existence of conflict and collaboration may bolster relationship ambivalence (e.g., Rees et al., 2013), impact how partners work out their disagreements, and, potentially, produce different ranges of conflict management strategies than those so far considered in the conflict management and resolution literature. For instance, an anticipation of future collaboration, foreshadowing the future, should create a disincentive to further escalate conflict, because it could substantially diminish access to partner resources and threaten the continuity of the exchange. In essence, the simultaneous experience of both the valence and ambivalence that emerges invites further investigation of the antecedents, forms, and consequences of conflict–collaboration coexistence.

The tendency in conflict management and resolution research has been to analyze conflict strategies at a single point in time. However, conflict management is characterized by an interaction process in which two parties react to one another, wherein individuals alter their behavior to adapt to the situation, to achieve the best possible outcomes. An effective management tactic might not emerge in the immediate aftermath of conflict (Olekalns et al., 2020), and when an initial tactic is unsuccessful in providing a fair response to conflict, an alternative is required.

Integrating a temporal perspective into the conflict management process will provide a more fine-grained understanding of precisely what happens in a conflict situation in terms of partnering parties' behaviors and conflict intensities. It will also allow evaluation of how these dynamics evolve within the buyer–supplier relationship during the conflict situation and over the relationship life cycle. This temporal evaluation should allow researchers to better concentrate on conflict management strategies and their utility within different organizational settings. Understanding conflict management as it occurs would draw a more complete picture of its trajectory by highlighting factors that contribute to conflict resolution or, in its absence, the migration of the relationship toward termination (Johnsen & Lacoste, 2016).

## 4.4 Conflict Outcomes

Conflict outcomes may pertain to various levels. While supply chain conflicts are often conceptualized at firm level, their management is an inherently individual-level activity with potential consequences for the managers involved. There is a research opportunity to investigate whether successful conflict management is prized by the executive and leads to professional advancement. Service recovery research has embraced this perspective in exploring the combination of recovery metrics with employee reward systems (Michel et al., 2009) and could provide a template for developing research propositions in the context of supply chain conflict.

Another research direction worth exploring is *conflict contagion* (Sinha et al., 2016). For instance, utilizing emotional contagion theory, organizational team researchers demonstrated that dyadic conflict spills over to the teams involved (Jehn et al., 2013). Given that supply chain relationships are embedded within a network of relationships, this *spillover* or *contagion* process is worthy of further investigation; for example, it would be interesting to investigate conflict contagion across tiers of the supply chain over time.

Debate around conflict outcomes has been ongoing for decades in intra- and interorganizational conflict research. Results among studies have been inconsistent – sometimes positive, sometimes negative. Researchers have incorporated a variety of factors to try and unpack this paradox, including conflict types and conflict management strategies. However, a universal conclusion has not been achieved. De Wit et al. (2012) suggested that one way to further decode conflict outcomes is to distinguish between those that are distal and those that are proximal. Proximal outcomes refer to short-term effects – that is, emergent states, which include the cognitive, motivational, and affective states of individuals. Distal outcomes refer to long-term effects and include performance outcomes such as innovation, productivity, and effectiveness. Consequently, one way to advance theory on conflict outcomes is to conduct studies through a temporal lens and assess both the short- and long-term effects of different conflict types. This approach could better explain how conflict disrupts relationship function and how partners might overcome conflict to improve relationship performance.

Supply chain partners can exhibit perceptual differences with regard to a conflict situation. Recent organizational studies have touched upon this aspect under the theme of *conflict about conflict* to describe situations where there is a perceptual incongruity among team members about the conflict episode (De Wit et al., 2012). Two types of asymmetries might emerge: (1) *within-conflict types*, wherein partners do not share the same perception of the *intensity* of task (relationship) conflict and (2) *across-conflict types*, wherein partners perceive the *nature* of the conflict differently – one party perceives the conflict to be task-related and the other perceives it to be relationship-related.

Past studies of conflict in supply chain relationships have often ignored such notions of asymmetry and assumed that buyers and suppliers work together on a task as if they had similar perceptions. Consequently, we still do not know much about the *perceptual convergence/divergence* regarding conflict within supply chain relationships. This line of study is particularly significant because researchers have argued that perceptual conflict asymmetry predicts conflict outcomes (Ma et al., 2018). Empirical results have demonstrated that asymmetrical task conflict perceptions decrease both performance and the creativity of interacting employees (Jehn et al., 2010).

Consequently, to advance research in conflicts in supply chain relationships, a rich area for research is that of understanding the antecedents of conflict asymmetry, particularly the factors that amplify, attenuate, or obfuscate incongruence in conflict perceptions among exchange partners. The investigation of asymmetry is also important because its existence may drive inappropriate and/or inefficient conflict management processes; for example, if a supplier perceives a conflict as task-related, it will deploy tactics targeted at managing the task, but if the buyer perceives the same conflict as relationship-based, it may perceive the supplier's actions as inappropriate, exacerbating the situation and making dysfunctional outcomes more likely.

In addition to understanding the antecedents of asymmetry, further research could explore the specific impacts of asymmetries on conflict outcomes, particularly in the context of different conflict types; for example, is high task-conflict asymmetry more or less related to specific outcomes than high relationship-conflict asymmetry? Another fertile research direction would involve study of the impact of asymmetry on the features (including intensity and duration) and outcomes of conflict, using a magnitude–symmetry approach (Liu et al., 2012). The study of asymmetries in relation to time is another promising area, specifically, the timing of their emergence, as well as their dynamics over time.

We have highlighted a rich future research agenda for scholars on the topic of conflict in supply chain relationships. Broadly taken, this research agenda covers many aspects, exploring the nature and dimensions of key constructs (the "what"), actors (the "who"), contextual and environmental conditions (the "where"), temporal or change-related dimensions (the "when"), and process or dynamic development aspects (the "how"). Table 1 provides a comprehensive overview of the opportunities we have identified to advance our understanding of and insights into conflict in supply chain relationships. Pursuing these various questions in future research will help address the fundamental gaps identified and discussed in this chapter.

## 5 Managerial Implications

Conflict resolution represents a core obligation and responsibility for managers. Moreover, supply chain scholars have indicated that supply chain agents spend 1 in every 6 h of their time dealing with conflict (Bobot, 2011). Therefore, it is critical that managers understand how and under what conditions conflict can emerge, escalate, and be resolved.

This chapter is useful to managers, because it reveals the complexities inherent in conflict and the variety of challenges that need to be addressed when it arises within supply chain relationships. The identified themes can help practitioners develop a fuller understanding of the various dimensions of conflict, the relevant topics (and issues) for practice, and how they may be addressed. For instance, the theme of conflict asymmetry is particularly useful to managers in enabling them to comprehend the perspective of the other party in relation to a conflict situation and thus work to ensure mutual understanding. Being on the same page in this way helps managers to deal better with conflict by crafting resolution approaches that are tailored to the specifics of the situation.

Managers should understand that a conflict with a buyer or supplier is embedded in the bigger picture of the relationship, and that conflict dynamics, resolutions, and outcomes can involve factors beyond the dyadic relationship. Moreover, understanding the dynamics of conflict resolution should enable managers to avoid negative inflection points in the resolution process, to assuage the severity of conflict impact on buyers and suppliers, and to build long-lasting collaborative relationships. Managers should not only understand different resolution strategies and tactics but also appreciate how these strategies are likely to work across a wide variety of conflict situations of differing intensities.

Much is already known about conflict management in the supply chain as a result of the many studies conducted to date. Organizations and managers should find this resource valuable to them as they develop training programs and effective implementations of some of the research observations. Given different contextual situations, organizations may wish to experiment with a variety of considerations and strategies. The antecedents of conflict are also significant in that managers

**Table 1** A research agenda for conflict in supply chain relationships

| | What? | Who? | Where? | When? | How? |
|---|---|---|---|---|---|
| ***Key concepts*** | Dimensions and characteristics of different conflict types and levels<br>How to measure and operationalize conflict valence and asymmetries<br>Characteristics of different supply chain relationships<br>Nature and boundaries of interorganizational relationships (dyad, triad, network)<br>Characteristics and degree of conflict in goals/objectives between public and private actors, and their impact on conflict emergence and management | Individuals and teams: Job roles, personal and professional interests, cognitive orientation, experience, bargaining power<br>(Public and private) organizations as part of the relationship: size, contracting capabilities, relational capabilities, degrees of public- and privateness of the collaboration, parties' (lack of) prior experience; foreshadowing the future<br>Supply chains and networks (including size, nature, structure) | Contextual factors: Socioeconomic dimensions, informal institutions, political and legal institutions, environmental and market dynamism<br>Impact of specific political, environmental, or social events (e.g., BREXIT, pandemics) on conflicts in supply chain relationships<br>Impact of diverse forms of environmental uncertainty<br>Micro-foundational and entrepreneurial aspects of the collaboration | Temporal considerations: Timing of collaboration establishment, phases/lifecycle of the cooperation, contract management phases<br>Investigating conflict episodes (start, middle, end), and the differences between conflict types, as well as the impact of different resolution strategies<br>Differences between distal and proximal outcomes | Strategies and practices to minimize and address conflict in different types of supply chain relationships<br>Gaining benefits from conflicts in supply chain relationships<br>The role of relational and contractual governance mechanisms to suppress or manage conflicts<br>The role of different types of contracts (e.g., performance-based) on conflict emergence and resolution |
| ***Potential research questions*** | What are the differences in conflict valences between exchange partners?<br>How do parties react to mixed conflict valences (ambivalence)?<br>What are the factors that | How does managers' conflict valence weighting bias impact conflict outcomes at the buyer–supplier relationship level?<br>What are cross-level | What is the influence of critical events in the wider supply network or market on conflict in buyer–supplier relationships?<br>How do events at | How do different relationship phases influence different conflict types?<br>How does the relationship length (and/or prior experience) | How are relational and contractual governance mechanisms used in practice to suppress or manage conflicts in supply chain relationships? |

| | | | | | |
|---|---|---|---|---|---|
| | affect the impact and occurrence of asymmetries?<br>What are the antecedents of conflict asymmetries in supply chain relationships?<br>How do asymmetries impact conflict outcomes?<br>Do relationship and task conflicts act as substitutes or complements in a conflict episode, and what is the impact on performance?<br>What is the impact of different levels of conflict perception between public and private actors in a relationship?<br>What is the impact of contract framing (e.g., promotion vs. prevention) on conflict emergence and management?<br>How can (degrees of) collaboration increase/ decrease the emergence of different conflict types? | factors that impact conflict and conflict resolution?<br>What is the impact of dyadic conflict on different layers of the supply chain relationship?<br>How do different dimensions of supply chain relationships (e.g., shadow of the past/ future; product/service complexity) influence conflict emergence and resolution?<br>How do private/public employees' (individual actors such as managers, consultants, engineers, or lawyers) preferences in managing conflicts impact conflict resolution?<br>How does (degrees of) interpersonal and interorganizational conflict emerge?<br>How does the involvement of specific (public and private) actors in the wider | multiple levels and their timing over the conflict episode impact conflict dynamics?<br>How do characteristics of the specific environmental context, such as the legal system (e.g., maturity, enforceability) influence conflict emergence and resolution?<br>How do regulatory and normative features facilitate or hinder conflict emergence and resolution? | impact conflict management?<br>When are relationships more (or less) resilient to surviving different types and levels of conflicts?<br>When do conflict asymmetries occur and when do they matter between partnering organizations?<br>What are the dynamics of conflict asymmetries over time?<br>What are the temporal transitions of conflict valence patterns?<br>What are the patterns of conflict types over time?<br>What is the effectiveness of conflict resolution tactics over time?<br>What are the short- and long-term consequences of a conflict episode? | How do different types of contracts (e.g., performance-based) impact conflict emergence and resolution?<br>How can organizations coordinate and control activities and actions during a conflict episode?<br>How can conflicts in supply chain relationships be resolved fairly and justly, and which resolution strategies are most appropriate?<br>What is the impact of the conflict episode on the buyer–supplier relationship in terms of, for instance, information exchange and trust?<br>Does one (or multiple) conflict episode(s) lead to reduced information sharing between formerly trusting organizations?<br>Are idiosyncratic public, nonprofit, and private |

(continued)

**Table 1** (continued)

| | What? | Who? | Where? | When? | How? |
|---|---|---|---|---|---|
| | | supply network impact conflict emergence and resolution? | | | sector capabilities and resources complements or substitutes when resolving conflicts? |
| ***Possible theoretical lenses*** | Framing theory, information processing theory, regulatory focus theory | Information economics, attribution theory, real options theory, strategic choice theory, prospect theory, reputation and power dependency theory, self-determination theory, relational exchange, (extended) resource-based view, social network theory/analysis, stakeholder theory | Institutional theory, weak ties theory, complexity theory, complex adaptive systems | Dynamic capabilities, organizational learning theory/knowledge-based view | Justice theory, fairness theory, capabilities, (extended) resource-based view, resource orchestration theory |

should encourage enablers of effective management of conflict when it does arise and seek to eliminate its dysfunctional antecedents. The consequences and outcomes of supply chain conflicts – although by no means fully understood – do, nevertheless, provide insights into potential practical solutions for managing them.

## 6 Conclusion

Although we have learned much about conflict in supply chain relationships, its various antecedents and outcomes, and its management and resolution, there remains much that needs further exploration if we are to advance our understanding and gain new insights. In this chapter, we have proposed multiple research areas that will help advance conflict theory, particularly as it pertains to conflict types, their antecedents, their outcomes, and the process of their management and resolution. We suggest specific research questions and position a detailed agenda for further research efforts. We hope this chapter both motivates such research and informs business practice so as to augment our understanding and management of conflict in supply chain relationships.

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# Human Resource Management in Supply Chains

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## Contents



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**Abstract**

Human resources (HR) are a fundamental asset and vital resource in achieving organizational goals and objectives. Appropriate understanding of the workforce and their management and strategic decision-making to train and enhance them are important considerations for supply chain firms. Through examining international human resource management (IHRM), the chapter discusses the international nature of supply chain firms and how this has not only brought increased competition for talent but added complexities and cultural dimensions that need to be appropriately managed. Strategic human resource management (SHRM), workforce analytics, and various environmental forces – customer demands, complexity in global supply chains, and uncertainty from global pandemics – and their impact on HRM are also discussed. Digital transformation of the supply chain has also meant that HRM practices may be disrupted. The chapter covers these various issues and the challenges facing supply chain firms along with identifying key trends in HR practice. It also highlights key managerial concerns for the future of HR and how these may affect supply chain firms.

**Keywords**

Human resource management · Supply chain performance · HRD · IHRM · SHRM · Workforce analytics · HR trends

## 1 Introduction and Background

The complex mix of cross-cultural global forces, the Fourth Industrial Revolution, and growing digital transformation all have a great impact on the workforce. To weather these uncertainties, requires strong leadership, analytical thinking, and employee development (Ozkan-Ozen & Kazancoglu, 2021; Srinivasan et al., 2020). These forces, alongside an ever-demanding customer base, have an inevitably effect human resources (HR) and, with it, the overall success of supply chains.

Industry 4.0 (I4.0) has created opportunities to embed and adopt impactful technologies that not only streamline supply chain management but provide avenues to create greater impact across different stakeholders. A subsequent product of this is the need to develop the workforce accordingly through aspects of training and upskilling as well as to focus upon creating stable human resource activities for the future. Middle and senior managers increasingly find themselves managing and leading in a global marketplace fraught with complexity, where dimensions such as cross-cultural knowledge, change management, and the digital disruption require new skillsets.

Constant global marketplace uncertainties and ever-changing end-user demands require supply chains to be both reactive and proactive to these dynamics. Often this response requires quick shifts, agility, and flexibility not only in systems and processes, but in HR realignment (Butcher, 2007). This realignment has meant companies need to not only hire the best but also train and develop their employees for this dynamic environment.

Supply chains have also been altered as part of digitalization and similarly, with the shift away from brick-and-mortar stores, toward rapid growth in e-commerce platforms. New skills are required to continue to keep up with shifting customer demands. COVID-19 and the pandemic have only accelerated this trend, where heightened demands for online shopping and home deliveries have placed new pressures on supply chain firms (Butt, 2021).

People are an important parameter across all dimensions of the supply chain, and therefore appropriate resourcing and investment is needed to develop this vital resource. Where tangible equipment can be purchased and repurposed, the nature of the workforce as an intangible resource requires different forms of development, nurturing, and management to achieve the best from employees and leaders within the field of supply chain.

## 2 What Is Human Resource Management?

Human resource management (HRM) is aligned to a number of people management functions – hiring, training, performance management, and ultimately rewarding employees (Cascio, 2016). The gamut of functions reflects the ever-changing needs and complexity in organizations and the global marketplace. The study of HRM is focused upon strategic methods to effectively drive the workforce to achieve organizational objectives. Armstrong and Taylor (2016) defines HRM as a strategic and coherent approach toward the management of people working within an organization, in order for them, individually or collectively, to contribute to the achievement of planned objectives. HRM is also broadly defined as the coordination and utilization of labor toward the production of goods and services, where the workforce is viewed as one of the organization's most valued asset (Armstrong & Taylor, 2016).

Cultural considerations, developmental opportunities, and current innovations in HR analytics are all within the remit of HRM. HRM or HR is a function within organizations created to maximize employee performance with the overarching aim to meet strategic organizational goals (Armstrong & Taylor, 2016).

HRM has great potential in impacting organizational performance, where strategic decision-making aligned to the deep understanding of the workforce can create synergies that support the delivery of business objectives (Ozkan-Ozen & Kazancoglu, 2021). The global presence of supply chain firms and the complex links across its networks only further highlight the vital importance of employees as a resource and the inherent difficulties in managing such an intangible asset. HRM's focus is not only to support the organization's strategic initiatives but to align the workforce and motivate it accordingly (Gowen & Tallon, 2003). It is also focused on positioning talent in the right place and right time, across the different departments and locations.

## 3 Human Resources Management Historical Foundations

HRM emerged as a product of the human relations movement in the early twentieth century. Academic research emerged from this movement by examining the strategic management and value of staff and the workforce. Early examination into this area was dominated by a highly procedural and transactional aspect with bureaucratic dimensions such as payroll, staff leave, and benefits taking overarching precedence. Early employee specialists were known as personnel managers, focusing on these transactional activities, delivering compliance but with little greater understanding on how they fit into the large organizational dimension or its objectives. Rotich (2015) indicates four major stages in the development of the HR perspective.

- *Stage one (1900–1940s) – Welfare stage*
  Early understanding of staffing, more greatly focused on personnel functions. These were performed by supervisors, line managers, and early functional specialists. The profession of HR or HRM was non-existent with early notions focused on scientific management theories and behavioral sciences in the management of staff.

- *Stage two (1940s–mid-1970s) – Welfare and administration stage*
  Here greater understanding and the development of more professional approaches to HR started to develop. A focus upon staff welfare was utilized both to ensure staff well-being but similarly to attract, retain, and ensure continued workforce productivity. Deeper understanding of behavioral and management theories leads organizations to invest in employing specialists to undertake early HR functions of recruitment, training, and staff welfare (Rotich, 2015). Strengthening of unions and industrial relations with expansions into work and pay conditions (McIlroy, 2009). Overall, this was a period of growth, although these functions were often still conducted in silos and in isolation away from the wider organizational objectives.

- *Stage three (mid-1970s–late 1990s) – HRM and SHRM*
  This stage saw increasing understanding and refinement in HR focused theories, leading to the creation of sources of knowledge dissemination aligned to research in HRM. Personnel management functions were developed toward HRM practices with greater understanding and integration with organizational strategies. A major shift was the view that staff were no longer employees but rather a vital human resource. Here, HR were viewed as a vital and important asset to their organizations that required careful management of their future potential, aligned to, and integrated with organizational management strategies, leading to birth of strategic human resource management (SHRM) in 1984 (Kaufman, 2015). A more holistic view of the different personnel functions was achieved, delivering on new thinking on the people-related aspects of managers. Control, management, and monitor of staff was now within the hands of line

managers, creating new dimensions of performance-related systems and pay and reward structures along with flexibility in recruitment approaches.

- *Stage four (Beyond 2000) – The present and future of human resource management*
  Continued globalization and the transformation of HR practices leading toward fundamental changes of workforce management and planning in the future. Employment and workplace conditions along with the value placed on staff as an asset to the organization are likely to continue to expand where global shifts in demographics, economic stability, compensation systems, and wealth will play a role (da Silva et al., 2022; Sivathanu & Pillai, 2018). The highly intertwined nature of global economies would also impact and add complexity in the management of HR, regulations, and cultural perspectives, bringing into the fore international human resource management (IHRM). Growing demands for a HR architecture focused on value development and maximization of workforce talents could alter resourcing priorities, with the potential move toward greater outsourcing or devolution of HR functions such as through consultants.

The evolutionary nature of HR has altered this traditional dimension toward more strategic aspects such as talent management and succession planning, alongside contemporary issues such as sustainability, ethics, and employment relations. Similarly, as both workforce size and complexity has expanded, a greater focus on metrics and analytics emerged, as managers and strategic decision-makers look to capitalize and plan on how best to enhance their human capital. Staff well-being, agility, and expertise alongside with the push toward Industry 4.0 set the scene for an interesting future of HRM (Srinivasan et al., 2020; Hohenstein et al., 2014). This shift toward HRM away from personnel management provided more insightful knowledge of HR, enriching the value of the workforce and the philosophies of its management (see Table 1).

## 4 The Value of HRM in Supply Chain Management

HRM in supply chain management can provide value as an intangible measure that can contribute to competitive advantage a network of organizations. Hohenstein et al. (2014) and Sweeney (2013) cite the importance of human capital across the interorganizational logistical concerns and how communication and the relationships between people help facilitate both efficiency and effectiveness. Supply chain network links are bolstered by the strength of these relationships, social engagement, and employee belonging all contributing to a human-centric environment (Myers et al., 2004; Nahapiet & Ghoshal, 1998).

Sweeney (2013) contends that supply chains essentially reflect a “human chain” where people are charged with managing its operations and overall effectiveness. Employees and people across the network of firms are part of the framework and connections across the supply chain. Similarly, with growing complexity in logistics,

**Table 1** Differences between personnel and human resource management

| | Personnel management | Human resource management |
|---|---|---|
| Timescales and approach | Short-term focus, transactional and end-goal orientated | Long-term ideology, strategic alignment, and collaborative |
| Staff viewpoint | Mechanistic, low value, compliance based | Welfarist, value-added concerns, loyalty and commitment based |
| Ideology | Bureaucratic, formalized, directional, centralized and highly structured/ defined. Cost focused | Dynamic, inclusive, holistic, integrated. Human resources as an asset |

Adapted from Vardarlıer (2016), Lundy 1994 and Ahammad (2017)

supply chain personnel need more skills, new abilities, and expertise to function in the global marketplace (Akbari et al., 2022a). New demands on HR practices and workplace planning along with its management have placed more importance on HRM concepts. Managers in supply chain firms are moving away from solely operational oversight toward more strategic understanding and management of global networks (Sweeney, 2013; Ellinger & Ellinger, 2014).

Growing international demand for goods and services has resulted in additional pressures on supply chain firms to maintain operational activities (Akbari, 2018) while being able to recruit appropriately skilled labor (Akbari et al., 2017). There are concerns with a lack of available talent within no short-term solution to remedy this need. The perfect storm of increasing demand for talent alongside a limited pool of upcoming workforce to match the skilled needs of the marketplace has further highlighted the value of HRM in supply chains.

Geographical and demographic disparities are also concerns – with aging populations, there is likely to be considerable shortages in skilled labor (Wolff et al., 2009). The contrasting scenarios affect supply chain firms, where logistics and operations in a global network require organizations to control for these predicaments. Overall, the limited pool of talent is a result of labor market shortages, economic uncertainties, and the lack of sufficiently skilled individuals (Cottrill, 2010).

Realizing the full HR potential provides great opportunities and challenges to supply chain managers in the highly specialized and technical knowledge required for global supply chain firms (Sweeney, 2013; Ellinger & Ellinger, 2014). Similarly, engaging, motivating, and retaining talent ensure knowledge management and knowledge transfer that benefits supply chain firms. Supply chain firms gain efficiency and effectiveness from a skilled and motivated workforce – these workforce characteristics also improve employee retention and loyalty.

The international perspective of logistics today has given rise to "boundaryless" careers where skills are no longer limited by geography, but rather talent is acquired globally (Carr et al., 2005; Goffnett et al., 2012). This situation has led to both a struggle to retain and increasing competition to attract, where pay has led to labor movement. Likewise, with labor costs being an important factor in organizational profitability, geographical clustering of cheap labor and niche expertise have added further complexity to workforce hiring and management. HR provides a vital conduit to ensure elements of the supply chain and the scattered workforce are not only aligned to organizational goals but effectively operate as one "boundaryless" entity.

## 5 Human Resource Development

Another vital aspect of HR is focused upon training and development. Ellinger and Ellinger (2014) discuss the shortage of supply chain managers with suitable expertise and broad skills set to address the growing changes and demands of the role. Given the impetus of cost savings but yet the enhanced role and relationships between customers and suppliers that supply chain managers have, the relative lack of human resource development (HRD) is a future worry (Sweeney, 2013).

Likewise, Aguinis and Kraiger (2009) support the use of training to improve performance, overall profitability, effectiveness, productivity, and revenue per employee. Sweeney (2013) states that human interactions permeate and influence supply chain practices – HRD would naturally lend itself to performance enhancement and achievement of these business goals. Hamlin and Stewart (2011) identified key HRD objectives to:

- Enhance the individual and group effectiveness and overall range of functions
- Support the effectiveness and performance of the organization
- Foster, nurture, and enhance skills, expertise, and competencies
- Provide avenues for enhancing HR and individual growth

Akbari et al. (2022b) suggest that there is also value in HRD early in employee careers, providing authentic learning experiences related to supply chain management to better adopt and reflect the needs of organizations. HRD has both a short-term and longer-term focus to ensure appropriately skilled workforce for now and the future. Rana and Sharma (2019) view three functional areas where development opportunities should be focused upon for the benefit of supply chain:

- Personal development (competencies)
- Team development (collaboration)
- Organizational development (structure and processes)

Given the dilemmas in cross-functional collaboration, the unstructured, informal communication channels used by HRD can support better organizational alignment of the workforce and thus, help remove restrictive silos that may exist within supply chain networks.

Cottrill (2010) suggests that several key skills are required for HRD focus in supply chains:

- Higher-order problem-solving – technical acumen to deal with operational issues alongside analytical mindsets and critical thinking toward solutions and the wider context of their role
- Managing ambiguity – in a world of constant uncertainty, be able to utilize experiences, learning, and expertise to apply knowledge toward complex and individualized situations
- Multi-level communicator – ability to communicate and work across organizational units (horizontally and vertically) and a network of firms with equally diverse business entities
- World citizen – manage, relate, and understand the multiple contexts, nations, and cultures that supply chain teams and firms span

## 6 International Human Resource Management

The global nature of supply chain firms aligns with the theoretical considerations of IHRM where a set of defined activities, functions, and processes are focused on facilitating and effecting the workforce operating in international organizations (Taylor et al., 1996). A similar definition by Schuler et al. (2002) considers the specific nature of multi-national enterprises (MNEs) where IHRM functions in the worldwide management of HR to ensure business success globally. Likewise, globalization has created a highly networked and interlinked international marketplace of manufacturers, retailers, and customers, where industries no longer solely focus on regional marketplaces, but essentially have widened their sourcing and targeted end users. The nature of business today is focused on internationalization and through the global procurement of materials and supplies has transformed how supply chain firms operate. This situation creates opportunity, but in an increasingly global marketplace, the challenges aligned to workforce management have followed suit. Here, IHRM's remit extends not only to the deeper understanding and needs of the business but also the globalized nature of the workforce and its inherent diversity.

Briscoe et al. (2009) examine this situation, by considering the multiple stakeholders alongside internal and external contexts that IHRM can impact as part of its global perspective. Supply chain firms, the network of organizations, and the varied workforce across its chain of activities and processes indicate complexity as well as multifaceted dimensions in managing the workforce. These notions are not lost in IHRM where multiple dimensions affect and have an impact upon workforce effectiveness.

González-Loureiro et al. (2014: p699), for instance, position "context, culture and institutions" as a vital IHRM focus, where there exist convergent and divergent patterns of practice. Here IHRM is focused on finding equilibrium and an appropriate balance between standardization of organizational practices while still retaining the local context. Ensuring both contexts co-exist provides a balanced approach to organizational operations, facilitates deeper understanding and harmony of the workforce, and breaks barriers, ultimately bridging geographical differences toward developing beneficial synergies.

Inevitably culture barriers and conflicts exist both in the differences due to geography but also due to varying stakeholders and institutions within the chain. The different approaches and cultural permutations that are unique to each provide interesting dimensions but also increase the chances of conflict. Thus, workforce management and getting the best out of the different institutions that form part of the supply chain are difficult and often a minefield, with many potential unintended consequences. As such through effective IHRM, the broader contexts which supply chain firms operate within are considered, managed, and where possible allowed to flourish to the benefit of the organizations.

## 7 Strategic HRM

While the various functions of HRM focus a range of activities aligned to the workforce, strategic human resource management (SHRM) involves wider understanding of the future needs of the business. SHRM seeks to develop or implement HR approaches to support long-term organizational goals. As such, SHRM plays a vital role in supporting the strategic decisions of organizations, seeking to mobilize, hire, or develop the current workforce and labor practices in its own strategic manner to contribute to these business objectives.

Wright and McMahan (1992) view SHRM as a pattern of planned workforce deployments to enable an organization to achieve its goals. This perspective is aligned to the view that the pattern of movement of HR is not constant, but rather reflects dynamism and change that develops over time into steady states that supports the achievement of the organization’s strategic aims.

González-Loureiro et al. (2014) suggest that SHRM is equally aligned to IHRM. Globalization, the impact of international events on strategic decision-making, and the global positions of talented individuals support joint SHRM and IHRM consideration. For SHRM to be successful in attracting and retaining the most talented employees, supply chain firms need to be ready to actively compete at international levels and cope with the challenge of talent management. Overcoming competitors and being able to manage the global challenges of IHRM will support the development of strategic capabilities within the organization.

Lepak and Shaw’s (2008) literature review of SHRM in North America reflects these issues, where SHRM can be examined from a macro-level perspective aligned to a business unit or firm. Similarly, and in accord with supply chain firms, SHRM views HR as an interdependent system of practices and pattern of activities where different aspects of the business are associated and linked together. Here, the different parties as well as patterns of HR practice are both associated in strategic movements and equally impacted by environmental forces, where strategic decision-making encompasses the different parties and dimensions that affect organizational success. SHRM seeks to facilitate performance outcomes, impacting the practices and interdependent units toward positive achievements.

Given the vital importance of HR in firms, strong strategic alignment between HR practices and business goals ensures not only sufficient critical mass in the workforce today but also for the future. SHRM is particularly dominant in large global firms and MNEs, where a scattered workforce requires appropriate management and development and where growth strategies are aligned with the need to recruit talent (De Cieri & Dowling, 2006). These are similar factors affecting supply chain firms, where the scattered nature of organizations and employees across the network need not only operational alignment, but strategic oversight to ensure efficiency and effectiveness and that the HR function is successfully embedded.

The term alignment is often used with SHRM and the strategic decisions of the organization. The closer and more aptly attuned both are, the more likely organizational goals are achieved. A sufficiently motivated and critical workforce mass for now and the future provides both opportunities and resources strategic organizational success. SHRM and strategic organizational goals alignment also supports agility and flexibility, allowing the organization to pivot and change quickly, as well as anticipate and respond to customer demands. These aspects are similarly true in supply chain firms. In particular, benefits of SHRM include (SHRM, 2022):

- Addressing key issues in a timely manner to avoid crises
- Promoting employee productivity and overall organizational success
- Providing a sense of direction to positively affect how work gets done
- Keeping employees focused on organizational goals
- Providing a strategic focus to guide training and development initiatives
- Giving leaders tools to help focus and implement their strategic initiatives

In order to ensure organizational success, there is a need to have definitive understanding of the current capacities and future growth of the workforce to ensure critical mass of qualified employees. Recruiting, training, and developing effective HR require extensive strategic planning and foresight. These strategic planning processes need to assess current organizational situations and then create a vision of a future state, with clarity and robust metrics to monitor its successful transitions. A SHRM organizational structure begins with four critical questions that assess the current and future desired HR position and then identifying the best approach to achieve this (SHRM, 2022):

- Where are we now? (Assess the current situation.)
- Where do we want to be? (Envision and articulate a desired future.)
- How do we get there? (Formulate and implement a strategy and strategic objectives.)
- How will we know if we are on track toward our intended destination? (Establish a mechanism to evaluate progress.)

The greatest mistake by firms is in not sufficiently understanding difficulties in future workforce planning, underestimating the resourcing needs of the process, cross-cultural dimensions, and understanding organizational requirements to be effective for the future (Vance & Paik, 2015). Strategic planning requires understanding of an organization's vision including how to manage the global nature of supply chain firms, the diversity of its workforce, and the often-transient nature of employees. Global events such as the COVID-19 pandemic, geo-political tensions, and the uncertain nature of economic factors have had a major impact on strategic decision-making and with it the movement of people, labor markets, and socio-demographic changes of the workplace.

To address these uncertainties and to navigate past these numerous hurdles, the Society for HRM (2022) indicates that a result-oriented focus, broadly considering different metrics and assessments, can aid in:

- Correctly assessing staffing and skills needs for now and the future
- Ensuring competitive pay and reward structures
- Performance management and rewards that continue to drive motivation
- Understanding competitors approaches to recruitment and HR
- Developing regulations, training, and practices that uphold and support the organization's values

SHRM remains a great challenge as well as an opportunity for businesses. Given the complex nature of supply chain firms and their multidimensional geographical operations, effective SHRM has the potential to strengthen strategic decision-making and create synergies across HR functions for the benefit for all stakeholders within the network. Its alignment to organizational strategic decision-making provides avenues for long-term proactive planning, which, given the increasingly turbulent external environment, will assist in ensuring the achievement of business goals.

## 8 Electronic Human Resources Management and Human Resources Metrics

Early definitions of e-HRM or electronic-HRM identify the use of web technology in the implementation of HRM strategies, approaches, and regulations within organizations, networking two or more individuals in the performance of HR-focused activities (Marler & Fisher, 2013). These basic notions of e-HRM are technological aspects merged with people management or of the HR function within organizations. They provided a simple but forward-looking trend of information management applied to the workforce (Marler & Fisher, 2013). These early definitions and approaches have led toward more advance analytical tools which not only visualize but can help provide predictions of the workforce.

E-HRM provides opportunities to support the increasingly complex landscape of workforce management and development. The approach provides useful computerized tools for supply chain managers to not only manage but plan and identify long-term needs in staffing.

Analytical tools and dashboards allow managers to examine the landscape of their workforce, visualizing demographic datasets as well as identifying capacity requirements and training needs to effectively forecast for the future. Succession planning, an aging workforce, recruitment metrics, and training resources provide additional datasets and information sources to make informed decisions. Nonetheless, with all these extensions to HR practices, workforce challenges are still one of the major challenges in the implementation of I4.0.

In addition to e-HRM, the terms HR metrics and workforce analytics have been used to describe the advances in HR and the adoption of technological tools to support staffing decisions. Huselid (2018: p680) defines workforce analytics as the processes involved with “understanding, quantifying, managing, and improving the role of talent in the execution of strategy and the creation of value.” Huselid (2018) also suggests that the term in this case is not to focus only on metrics but rather analytics where deeper understanding of how best to manage and improve functions that are critical for business success are undertaken.

Rana and Sharma (2019) view workforce analytics as a form of Smart Human Resources 4.0 (SHR4.0), highlighting several benefits in its use. Not only do the approaches help streamline and create more efficient HR processes but it enables futureproofing of talent. They indicate that the main benefits of SHR4.0 are in:

- Drawing, developing, and retaining new age talent
- Efficient and quicker HR operations
- Leaner HR departments

As the network of supply chain firms grows and with the increasingly complexities and demands of the marketplace, the HR dimension is overwhelmed with significantly larger volumes of data. The range of HR policies, across a global workforce and the increasing number of organizations, mean that supply chain firms are often drowned in paperwork and data. There is a vital need to turn these data sources into valuable forms of information, where strategic, operational, and forward-looking decisions can be made effectively.

Expanding these concerns across different links within supply chain firms provides specific targeted data as well as more holistic understanding of the entire chain. Such information allows informed decision-making through real-time data sharing, aligning strategic initiatives with workforce planning.

Expansions, mergers, and acquisitions or reacting to changes in the marketplace can each be undertaken in a more agile manner through e-HRM and HR analytics. Staff deployment and shortfalls are more effectively managed and their performance better charted, monitored, and understood. The quality of information is vital in making robust and impactful decisions for the workforce and organizational strategy (Marler & Fisher, 2013). Here the various transactions of supply chain firms and their workforce are not only mapped but charted to provide meaningful data to steer, provide progress reports, and even accelerate successful initiatives. The value of human capital is effectively monitored and maximized.

HR analytics are forward looking, utilizing previously collected data to help forecast and support future decisions, driving organizational strategies and objectives in a performance-based manner aligned with staff career orientation (Huselid, 2018). The nature of HR is intangible, and this resource is often hard to fill; forward-looking plans provide strong avenues to ensuring business success. The value of interventions can also be measured and identified using HR analytics. It can help identify causes of workforce deficiencies as well as how well investment in training and development supports employee performance.

Real-time mapping and monitoring of employee performance provide a multi-faceted, data-driven approach to people management and interventions (Edwards & Edwards, 2019). Similarly, deeper understanding of demographics and workforce segments also provides avenues to develop specific and targeted initiatives that can help enhance their performance. These deeper insights into employee motivations and drivers can help shape training, rewards, and approaches to retention across the supply chain.

Career trajectory, age, and years of experience or seniority (Edwards & Edwards, 2019) can each be monitored with employees deployed in different guises across the supply chain. Here, a senior mentor or a young energetic employee placed in the most appropriate organizational setting can be supported to develop and rewarded accordingly with each success. Indeed, these differences similarly exist in the different firms within the supply chain which can also be addressed in a positive manner, affording targeted interventions that are not only appropriate but impactful.

These many datasets and deeper understanding of the workforce through HR analytics allow greater strategic oversight and a more informed understanding of SHRM opportunities (Edwards & Edwards, 2019; Marler & Fisher, 2013). Given the expansive nature of supply chain firms, HR analytics provides a scientific and evidence-based approach to ensuring the diverse workforce is appropriately managed.

## 9 Current Issues and Challenges in Human Resource Management in Supply Chains

There are also several major challenges facing HRM in supply chains, namely, in the form of change and performance management, the global competition for talent, and the inherent difficulties in recruitment and retention. Addressing these issues effectively is necessary for long-term success of this integration.

### 9.1 Change Management

The changing demands of the consumer market and supply chain have added new pressures on supply chain firms with aspects of last mile delivery, online shopping, and shorter lag and delivery times. This has meant that HR dimensions such as training and skills development, which are very costly, have not always been at the forefront of logistical considerations. There is a need to do more with less with a similar ideology applied to staffing and the workforce – requiring a change in thought and practice. While automation and technology are vital for these new demands, Machado et al. (2019) highlight the often lack of readiness, robust training, or dissemination of knowledge.

Similarly, with technology there is also a vital need for knowledge management and information dissemination – to aid in change management of organizations in the supply chain. How can these information sets be utilized and applied within an international setting or within a network of supply chain firms? The notion of IHRM and how the knowledge can be shared, passed, and spread across the workforce is a major challenge facing supply chain firms. With larger and more complex networks, how to embed as well as disseminate knowledge across the various departments, firms, and staff is a growing concern for HRM. Indeed, Collins et al. (2010) suggest that the ability to create systems and approaches where knowledge management and supply chains align and intersect with HRM practices, would create significant synergies and competitive advantage as part of a highly integrated workforce.

Change is inevitable within supply chains. While systems, infrastructure, and investments in tangible assets can be altered, change management approaches need to be more carefully and appropriately managed in the workforce. Aspects of culture, organizational dynamics, and management styles are less straightforward to alter. In an industry of constant change, change can be hard to manifest in the workforce, requiring active understanding and planning along with the multidimensional aspects of staffing. Here IHRM supporting the cultural and the multifaceted dimensions of the workforce as well as longer-term planning through SHRM is needed to deal with such challenges.

## 9.2 Performance Management of HR

Performance management remains an important and difficult process in organizations, let alone supply chain firms. Identifying the appropriate measurements and tools in the management of people is not an easy task – especially given the many tangible and intangible measures that exist. Appropriate use of intangible resources – not just tangible ones – are more likely to yield a competitive advantage (Hitt et al., 2001).

With increasing complexity and diversity in the workforce along with the cultural and international dimensions of IHRM, supply chain managers need to be able to motivate and deliver actionable outcomes. HRM needs to set suitable foundations for appropriate metrics to be achieved by employees, with appropriate rewards and penalties. That being said, international variations and different cultures within the supply chain may not support uniform approaches but rather result in various tiers of HR policies.

White (2010) suggests instances where overmanagement or micro-managing hinders highly talented people or teams. This type of management would hinder employee performance rather than foster innovative solutions and performance endeavors. This is the quandary faced by supply chain managers and by HR departments, where traditional notions of quality and performance are appropriate for transaction and repetitive tasks, but less so for processes that involve innovation and problem-solving. Yet, highly skilled individuals – emblematic of many supply chain workers – do not align to such metrics. While there are inherent benefits across the supply chain such as sharing of best practice, cross fertilization of values and knowledge and working practices, performance management attuned to traditional frameworks of excellence, and key performance indicators can be restrictive. The challenge for HR managers and supply chain firms is to find a balance in autonomy and empowerment while still being able to manage and achieve the strategic desires of the organization.

### 9.3 Global and Cross-Cultural Competition for Employees

Global supply chain firms and their international operations often compete for the same global talent pool. In order to have the best employees, they do not limit their recruitment and selection processes to a regional pool, but rather focus on hiring the best and brightest globally. As a product of this and given increasing demands and pressures on supply chains, there has been fierce competition between firms in a talent selection pool that is decreasing in size and options. As such, increasingly HRM plays a vital aspect in business operations. This competition is likewise heightened when focusing upon specialist roles where high-potential employees are in short supply. Chambers et al. (1998) view this as the *war for talents*.

Similarly, managerial abilities and technical expertise alone no longer suffice with recruitment and retention along with globalized skills increasingly asked of managers. These skills are even more important when viewed from a middle to senior management perspective. Reflecting the dynamics of global supply chains, senior employees are required to have a widened understanding of operations, culture, and their workers in order to effectively compete and manage in an increasingly diverse world. Harvey et al. (2013) suggest that the need to manage and understand global interorganizational relationships, requires supply chain managers to have deeper awareness of international marketplaces and with it a multi-faceted mindset. Harvey and Richey (2001) highlight the importance of global orientation, where deeper understanding of cultural differences and diversity, along with respect, are required knowledge sets for supply chain managers. Open-mindedness is a vital and important element for the benefit of the global operations. Given how these skills and traits promote compatibility and better working relationships, it is important that managers either have or are trained to have better understanding of how best to build bridges rather than become hurdles themselves (Fawcett et al., 2008).

Hiring managers with the knowledge and deep understanding of these multiple dimensions adds difficulties to an already limited talent pool. This further reflects the difficulties and restrictive recruitment patterns that exist in supply chain firms at all levels of the workforce. Given the many arguments on the value of HR on the overall performance and successes of the firm, the lack of available expertise alongside the increasingly complex international patterns of work practice suggests a growing concern in the area of logistics and supply chains.

### 9.4 Recruitment and Retention

Globally, firms are increasingly considering multiple avenues to recruit given the highly competitive environment in talent recruitment. The nature of global supply chain firms means that this competition is not only enhanced but retention of their best and brightest talent is also of great concern. Ultimately, the aim of any recruiter is to identify the largest pool of appropriately qualified and experienced employees that possess all skills, knowledge, and acumen required to perform the role well (Hohenstein et al., 2014).

Unfortunately, the pool of talent in supply chains is not only limited, but the niche expertise of certain roles mean that many companies are often seeking to hire from a small pool of potential employees. This has led to recruitment packages and compensation that include a multitude of incentives, to entice, retain, and also display the value of their worth. The global marketplace also adds further complexity, with remuneration packages being adapted to match the local or international parameters of the role. Aligned to employee retention and loyalty is the aspect of incentivization, where performance is recognized and appropriately rewarded and other aspects of the employee lifestyle – such as work-life balance and non-financial benefits – are applied. The difficulty for HR managers and supply chain firms is creating clear targets while balancing rewards structures where "internal and system-wide performance metrics used for managing supply chain performance would need to be identified and associated with specific offices or roles" and indeed at different levels (Menon, 2012: p783).

## 10 Emergent Concerns and Future Directions

A number of prevalent HR trends (see Fig. 1) can have either a positive or negative impact on the performance of the workforce and on organizational success in the short- and long-term future. In particular, the changing trends in the world of work and ways of working along with technological shifts have an impact on the future directions of people management in supply chains.

### 10.1 Workforce Transformation and Analytics

Workforce transformation and analytics is a growing concern. The ever-changing external environment which supply chain firms operate within requires an agile workforce that is constantly being developed to fit changing demands. Workforce transformation takes the guise of training and development, along with sufficient upskilling to *futureproofing* employees across the supply chain.

Transformation in the form of ensuring sufficient knowledge and the appropriate upgrading of workplace tools are vital to enable the workforce to deal with highly disruptive environments. For example, Eaton et al. (2021) highlight – as part of the

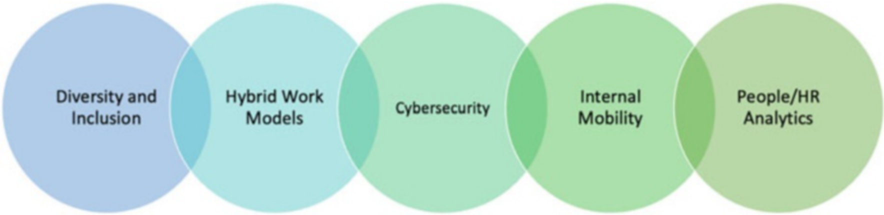


**Fig. 1** HR trends for the future

digital revolution and as a product of the impact of COVID-19 – competencies and capabilities in the digital and virtual sphere are part of the reimagined workplace. Being able to upskill employees and transform the workplace not only limits lost productivity but facilitates seamless transitions into different modes of working – offline, online, and hybrid.

The future workforce is influenced by transformational ideologies. Stepwise improvements can help build on basic knowledge toward expansion of expertise to ultimately staff taking a leading role in the new workplace. COVID-19 pandemic's push toward new ways of working toward a new normal is indicative of the need for workforce transformation. For supply chain employees and managers, the pandemic has brought about change toward a *new normal* (Akbari et al., 2022a). Adaptability, resilience, and a *creator's mindset* where employees have the agency to shape the organization are also skills necessary in this new environment (Eaton et al., 2021). Any organization that can transition their workforce to deal with adversity and then set about delivering new approaches to the workplace successfully can benefit supply chain performance and competitive advantage.

The market for talented individuals is becoming much more efficient. The workforce is becoming more expensive, easily lost to competitors, with the ability to recover from movements in staff becoming more difficult. Workforce quality as a differentiator, while valuable, is becoming much more difficult to maintain. Workforce quality requires HR strategies, investment, and managerial knowledge to recruit and retain employees for the future. This situation has meant that supply chain managers are facing increasing pressures and accountability upon them as their role in the management of staff toward organization strategies (Collins et al., 2010).

This situation has also meant investment in middle to senior level managers in the form of training, stakeholder, and change management approaches, along with HRM, to become more agile, efficient, and effective in talent management. There needs to be greater understanding of the subsequent results of the actions of supply chain managers, especially given the globalized purview (González-Loureiro et al., 2014). Human activities are the main compound that helps promote or hinder changes in organizations (Bui et al., 2020); therefore in order for technological implementations to be successful, HR needs to be supported to achieve operational excellence and deliver workforce transformation practices to suit the needs of the business.

## 10.2 Diversity and Inclusivity

A key future HR focus is an inclusive workforce recognizing diversity, equality, and equity as a vital for ensuring the brightest talent is recruited and retained (da Silva et al., 2022). HR is also responsible for developing strategies that help support these goals. Gupta et al. (2022) suggest that while much has been done to ensure equity and diversity, significantly more work and understanding is required. Gender inequality and wage disparities, harassment, ageism, and discrimination in the workplace further suggest that there are still avenues for improvement (Barrientos et al., 2019; Gupta et al., 2022). Supply chain firms with the amount of diversity they exhibit with their global presence will need to abide by the legal frameworks in the countries that they operate in, but similarly have an opportunity to go further. These issues are barely addressed within a supply chain context.

A diverse workforce brings with it new knowledge and creativity, where differences are not only celebrated but where their specific characteristics can become a strength (Carrero et al., 2019). Different approaches to problem-solving, the sharing of wisdom, and the knowledge that comes with such experiences are a vital asset for the complex world that supply chain firms operate within.

## 10.3 Hybrid Work

The global pandemic has forced almost all organizations to look at new approaches to work practices. The shift to virtual online approaches in the workplace and work practices has accelerated the digital transformation. Appropriate resourcing and training of staff often lagged behind investments in digital infrastructure.

Haleem et al. (2020) highlight the mental toil and stresses that the workforce underwent during the lockdown periods of COVID-19 and the uncertain nature of global, regional, and local travel restrictions. Alonso et al. (2021) discuss how improvisation, bricolage, and the appropriate mindset were part of the drive toward organizational survival in such unprecedented difficulties. While the world is emerging from these difficulties, a positive outcome has been greater engagement with the notion of hybrid and remote working arrangements (Deloitte, 2021).

The complementary approaches of offline and online – hybrid – mediums of staff work and human-automation mix have changed the way organizations function. Supply chain firms and partnerships are not immune to these changes and, similarly, have embraced such approaches. Virtual meetings across continents and time zones, and reducing cost implications while still ensuring productivity, are seen as issues and goals. Hybrid work patterns have also allowed staff to have better work-life balances, performing well at work while still being able to complete their personal or home-life obligations. Similarly, investments in infrastructure toward automation of non-human-dependent tasks have also helped ensure safety and well-being while still protecting the jobs of employees (Korinek and Stiglitz, 2021). The question is whether face-to-face meetings across organizations in the future will be online or otherwise.

In essence – and aligned to employee well-being – these hybrid workplace changes have provided an additional option for supply chain managers to support their staff and free up wasted time (often due to commuting) while still ensuring a chain of command and monitoring that continues to develop on organizational objectives. Nonetheless, Korinek and Stiglitz (2021) suggest that while automation and technology may reduce the reliance on labor, real benefit exists through the human element of interactions, where post-pandemic ideologies of technology should seek to complement rather than exacerbate the fear of being made redundant.

## 10.4 Cybersecurity

With I4.0 and the digital transformation of people analytics and HR metrics, there is also a need to ensure appropriate awareness of cybersecurity, privacy, and confidentiality. Increasingly, there are negative forces seeking to profit from lapses in digital security, and with HR departments retaining much sensitive and private information, protective measures are required.

Indeed, Kache and Seuring (2017) indicate that companies only have limited or fragmented understanding of the true concerns around data security. Cybersecurity training along with awareness of digital vulnerabilities will need to be undertaken not only with the workforce but with senior managers to ensure that appropriate safety measures are put in place and adhered to (Mullet et al., 2021). Mullet et al. (2021) suggest that employee awareness is a priority for HR as staff are often the root of successful cyberattacks, due to a lack of knowledge, negligence, malicious behavior, or process failures. They also advocate that HR departments themselves need to address cybersecurity concerns and their own awareness as they are often the main conduit for employees in the organization.

## 10.5 Staff Mobility

The strain of recruitment has led organizations to consider more creative solutions toward staffing. Not only are a growing number of firms investing in appropriate training and upskilling of staff members, but they are also similarly examining the opportunity for different forms of staff mobility (Roy et al., 2019; Deloitte, 2021). Mobility is aligned to several common facets (see Fig. 2) such as a desire for talent development or the need to create a line of succession for longer-term organizational stability. Once utilized as a form of staff development or to enhance motivation, increasingly, internal mobility or job rotation and transfers of staff have been undertaken as a means to fill gaps in knowledge and expertise across organizational units or levels (Mahato et al., 2021). The internal transfer also allows for the sharing of best practice alongside different forms of management to the benefit of the organization as a whole.

The opportunity to gain new knowledge and attempt differentiated work and avenues toward promotion has also enhanced staff morale, retention, collaboration,

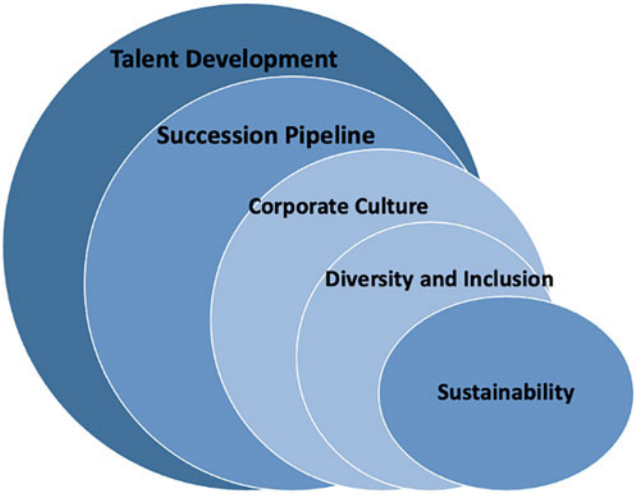


**Fig. 2** Main reasons for staff mobility

and performance (Roy et al., 2019; Deloitte, 2021). The protection of both critical sectors of work through appropriate staff redeployment and active retention of key talent within the organization, during increasingly competitive environment of recruitment, has meant that internal mobility is not only a current trend but will be one for the short- and medium-term future of HR.

## 11 Managerial Implications

Ultimately, these changing dimensions together with growing uncertainty in the global economies have meant that managers increasingly require a strategic human resource focus and wider understanding of workforce implications. The digital transformation, shrinking of the talent pool, and changes in the workforce demographics add more complexity in managerial decision-making.

### 11.1 Leading During the Digital Transformation

Co-evolution in multi-national corporations (MNCs) (Madhok & Liu, 2006) suggests that the different firms within a supply chain form a network of valuable entities, where talent within each of organization has the potential to affect the entire supply chain. Therefore, supply chain entities have the potential to affect processes, culture, and context of the entire supply chain positively or negatively. Indeed, the institutional approach within the country of origin and its destinations can have a significant impact on its success. Managerially, these issues suggest that effective management and deeper cultural understanding of the institution and its origins may provide a means to effect other aspects of the supply chain. There needs to be a phased approach to workforce transformation for a digital world, with a myriad of different approaches and factors that position the human at the center of these changes (see Fig. 3).

In line with culture and organizational paradigms, supply chain managers will need to take heed of these changes and the potential opportunities and ramifications that emerge or impact the workforce, where people-driven technologies, digital leadership, and futureproofing skills (Catlin et al., 2017; Deloitte, 2017) are vital considerations. Motivational incentives and approaches to HRM will need to be considered against the diverse demands of the workforce, where clashes and differences exist not only through culture but against different levels, units, and stakeholders within the supply chain.

While I4.0 progresses, changing in infrastructure, technology, and innovation need to be matched with developments and expertise in the workforce. There is still much unknown about the future implementation of I4.0 technologies. The range of technologies – including augmented reality, Internet of Things, robotics, blockchain, and multiple others (Akbari & Hopkins, 2022) – suggest that there is still much skilling required in the modern workforce; these technological characteristics cover multiple firms in a supply chain. The digital disruption provides opportunity but similarly uncertainty, where systems thinking is important against the dynamic structure of I4.0. Staff are often fearful of their role or lack of it as technologies become more permeated. Aligned with the turbulent nature of the marketplace, stakeholders, and the environment which supply chain firms operate, workforce agility and a resilient mindset are particularly important.

Adobor and McMullen (2018) highlight the importance of instilling an employee mindset focused upon embracing change, growth, adaptability, and resilience. How can middle and senior supply chain managers instill these intangibles but highly valuable traits to their highly disparate and global workforce? The investment in training and workforce technologies has sought to address this issue. There is also a

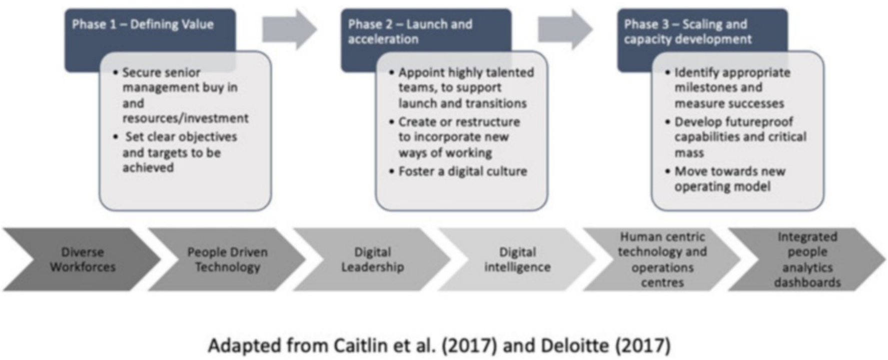


**Fig. 3** Digital transformation of the workforce

growing focus on staff well-being with a community of practice and employee-centered policies. Under the global pandemic, welfare support and virtual social and networking events facilitated social interactions to bolster a sense of community and display genuine organization care for their staff.

Digital transformation means closer relationships through different mediums of communication, human contact, and engagement are still vital in managing, motivating, and synergizing the workforce, particularly informal mechanisms, which facilitate exchanges such as in negotiations.

## 11.2 Strain on Workforce Supply

Even with the numerous remedies and approaches being put in place, the shortage of talent will continue to affect supply chains. A shortage of qualified professionals along with the lag time in training new staff (Horváth & Szabó 2019) will mean that supply chain firms will continue to suffer what we call a talent shortage *tsunami* (Cottrill, 2010; Ellinger & Ellinger, 2014). Even with a pipeline of young and driven employees, the evolutionary nature of the supply chain and its constantly advancing demands upon a set of skills and competencies add to these difficulties. The globe-spanning perspective, knowledge set, and wide-ranging expertise required of supply chain professionals highlight the importance of HRM, in both its international and strategic value.

## 11.3 Accountability and Deeper Understanding of the Role of Talent

The workforce is critical for firm success of firms. Fuller et al. (2019) suggest that this notion is not always universally shared nor are activities to recognize this situation fully developed or aware. While SHRM provides a holistic perspective of HRM, the wider understanding of how one firm supports another in the chain is not always clear to line managers. As such, there needs to be more expansive training and clearer understanding of the role of talent in driving and achieving business processes and objectives.

The diverse skillset of supply chain employees needs to be matched with appropriate line management expertise. HR analytics and metrics provide data and potential sources of information; thus appropriate training and understanding of complex points of information is vital for managers and organizations to make informed decisions (Ozkan-Ozen & Kazancoglu, 2021). Managers need to identify useful data and similarly the right questions concerning data and information needs across the supply chain.

Huselid (2018) indicate that generic analytics and datasets are unlikely to afford strong insight or any value in developing the workforce as a source of competitive advantage. Huselid (2018) also suggests that with increasing demands, and increasing rewards, managers need to be held accountable to their direct reports and the talent that they oversee. The workforce is often one of the largest costs and financial outgoing, where mismanagement and faulty decision-making have greater ramifications upon the organization's bottom line and success. Additionally, upskilling managers for the future is challenging. Senior managers have not only been developing their skills for many years but similarly through professional training, work experience, and performance evaluation opportunities. It is rare to see truly low performers at this level where enhancements are likely to lead to only minimum percentage gains in their individual performance. There are challenges to identify suitable training for further development. Therefore, investment in different levels of the organization and across firms in the supply chain will need to identify where the most impact on performance can be had through enhancing their workforce skills.

### 11.4 A Multi-Generational Workforce

In industries that require both technical expertise and experience, a multi-generational workforce is vital in creating a mix of talent that encompasses these two distinct needs. A multi-generational workforce provides a safety net where more experience and senior staff would mentor or coach junior or younger employees.

The transfer of knowledge and sharing of best practice, along with detailed insights into workplace operations, ensures a competitive advantage. Likewise, organizations that embed such dimensions in their workforce benefit from the innovation and creativity that is emergent from more junior colleagues who may not be stuck in operational paradigms, although they will need to support their employees' adaptation or re-adaptation (Matt et al., 2020). The notion that new energy, thinking and innovation is supported through the wisdom of previous and multi-generational knowledge. In supply chains where technical know-how and operational real-world knowledge intersect, a multi-generational workforce provides a strong bridge between these two needs.

## 12 Summary and Conclusion

It is clear that staff, personnel, employees, and the workforce, no matter which term is being utilized, are an important and vital resource for successful and competitive organizations. Supply chain firms are no different – but the relationships among the chain of firms must be aware of the various HR concerns both within and external to their organizations.

With global networks and span of organizational units across the chain, even more priority and value are to be placed upon the workforce. The need for this deep strategic oversight and operationalization over continents brings prominence to

SHRM and IHRM. If the workforce is a vital asset, then it needs to be mobilized appropriately to match the goals of the business, developing a strategic perspective and plan for how staffing and the workforce can be recruited, trained, or retained to achieve these. IHRM provides a global perspective, examining the cultural dimensions and the cross-cultural hurdles that can impact the global operations of supply chain firms.

The challenges of digital transformation and I4.0 provide both opportunity and risk where the demanded skills of the workforce require constant upskilling along with a digital mindset. The increasing use of HR metrics and analytics, which utilises technology to support HRM decision-making, planning, and strategies for the short- and long-term future, has an enormous potential to assist supply chain managers accordingly.

Yet while people are a strength, by their very nature, their management, development, and motivations are complex and difficult to fully manage. Huselid (2018) suggests that impact of talent on business success is "both longitudinal and multivariate" where long-term ideologies, plans, and considerations on the workforce will take time to fully realize their full potential.

HRM and the management of the workforce are not linear but rather multidimensional, with culture, demographics, geography, and a multitude of other variables at work. This complexity is similarly a part of the beauty of people, spurring innovation, agility, and adaptability. These are all powerful and vital traits within the workforce of the future. Given the upcoming challenges that are yet to be seen or identified by supply chain firms (and others) realizing the full potential of the workforce would help not only remedy these hurdles but provide opportunities to deliver on organizational goals.

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# Putting Worker Safety at the Heart of Supply Chain Management

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## Contents



**Abstract**

The emphasis of this chapter is on humanizing supply chain management in a manner that benefits workers and the supply chain. This chapter is based on two suppositions with foundations in the extant literature. First, that the safety of the workers in the supply chain is foundational to supply chain management outcomes. Second, that operational or supply chain managers should be responsible for safety management systems. We interrogate these suppositions considering that the COVID pandemic has arguably changed the role of both supply chain and safety management. This likely has significant implications for the relationship between supply chain management and safety, especially when it comes to managing risks. We delve into these recent events and suggest that safety managers might be best placed to manage supply chains risks. Finally, the chapter

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concludes with a future research agenda so that workers are no longer absent from supply chain management thinking, practice, and research.

**Keywords**

Safety · Risk management · Decent work · Integrated management systems

## 1 Introduction

Workers are strangely absent from a great deal of supply chain management thinking, practice, and research. And when they do appear it is often as an undifferentiated human resource where interchangeable "workers" are optimally scheduled to minimize costs or maximize flexibility (e.g., Hashemi-Petroodi et al., 2021). This optimization is almost always done from the perspective of the focal firm doing the scheduling, and with little thought to how this might impact workers' performance at work – let alone their wider well-being.

This perspective is strange on multiple levels. First, the roots of the supply chain discipline are in scientific management, where maximizing the productivity of individual operational workers was the initial concern. Second, one of the foundations of supply chain management thinking and practice for most of the last 30 years has been the centrality of lean management principles, as best practice in managing supply chain operations. A key component of lean is empowering workers to help in continuously improving the supply chain, an activity that only occurs if workers are well trained, highly valued, and hence willing and able to accumulate and use firm- or supply chain–specific knowledge. Finally, focusing on worker knowledge and motivation ties well into the human capital perspective on how firms and supply chains create and maintain competitive advantage via the firm-specific knowledge created by their workforce.

Hence, the well-being, training, and motivation of workers should be central to optimizing supply chain outcomes. Workers whose well-being is either not prioritized or worse, or whose well-being is at risk, will not be motivated to engage in any activities that benefit the supply chain (e.g., Das et al., 2008). In other words, to leverage the human capital in a supply chain, worker well-being needs to be protected. And, while workers who are safe may still be in precarious jobs (e.g., Wiengarten et al., 2021) or have low levels of well-being; workers who are not safe in their jobs cannot have the needed levels of well-being. This chapter's first supposition is that the safety of the workers in the supply chain is foundational to supply chain management.

Safety is defined as the degree of certainty that operations are in a state where potential risks, dangers, and loss have been avoided or controlled in a proper manner to ensure freedom from loss, and that this state is maintained (Black et al., 2011). Workers who are safe are protected from physical and psychological harm. In most firms, safety is managed by a stand-alone safety function, as part of a larger environment, health, and safety (or compliance) function, or via the human resources department (e.g., Veltri et al., 2013). This structure seems intuitive, but it is misguided. One of the core principals of lean or other continuous improvement-based operational management systems is that quality is everyone's job; quality cannot be managed by a quality department alone. The same holds for safety, which needs to be an operational or supply chain responsibility, not managed as a separate safety silo or sidecar (Pagell et al., 2015; Hasle et al., 2021).

Safety needs to be an operational or supply chain responsibility for multiple reasons. First, the workers most likely to suffer physical harm at work are operational workers in the supply chain (Pagell et al., 2020). Supply chain decisions about what rules are or are not enforced, how fast work needs to be done, how workspaces are maintained, and so on can be significant determinants of worker safety. Equally, safety management systems are mainly designed to protect workers from hazards as they do their jobs, once more with a focus on supply chain workers (Pagell et al., 2015; Shevchenko et al., 2018). Even in firms where the supply chain and safety are managed separately, the safety management system is designed to help control hazards in supply chain operations.

Finally, the best practices associated with safety management include a preventative focus, continuous improvement, and valuing human capital; effectively the same best practices associated with supply chain excellence via lean and other excellence programs (e.g., Pagell et al., 2015). The management of safety focuses on the same workers in the same supply chain system and often uses the same "best practices" as managing the supply chain (e.g., Pagell et al., 2014a; Shevchenko et al., 2018). Hence, it has been argued safety should be an operational responsibility (e.g., Pagell et al., 2014b, 2015). Our second supposition is that operational or supply chain managers should be responsible for safety management systems.

These two suppositions result from much of our own previous work and guide the chapter. However, the theory and empirical evidence linking safety to supply chain management does not always agree with these predictions. While there is no debate over supply chain workers being the focus of safety management systems and therefore the interdependency between safety and supply chain management systems and outcomes, there is s still a robust debate as to the nature of these relationships (e.g., Neri et al., 2022). Equally, much of this debate is based on research conducted prior to the COVID pandemic. The pandemic has arguably changed the roles of both supply chain and safety managers and hence likely has significant implications for the relationship between supply chain management and safety especially when it comes to managing risks.

The rest of the chapter first reviews the debate on the nature of the interdependency between supply chain management and safety, then discusses recent events that suggest that safety managers might be best placed to manage supply chains risks, and finally concludes with a future research agenda so that workers are no longer absent from supply chain management thinking, practice, and research.

## 2 Relationship Between Supply Chain Worker Safety and Operational and Firm Performance

The relationship between worker safety and operational and supply chain performance has been hotly debated (e.g., Tompa et al., 2016; Neri et al., 2022). The managerial literature typically posits that the well-being of the workforce goes hand in hand with operational performance (e.g., Das et al., 2008; Pagell et al., 2014a, 2015). In other words, safe workers are associated with more profitable and operationally effective supply chains. This proposition is typically grounded in the idea of building human capital (Becker, 1993; Hatch & Dyer, 2004).

Human capital theory draws from the resource-based view of the firm, and economic theory, to propose that workers' capacities to learn constitute value for the firm comparable to other firm resources (Becker, 1993). These capacities offer unique, long-term competitive advantage because they are thought to be intangible, firm specific, and socially complex (Hatch & Dyer, 2004). According to this view, firms which care for their employees' well-being cultivate human capital – leading to greater productivity. For example, one study indicated employees whose health was improved by corporate wellness programs increased their productivity by about 10% (Gubler et al., 2018).

Workplace accidents negatively impact both the victims of accidents, and those who work alongside them (Gonçalves et al., 2008) – destroying human capital. Occupational illnesses and injuries are associated with decreased job satisfaction and distrust of management (Barling et al., 2003). Therefore, it is no surprise that perceptions of a poor safety climate in the workplace lead to increased stress and decreased psychological well-being (Griffin & Curcuruto, 2016), and greater turnover intention when combined with occupational illnesses and injuries (McCaughey et al., 2013). Workers that perceive their working environment as safe do not need to self-protect, will be more motivated in their work, and more invested in improving operational performance (Das et al., 2008). In this way, worker safety is paramount to the development of unique capabilities offering long-term competitive advantage (Das et al., 2008).

Poor worker safety can also impose financial and reputational costs on supply chains. Accidents with days away from work have direct costs for firms, such as lost work time and some workers compensation costs (Landsbergis, 2003). Further, stakeholder theory suggests that firms need to satisfy a broad range of stakeholders, beyond just shareholders (Freeman & Reed, 1983). This approach suggests that employees, customers, and a wide range of interested parties influence firm strategy and outcomes. Poor workplace safety may be perceived negatively by stakeholders including employees, customers, and financial analysts, harming the supply chain's reputation. Examples of this effect are that environmental incidents (Lo et al., 2018) and supply chain controversies (Tamayo-Torres et al., 2019) have been associated with a decline in firm value.

In closer relation to the safety context, there is some evidence within the ESG (environmental, social, and governance) literature that also supports this argument. Some studies find a positive relationship between social sustainability performance (of which worker safety is just a part) and firm financial performance (e.g., Waddock & Graves, 1997; Aouadi & Marsat, 2018). Similarly, increased levels of coverage from financial analysts have been found to reduce workplace accidents – presumably because of increased monitoring from stakeholders (Bradley et al., 2021).

The goals of occupational health and safety regulation are also aligned with this argument. Occupational health and safety regulation is designed to keep workers safe and offer competitive advantage to firms which do so (Purse & Dorrian, 2011; Occupational Safety and Health Administration (OSHA), 2019). Firms which do not comply with regulation are sanctioned by the regulator, leading to direct costs, but also censure from stakeholders (e.g., Johnson, 2020). Studies of the effectiveness of OSHA inspections have mostly focused on whether the inspections lead to improved workplace safety (e.g., Johnson et al., 2020). However, Levine et al. (2012) found that inspections improve safety for workers, without negatively impacting firm survival. In a similar vein, the introduction of legislation to protect workers, such as the modern slavery act in the UK, may offer competitive advantage to firms which have a history of socially responsible sourcing (Cousins et al., 2020).

Moreover, the processes and challenges of keeping workers safe could make firms more effective and innovative. First, the limitations imposed by well-designed regulation could drive improvements to operational efficiency and innovation. Porter and Van der Linde (1995) proposed that environmental regulation leads to firms becoming more effective and innovative. Their argument rests on the idea that necessity is the mother of invention; when firms need to become more efficient to comply with environmental regulation, they will innovate to do so. This argument would just as well apply to worker safety. If firms need to keep workers safe to survive, then they will find ways of doing so, and in the process improve their operational capabilities.

Arguments for this perspective can also be derived from day-to-day management of supply chain operations – the processes required to keep workers safe are very similar to those required for high product quality and innovation. First, firms who are oriented toward quality will need to adopt operational processes designed to reduce errors and improve efficiency – which should also improve worker safety (e.g., Das et al., 2008; Pagell et al., 2014a). Second, worker motivation is critical to product quality, because workers are needed to intervene in problems as they develop on the shop floor and to engage in continuous improvement activities. Workers who perceive that they are not safe will be less motivated to engage in these continuous improvement processes (Das et al., 2008).

Similarly, process management systems such as Six Sigma are designed to reduce errors, which could improve worker safety (Lee et al., 2021) and also enhance innovation (Yiu et al., 2020). Safety and innovation management both rely on a managerial orientation toward continuous improvement (Griffin & Curcuruto, 2016). On the whole, when safety and other operational goals are managed jointly, at the routine level, they may be complementary, but can behave as competing goals when treated as such by managers (Pagell et al., 2015).

While much of the research on this topic has focused on whether protecting workers causes improved operational and financial performance, there may be reasons for reversing the causality of the argument. In other words, the argument has typically been that firms which do good do well. It is also possible that firms which do well are in a better position to do good (Waddock & Graves, 1997), and more specifically in our context, to protect their workers.

Highly leveraged firms have more accidents (Cohn & Wardlaw, 2016), and are more likely to be in breach of safety regulations than their peers (Pagell et al., 2019). This situation may occur because managerial decision-making focuses on short-term outcomes (Pagell et al., 2019) – the benefits of investing in safety are only evident over the long term, and can be difficult to evaluate (Cohn & Wardlaw, 2016). Firms with a longer planning horizon may also be better able to mitigate trade-offs between sustainability and operational demands (Longoni & Cagliano, 2018). As noted above, keeping workers safe is likely to increase their motivation and engagement in their work. However, it is also true that more motivated and engaged workers have fewer accidents (Nahrgang et al., 2011). An implication of these findings is that it may be possible to create a virtuous cycle of safer workers and high firm performance, which could be supported by policy and regulation.

An opposing view is that keeping workers safe is costly for firms, and that there are inherent trade-offs in doing so. This view, deriving from the economics literature, is known as the costly regulation hypothesis (Palmer et al., 1995; Levine et al., 2012). According to this approach, keeping workers safe is costly for firms, and therefore financial performance suffers. Investments in safety can be perceived as expensive, and long term in nature; firms who do not invest in safety gain advantage by avoiding this burden (Pagell et al., 2015). Recent estimates put the economic burden of occupational illnesses and injuries in European countries at between 2.9 and 10.2% of GDP (Tompa et al., 2021). But, as noted by Landsbergis (2003), most of the costs associated with workplace illnesses and injuries are borne by workers and their families, and by society more broadly – not by the supply chain.

Some research on the effects of popular process management systems on safety, productivity, and innovation also supports the view that keeping workers safe will harm performance. Process management strategies which increase productivity by increasing the pace of work and reducing operational slack lead to more accidents (Wiengarten et al., 2017). For example, lean manufacturing has been argued as being harmful to workers' health and well-being (Hasle et al., 2012). Similarly, just-in-time manufacturing has been associated with more worker accidents (e.g., Pagell et al., 2014a), although this may only be the case when risks to workers are not appropriately mitigated with human resources management and prevention practices (Longoni et al., 2013). Further, systems designed to maximize product quality (such as total quality management) are oriented toward error reduction, which has been argued to make workers safer. However, within the organizational behavior literature, errors and failures are often considered to facilitate innovation (see for instance Yiu et al., 2020). Therefore the process rigidity associated with quality-oriented systems – which keep workers safe – could also potentially restrict innovation. For example, ISO 9000 has been associated with reduced innovation (Naveh & Erez, 2004).

Also in support of the position that safety reduces innovation, findings regarding the firm performance benefits of sustainability efforts, and keeping workers safe in particular, have been mixed. First, the competitive advantage of engaging with sustainability in general does not seem evident to firms themselves. The typical firm has not begun to address sustainability issues (Kirchoff et al., 2016) and firms which do address sustainability tend to do so only when it pays from an instrumental perspective (e.g., Shevchenko et al., 2016; Xiao et al., 2019).

Research on ESG and corporate social responsibility (of which worker safety is just a part) have been conflicted. While some studies support the notion that socially sustainable firms perform better financially, others show no relationship (Zhao & Murrell, 2022) or even a negative one (Tamayo-Torres et al., 2019). Investors may view investments in safety as diverging from the firm's primary purpose of maximizing shareholder value (Friedman, 1970).

Previous research finds that expectations regarding delivery on earnings lead managers to underinvest in innovation – this finding could also apply to similar longer-term investments such as in safety (e.g., Bradley et al., 2021). Social programs may increase manufacturing costs (Gimenez et al., 2012). For example, improved safety programs may impose initial costs, and increase the time spent on certain processes.

Even research supporting the idea that it pays to protect workers suggests that many operationally effective firms also have poor sustainability performance (e.g., Pagell et al., 2015). Similarly, research showing that it is possible to create safe and productive workplaces also indicates that often firms fail to do so (Pagell et al., 2014b), and when there is a tension between safety and operational performance – safety loses out (Hasle et al., 2021). Consistent with these findings, one-third of US-based workers reportedly believe that their managers prioritize productivity above safety (Safety and Health, 2016). The occupational health and safety literature is broadly consistent with the notion that managers perceive trade-offs between safety and other firm goals (e.g., Zohar, 2000; Das et al., 2008). This literature suggests that while effective safety management systems exist, they are often ignored in practice (Hasle et al., 2021). The ongoing prevalence of workplace illnesses and injuries could also be considered evidence that many supply chains do not consider it profitable to protect workers.

While much of the managerial research supporting the human capital argument has been cross-sectional, involving small samples and exemplar firms (e.g., Pagell & Wu, 2009), a recent study using a large-scale longitudinal dataset finds support for the costly regulation hypothesis (Pagell et al., 2020). The findings showed that firms which had experienced relatively serious worker illnesses and injuries (ones requiring three or more days away from work) have a survival advantage over their safer peers. The size of this effect is substantial – on average firms which had experienced worker illnesses and injuries were up to 20% more likely to survive. Concerningly, the study finds that the firms in a position to do most harm (the largest and oldest) benefit the most from failing to protect their workers.

While the apparent benefits of worker accidents have a diminishing effect, even very high levels of harm to workers does not harm firm survival. That the dependent measure is survival is a limitation. But, given that this is such a critical outcome for firms, the finding in support of costly regulation suggests that market mechanisms alone are unlikely to protect workers in the long run (also see Kirchoff et al., 2016; Shevchenko et al., 2016).

The literature on the effects of regulation does not clearly contradict the costly regulation hypothesis. Several studies show that being found in violation during an inspection from the occupational health and safety regulator decreases accidents in the short term, but it does not improve long-term safety (Tompa et al., 2016). Firms which are inspected but not fined may even become complacent on safety, leading to more worker accidents in the future (Tompa et al., 2016). Many firms harm their workers without being inspected or fined (BLS, 2019), so the penalties for doing so may not be an effective deterrent.

The organizational learning from failure literature also suggests that firms gravitate toward a focus on traditional business goals over safety. Pharmaceutical firms conduct more clinical trials in the wake of a serious drug error indicating a greater focus on safety (Haunschild et al., 2015). However, over time their focus returns to more traditional business goals such as innovation (Haunschild et al., 2015). Firms may also fail at learning from safety incidents when the consequences are not dire for them. While firms learned from disasters and severe disruptions, they are less likely to learn from minor incidents, and what they learn is much more quickly forgotten (Madsen, 2009).

On the whole, the findings regarding the effects of worker safety on firm performance are mixed, and may be nuanced. While the managerial literature dominantly supports the idea that protecting workers can be profitable, the empirical evidence does not consistently support this argument. Moreover, the literature suggests that most firms do not behave as though this is true.

Prior to COVID, the literature showed most firms manage safety as silo or sidecar with the aim of minimizing the costs of complying with safety regulation. These firms may generally protect the workforce from accidents, but they do so in a manner that does not link the day-to-day management of safety to the operations of the supply chain. They incur the costs of compliance without reaping the benefits of building or leveraging human capital. For these firms, improved safety will not improve supply chain outcomes.

Some firms do manage safety and operations in a joint manner. These firms reap the human capital benefits from providing a safe workplace. For these firms increased safety should lead to increased supply chain performance. Finally, some percentage of firms is not concerned with safety. They obviously do not seek to harm their workers, but they also try and avoid the costs of complying with regulation. These firms do not build human capital from increased safety, but they also do not incur the costs of compliance, allowing their supply chains to survive even if the workers are not safe. Further research is needed to explore the contingencies under which these firms pay to be safe, and policies which protect their workers' competitive advantage.

## 3 A Risk Management Perspective on Safety in Supply Chains

Researchers and practitioners have typically addressed safety in a supply chain context by considering the relationship between safety and other supply chain outcomes and/or how to manage supply chains to be safe. This research is generally focused on the day-to-day operations of the supply chain. It is this stream of work (e.g., Das et al., 2008; Pagell et al., 2015) that leads to suggestions to use joint or integrated management systems. There is still a need for safety professionals in these suggestions, but the operations or supply chain managers are responsible for safety on a day-to-day basis.

These are suggestions we, as researchers, have made, and still support. However, this takes a rather limited view of safety. In the supply chain literature safety is typically addressed from an accident (prevention) perspective. The goal of managing safety is to prevent harm to supply chain workers. This perspective is evident in the way safety is operationalized in the supply chain literature – as accidents, breaches of regulation, and so on. However, safety is more expansive. Other components of managing safety have the potential to significantly impact how supply chain researchers and practitioners think both about safety and supply chain risk management.

Safety professionals use: (a) safety management systems to ensure that exposures to workplace hazards are controlled and the effects of changing operating conditions are accounted for; (b) risk management systems to conduct safety risk, danger, and loss analysis; (c) life cycle assessment to systematically analyze potential safety impacts on operations; and (d) emergency management to respond to incidents, mitigate threats and damages, and ensure continuity of basic operations.

Previous supply chain research has generally only considered safety management systems and their role in the day-to-day management of the supply chain's operations. But, safety professionals also work on risk management and responding to emergencies. The response to COVID-19 in many organizations suggests that this risk management capability could be exploited across the supply chain. Specifically, when COVID first disrupted organizations and supply chains, safety personnel were initially put at the forefront of organizational efforts to respond.

This reaction to the COVID crisis was natural, since safety managers deal with employee well-being and issues such as securing and appropriately using PPE on a daily basis. But given the full role of safety professionals, they remained involved long after the initial hand sanitizing stations were installed and PPE was sourced. The risk management components of managing safety were suddenly highly desirable across the supply chain, and most supply chain risk management strategies were not up to the task. COVID may have exposed these shortfalls, but they already existed.

### 3.1 Why Safety Managers Should Be Managing Supply Chain Risks

Supply chain risk management and resilience have been the subjects of a great deal of attention in the last few years (e.g., Azadegan & Dooley, 2021; Wieland, 2021). Today's supply chain systems bear an increasing burden to balance normal, internally occurring supply chain risks such as supplier raw material shortages, inferior performance and delivery, accidents, environmental incidents, and outsourcing with abnormal, externally arising supply chain risks such as earthquakes, extreme weather conditions, pandemics, terrorist attacks, geopolitical instability, climate change, and blackout*s* in order to maintain supply chain competitiveness. The increasing frequency of occurrence for both normal and abnormal supply chain risks (van der Vegt et al., 2015), as well as the adverse effects on supply chain performance (Hendricks & Singhal, 2005) and firm financial health from these risks manifesting (Baghersad & Zobel, 2021) have revealed deficiencies in how supply chains manage risks. This exposure has compelled managers to reconceive their risk management systems (Sodhi & Tang, 2021).

Normal risks traversing the supply chain typically comprise uncertainties which are known and can be assessed and managed using the standard principles of risk management. For instance, a fire at a supplier factory that causes a disruption in supply would constitute a known risk, the estimated probability and severity of which can be measured based on the supplier's history of environment, safety, and health noncompliance fines. Abnormal risks traversing the supply chain typically comprise uncertainties that are known by supply chain managers but that managers do not know how to manage. For abnormal risks, it is critical to reduce their probability of occurring, if possible, and to minimize their effects, employing emergency response and recovery efforts to maintain supply chain performance. For example, COVID-19 has rapidly exposed supply chain limitations (Harland, 2021). However, lost in the supply chain literature is that in many organizations COVID created further dependence on safety specialists to manage both the vulnerability and the disruption (Vu et al., 2022); safety managers became supply chain risk managers.

Relying on safety managers to manage supply chain risks (e.g., Vu et al., 2022) should go beyond responding to COVD19, because safety management already encompasses risk management, life cycle assessment, and emergency response – systems which can be applied in all supply chain risk scenarios. Leveraging the existing risk management systems that safety has already built is one of our core suggestions for going forward.

### 3.2 How Safety Managers Should Be Managing Supply Chain Risks

Applied in the context of risks within supply chain management, the systems already used by safety managers offer value to manage risks or losses and steer decision-making and operating action capabilities with the goals of: (a) eliminating risks so that they do not materialize, (b) controlling exposures that cannot be eliminated, and (c) minimizing the adverse effects of loss when control measures are deficient or not fully effective (Ng et al., 2015) .

The requirement to respond to both normal and abnormal risks will potentially differ by industry geography, and supply chain culture. However, the strategy of most responses is to make a supply chain more resilient in responding to and recovering from disruptions. When supple chain risks exist, integrated efforts should be focused on evading the risks entirely (avoidance). However, when risks cannot be avoided and will thus cause disruptions, integrated efforts should focus on providing immediate assistance to injured parties and containing and preventing further loss (response), as well as providing stabilization efforts to resume supply chain functionality (recovery).

Recovery and business resumption for affected firms may take many months or even years. Examples of this include Hurricane Katrina in 2005. Even now, New Orleans has not fully recovered; some areas still have storm damage or remain altogether uninhabited, and many businesses are still a work in progress. More recently, the California wildfires of 2021 have impacted supply chains by logging off affected agriculture freight lines, creating choke points for inventory traveling via truck and rail, and projecting substantial greenhouse gas emissions, with recovery expected to be months (Dong et al., 2022). COVID-19 has fragmented most of the transportation links and distribution mechanisms between suppliers, production facilities, and customers and is expected to take years to recover and resume business continuity (Kumar et al., 2020). All of this is of course known to supply chain managers (see chapter 107-for a more complete discussion of supply chain risk management), but the suggestion that supply chain managers turn to their safety counterparts to try and help manage these risks is not.

Although the application of safety management practices for eliminating risk, controlling exposures, and minimizing loss is consistent across supply chain settings, the characteristics, properties, and qualities of supply chain risk exposures are different. In contrast, safety system management practices and supply chain system management practices are similar (i.e., assessment, strategy, structure, financing, evaluation, and continuous improvement), allowing joint management systems to flourish. Previous literature has suggested the day-to-day management of both safety and operations should be integrated. More recent events suggest the same for risk management activities.

We continue to argue that the supply chain mangers should lead the day-to-day management of safety to ensure that safety does not get lost among other supply chain priorities. However, COVID has shown that the enhanced risk management toolbox that safety managers already possess means that safety managers are best placed to deal with risk management for the supply chain.

## 4 What Is Known and Needs to Be Known?

This chapter starts with the proposition that it is peculiar that the workers in the supply chain have been mostly absent from discussions of supply chain management. Hence, our primary conclusion is to echo previous calls to humanize the discipline (e.g., Soundararajan et al., 2021). In addition, many authors have proposed the argument that sustainability should not rest on the business case (e.g., Montabon et al., 2016), as this gives priority to financial performance over other elements of the triple bottom line. Safety at work is a fundamental component of the provision of decent work as encapsulated in Sustainable Development Goal 8. However, supply chains need to be financially viable, and that work can provide benefits beyond earning wages. The goal is to humanize supply chain management in a manner that benefits workers and the supply chain.

This chapter specifically focuses on safety because the safety of workers in the supply chain will mainly be a result of decisions that supply chain managers make (e.g., Das et al., 2008). Thus, a number of observations arise. First, when safety and operations are managed using a joint management system for the day-to-day operations of the supply chain, it is possible to have high levels of supply chain performance across all outcomes (e.g., cost quality, flexibility, delivery, and safety). Second, the joint management of the day-to-day operations of a supply chain should be the responsibility of supply chain managers. If safety is not an explicit supply chain management responsibility, safety will be deemphasized. Third, many supply chains do not currently use joint management systems to manage the day-to-day operations of the supply chain. These organizations either have suboptimal performance across multiple dimensions of supply chain performance, or they put workers at risk to increase supply chain effectiveness. Fourth, on average, the risk management systems developed and utilized in safety are more advanced than those used in managing traditional supply chain risks. Finally, these advanced safety risk management systems are then another argument for having joint management systems between safety and supply chain management, but in this case safety managers should take the lead.

In the proposed joint management systems, supply chain managers need to be responsible for the day-to-day operations of the supply chain, including safety management systems. Safety managers would be responsible for risk management systems, including supply chain risks, to conduct risk, danger, and loss analysis; life cycle assessment to systematically analyze potential disruption impacts on the supply chain; and emergency management to respond to incidents, mitigate threats and damages, and ensure continuity of basic supply chain operations.

These suggestions, especially those relating to roles and responsibilities, require future research and practice evaluation. However, prior to suggesting specific research questions or areas of research, a more general issue related to studying safety in the supply chain realm needs to be explicated. Specifically, almost all prior research has been conducted at the firm level of analysis, with a focus on preventing harm within a firm's own internal supply chain operations. Very little research looks at how safety is managed across a supply chain, especially from the perspective of how decisions in one node spread to other nodes in the network. Hence, while there is research that shows that practices do generally diffuse across supply networks (e.g., Marques et al., 2020) and that specific buying firm behaviors can lead to the use of modern slavery, the denial of worker rights, excessive overtime, and so on (e.g., LeBaron, 2021), safety is typically absent from these discussions. A rare exception would be Kim et al. (2022) who show that buying firm decisions do impact the safety behaviors of suppliers. A general suggestion for future research would be to explore the safety of supply chain workers at the supply chain, not just firm, level of analysis.

Each suggestion mentioned in this section also requires future research. The first suggestion is based on our interpretation of the nuanced findings regarding the relationship between safety and supply chain outcomes. Yet further work that combines the large-scale longitudinal nature of research such as Pagell et al. (2020) with much more nuanced research such as Hasle et al. (2021) is needed to arrive at valid and reliable conclusions on whether providing a safe workplace for supply chain workers is foundational to operational excellence and organizational performance. More definitive research in this space would provide more confidence in the suggestions to use a joint management system for safety and operations and for the day-to-day management of that system to be the responsibility of operational managers.

Equally, the joint management systems proposed for day-to-day operations of the supply chain were typically derived from management systems such as Lean (e.g., Pagell et al., 2015). However, events such as the COVID pandemic have raised significant questions about all of our existing best practices (e.g., Sodhi & Tang, 2021) and there is no reason to believe this would not also be true in the realm of joint or integrated management systems for the day-to-day safety of supply chain workers. Future research needs to then explore the content of these systems in light of other changes going on in the management of supply chains.

The third suggestion is also worthy of further exploration. While joint or integrated management systems are a likely path to providing a safe and productive supply chain, the literature has not really explored other paths. In other words, concluding that the lack of joint management systems means that either the firm, its workers, or both suffer is logical based on previous work. However, it is possible there are other paths to simultaneously protecting supply chain workers and improving productivity. Research that explores this possibility, both within firms and across the supply chain, is then needed. Equally, the supposition that the typical firm manages safety as a cost to be minimized, not as a means to competitive advantage and does not benefit from improved safety (e.g., Pagell et al., 2020), is based on practices we have observed. This needs to be empirically tested.

Finally, the suggestions regarding risk management warrant a great deal of future research. The supposition that the systems used to manage safety risks are more advanced than used for managing supply chain risks needs empirical support. Equally, empirical evidence is needed to evaluate the supposition that the efficacy of such systems lies in managing a wide range of supply chain risks, including safety risks.

Finally, the proposal that supply chain risk management should be the responsibility of safety managers is based on two assumptions. First, safety managers currently have these skills, or at least are more likely to have these skills relative to supply chain managers. Second, integrating safety management into the day-to-day supply chain management systems means that supply chain managers will have a more tactical/day-to-day perspective. This situation allows safety managers to conduct risk, danger, loss analysis, and life cycle assessments. These activities will help determine the likelihood and impact of potential supply chain risks manifesting or to revert to emergency response mode if risks do manifest. These assumptions themselves need to be tested. And while that is a simple statement to make, it raises a host of more complicated issues such as where responsibility should lie for each of these activities (e.g., who does emergency response), if it really matters who has responsibility for various actions or if the system itself is the key, if safety managers can really apply their skills to address other supply chain risks, and so on.

## 5 Conclusion

Workers are often ignored and safety is often treated as a narrow topic within the supply chain discipline. We would suggest that both are problematic. Workers are theorized to be a key element to creating both operational excellence and competitive advantage, to ignore them is then to ignore one of the most fundamental issues in the management of supply chains. Equally, how safety is managed, especially when taking a wider risk management perspective, seems to have significant implications for managing a supply chain, implications that deserve a great deal more thought and empirical exploration. Finally, this chapter makes a number of suggestions, such as safety managers should manage supply chain risk, that are presented as a single best path forward. Yet supply chain management is always situational and managers need to be cognizant of both their supply chain's capabilities and environment when acting on these suggestions.

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# Behavioral Supply Chain Management

H. Niles Perera and Behnam Fahimnia

## Contents




**Abstract**

Humans play a critical part in supply chain management. A lapse by one human or nonconformance to information system recommendations may create ripple effects across the supply chain. There are also instances where human intuition and ingenuity has led to more profitable outcomes that information systems have failed to deliver. The value of humans in the supply chain should thus never be discounted as it is difficult to imagine a supply chain without human intervention



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in the foreseeable future. These realities call for more thorough research on behavioral supply chain management (BSCM) with a view to understand human behavior that consequently aids with more effective decision-making that benefits all stakeholders. BSCM research studies how humans can be empowered to better contribute to supply chain practice, both individually and collectively, without compromising their own welfare. This chapter provides a brief introduction into BSCM research and identifies the key research subdomains and popular research methods.

**Keywords**

Behavioral operations · Behavioral supply chain management · Decision sciences · Judgmental forecasting · Inventory decisions

## 1 Introduction

Supply chains involve many human players ranging from blue-collar workers picking or packing in warehouses to white-collar managers making strategic investment and partnership decisions. Humans are inquisitive beings who possess cognitive skills; thus, it is clear that human decision-making can significantly alter the performance of a supply chain (Fahimnia et al., 2019). Decades of work have focused on automating supply chains through advanced information systems and mathematical optimization. There are however many touchpoints across supply chains where human interaction is critical toward achieving success (Fahimnia et al., 2019; Perera et al., 2019, 2020). There is plenty of empirical evidence on how humans have contributed and will continue to contribute to improve supply chain performance. There are also examples of how immature decisions to override system recommendations have led to suboptimalities in the supply chains. The one undeniable reality is that human behavior plays a significant role in supply chain decision-making.

Behavioral operations management (BOM) emerged in the late 1990s and early 2000s as a subdiscipline of operations management (Gino & Pisano, 2008). Researchers in this subdiscipline methodically studied operations management problems by borrowing methods and theories established in areas such as organizational behavior, psychology, behavioral economics, experimental economics, etc. (Fahimnia et al., 2019). Academic literature in this domain has steadily risen over the past couple of decades. While the initial focus was on BOM, the last several years has seen the emergence of the term behavioral supply chain management (BSCM) which focuses on problems integral to the supply chain (Fahimnia et al., 2019).

The body of knowledge in organizational behavior and social psychology are fundamental to BOM and BSCM. They encompass a wide spectrum, and it would be practically difficult to introduce all of them within this chapter. Therefore, the most widely applied concepts are introduced herein to aid a nascent researcher to BSCM while encouraging readers to refer Part II of the recent *Handbook on Behavioral Operations* (Donohue et al., 2019) for a deep dive into the behavioral aspects which are salient to succeed in BSCM. Some of the more prevalent foundations are presented in this section.

The impact of heuristic and biases on the supply chain has gained widespread attention over the past few years. A heuristic is a methodical strategy that people adopt as a rule of thumb to solve and understand difficult problems. These answers are not always optimal. The three main heuristics identified are "availability," "representativeness," and "anchoring and adjustment" (Tversky & Kahneman, 1974). Literature also reports how feedback can improve supply chain tasks. Task information feedback (or task properties feedback) refers to feedback relating to the environment where the task is performed while performance outcome feedback refers to feedback on the performance of a person or a team doing the task (Harvey & Reimers, 2013; Remus et al., 1996). People's decisions and outcomes may be affected by visual cues and how information is presented to them in judgmental forecasting tasks (e.g., via support systems, spreadsheets, and physical documents) (Bendoly, 2016). For instance, whether the presentation of data in graphical or tabular form alters the forecasting outcome has been a raging question for years.

Published literature on BSCM has provided much needed insights for both practitioners and academics to link supply chain decision-making process with the associated behavioral factors that prevail in the industry. This has been further buoyed by several systematic reviews focusing on areas within BSCM that have shed vital insights (Arvan et al., 2019; Donohue et al., 2020; Fahimnia et al., 2019; Perera et al., 2019, 2020). Table 1 presents a complete list of review papers relevant to BSCM. Despite the progress, there is plenty to be done within BSCM in the era of autonomation. This chapter synthesizes the key contributions made thus far within BSCM. Initially, the more common methods employed in BSCM research will be presented. This will be followed by a discussion of each identified key area within BSCM while outlining future trends and research directions.

## 2 Research Methods in BSCM Research

Laboratory experiments, field experiments, vignette-based experiments, mathematical modeling of behavioral constructs, and scenario/role play are some of the more prominently used methods in BSMC research (Fahimnia et al., 2019; Perera et al., 2019). More advanced methods such as neuroimaging (Zhao et al., 2016) have been used which emphasizes why researchers should think beyond what is already established in BSCM. It is believed that novel methods coming from domains such as medicine and engineering would further mobilize research in BSCM in the years to come.

**Table 1** BSCM review papers

| Authors | Title | Year | Source title |
|---|---|---|---|
| Goodwin et al. | Improving judgmental time series forecasting: a review of the guidance provided by research | 1993 | *International Journal of Forecasting* |
| Webby et al. | Judgmental and statistical time series forecasting: a review of the literature | 1996 | *International Journal of Forecasting* |
| Lawrence et al. | Judgmental forecasting: a review of progress over the last 25 years | 2006 | *International Journal of Forecasting* |
| Wachtel et al. | Review of behavioral operations experimental studies of news vendor problems for operating room management | 2010 | *Anesthesia and Analgesia* |
| Benda et al. | The predictive validity of peer review: a selective review of the judgmental forecasting qualities of peers, and implications for innovation in science | 2011 | *International Journal of Forecasting* |
| Leitner et al. | Experiments on forecasting behavior with several sources of information – a review of the literature | 2011 | *European Journal of Operational Research* |
| Croson et al. | Behavioral operations: the state of the field | 2013 | *Journal of Operations Management* |
| Kundu et al. | A journey from normative to behavioral operations in supply chain management: a review using latent semantic analysis | 2015 | *Expert Systems with Applications* |
| Schorsch et al. | The human factor in SCM: Introducing a metatheory of behavioral supply chain management | 2017 | *International Journal of Physical Distribution & Logistics Management* |
| Ren et al. | Modeling customer-bounded rationality in operations management: a review and research opportunities | 2018 | *Computers and Operations Research* |
| Greasley et al. | Modeling people's behavior using discrete-event simulation: a review | 2018 | *International Journal of Operations and Production Management* |
| Sharma et al. | A review of behavioral decision-making in the news vendor problem | 2018 | *Operations and Supply Chain Management* |
| Fahimnia et al. | Behavioral operations and supply chain management: a review and literature mapping | 2019 | *Decision Sciences* |
| Perera et al. | The human factor in supply chain forecasting: a systematic review | 2019 | *European Journal of Operational Research* |
| Arvan et al. | Integrating human judgment into quantitative forecasting methods: a review | 2019 | *Omega (United Kingdom)* |
| Zhang et al. | A meta-analysis of news vendor experiments: revisiting the pull-to-center asymmetry | 2019 | *Production and Operations Management* |

(continued)

**Table 1** (continued)

| Authors | Title | Year | Source title |
|---|---|---|---|
| Perera et al. | Inventory and ordering decisions: a systematic review on research driven through behavioral experiments | 2020 | *International Journal of Operations and Production Management* |
| Erjavec et al. | Behavioral operations management – identification of its research program | 2020 | *International Journal of Services and Operations Management* |
| Donohue et al. | Behavioral operations: past, present, and future | 2020 | *Manufacturing and Service Operations Management* |
| McAndrew et al. | Aggregating predictions from experts: a review of statistical methods, experiments, and applications | 2021 | *Wiley Interdisciplinary Reviews: Computational Statistics* |
| Yamini S. | Behavioral perspective of news vendor ordering decisions: review, analysis, and insights | 2021 | *Management Decision* |
| Yamini S. | A literature review on the anomalies observed in the news vendor ordering behavior | 2021 | *International Journal of Enterprise Network Management* |
| Yamini et al. | Inventory decision-making biases: a review and suggestions for future research | 2022 | *Benchmarking* |

## 2.1 Laboratory Experiments

Laboratory experiments are a proven method with their roots in experimental economics (Katok, 2019) which has been extensively used in BSCM research. Investigations in areas such as inventory ordering decisions and forecasting have vastly benefited from lab experiments (Perera et al., 2019, 2020). As an empirical method, lab experiments are ideal for observing behavior with the aim of collecting data for analysis. Lab experiments provide the researcher with more control by replicating a real-world problem in a laboratory environment. This allows the collection of the data to have a laser focus on the research questions without being adversely affected by externalities. Additionally, the laboratory provides a safe space to conduct research without disturbing day-to-day operations of an organization (Katok, 2019). Lab experiments are very popular due to these and other reasons among BSCM researchers (Katok, 2019).

Despite its advantages, designing a lab experiment is an extremely challenging task. A key challenge is identifying focal variables and nuisance variables to design the experiment to precisely focus on finding answers to the research questions. Once identified, the researcher needs to carefully design the experiment to eliminate nuisance variables that would otherwise distort the findings by giving prominence to the focal variables (Katok, 2019).

One of the main considerations of a lab experiment is whom to recruit as participants. Most publications report on results achieved through lab experiments which engaged university students. This is a major criticism against the use of lab experiments. However, there had been several studies that have debunked this by indicating that there is no significant difference between the decisions taken by seasoned managers and university students under specific conditions (Bolton et al., 2012; Hewage et al., 2022). Having said that, this observation cannot be generalized to specific contexts where industry experience plays a significant role in the decision-making process. The literature will benefit immensely from lab experiments engaging industry practitioners. This has been partially met by studies that engage participants completing part-time postgraduate degrees in addition to undergraduates (Hewage et al., 2022).

## 2.2 Field Experiments

Field experiments are an empirical method that allows researchers to observe the effects of decisions in a natural environment. Ostensibly, they provide a more realistic perspective of behavior as opposed to lab experiments that are conducted under controlled conditions (List et al., 2011). However, the field experiment should be meticulously designed to ensure that the experiment does not change the behavior of the supply chain actors due to the worry of being observed. The advantage of picking up real-world insights is not without its shortfalls. Field experiments are often influenced by nuisance variables that impact on behavior despite them not being a crux of the research questions that the researchers aim to answer.

Field experiments should be carefully designed to clearly identify cause and effect. This makes field experiments more expensive and time consuming compared to lab experiments. Unlike lab experiments, rerunning a field experiment is nearly impossible given the numerous factors at play (Ibanez & Staats, 2019). Therefore, the expert advice is for researchers to resolve to field experiments only if they are confident about rolling out the method and see no easier alternatives to answer the research questions (Al-Ubaydli & List, 2015; Card et al., 2011).

Convincing an organization to allow a field experiment is challenging. It should primarily focus on supporting a transformation which the organization wishes to apply to inspire a change in behavior among its personnel.

## 2.3 Vignette-Based Experiments

In vignette-based experiments, respondents are given a context-based scenario by a researcher usually in form of written text followed by a series of questions (Rungtusanatham et al., 2011). These replies typically entail a decision made from the options displayed or a Likert scale evaluation of a statement (Croson et al., 2013). Vignette-based experiments are growing in popularity among BSCM researchers. Some examples of this approach in BSCM research may be found in (Cantor et al., 2014; Chen et al., 2016; Hora & Klassen, 2013).

### 2.4 Other Prominent Methods

BOM was initially incepted on studies that primarily focused on mathematical modeling (Gino & Pisano, 2008; Schweitzer & Cachon, 2000). Naturally, this is a method with plenty of applications for the present and future given the practical behavioral concerns. However, there seems to be a reduction in the use mathematical models to conduct BSCM research at the time of writing.

Verbal protocol analysis (VPA) is another method that has been applied to a certain extent in the past decade (Cui et al., 2013; Gavirneni & Isen, 2010). VPA entails decoding the decision-making process of the participants by audio recording what led them to their decisions by requesting them to “think out loud.” This method is quite rich, but there is an argument that it is difficult for participants to fully engage in the task while talking. Moreover, there is an argument that “thinking out loud” itself may alter the decision process of the participants (Croson et al., 2013).

The study applying neuroimaging techniques reported earlier (Zhao et al., 2016) demonstrates how novel methods emerging from other disciplines can be successfully deployed in BSCM. One such method that is often considered revolves around the use of video recording decision-makers to observe their responses to the decision-making task visually. This includes eye tracking, pointer tracking, facial cues, and hand gestures, among others. Since BSCM is still in its growth stage, there is ample room for new opportunities to emerge as we move forward.

## 3 Popular Research Areas in BSCM Research

### 3.1 Judgmental Forecasting

Research on judgmental forecasting dates to the early 1980s (Perera et al., 2019). The premise of judgmental forecasting revolves around human intervention to forecasts, and the number of publications in this domain has steadily grown over the past four decades (Perera et al., 2019). This is understandable given that the continuous development of information systems has not reduced the level of human intervention toward the forecasting process. A recent survey conducted in the USA reported that nearly 70% of system-generated forecasts are adjusted by humans (Siemsen & Aloysius, 2019). Even those that are not adjusted are subjected to some form of human intervention as even the selection of the forecasting technique is largely made by humans (Petropoulos & Siemsen, 2022).

Lab experiments are the most popular methodology employed in judgmental forecasting. However, there are also many examples of analytically driven normative research. Other methods have been quite rarely reported in judgmental forecasting (Perera et al., 2019). The recent systematic review identifies six primary research clusters through a keyword analysis (Perera et al., 2019). These clusters reveal the nascent research trends while explaining key research gaps in brevity.

### Implications on Conventional Forecasting Methods

Extrapolation, causal and multivariate methods, computer-intensive methods, and judgmental forecasting are considered the four primary forecasting approaches (Fildes et al., 2008). The first three approaches are quantitatively driven while the fourth approach, as the name implies, is judgment heavy. Literature reports that human intervention begins from the selection process of forecasting methods, thus implying that all forecasting approaches are subject to some level of judgmental intervention (Petropoulos & Siemsen, 2022). Understanding how judgment plays a role in different forecasting contexts with the aim of bridging the divide between forecasters and support systems should dominate the future research agenda in judgmental forecasting (Perera et al., 2019).

Combinational forecasts involve combining two or more forecasts to create a forecast that maximizes the strengths of each of its individual components. The initial forecasts (that are building blocks for the final forecast) could be produced statistically and/or subjectively by various people, processes, or systems. Combining forecasts is a method that has been widely used to incorporate judgmental inputs into forecasts. It is typically feasible, affordable, and can result in significant accuracy increase (Armstrong, 2006). However, concerns on practical implementation of combining forecasts and the work required to overcome the challenges have been presented in a case study (Caniato et al., 2011). It is recommended to let someone who is not participating to a forecast to combine the forecasts since some research indicates that individuals tend to prioritize and attach greater importance to their own forecasts (Franses & Legerstee, 2013). Thus, methods to combine forecasts effectively while eliminating bias should be further explored. The integration of judgment in this process should also be further understood (Franses & Legerstee, 2013). This would allow practitioners to fully understand the strengths and weaknesses of judgmental and statistical methods to reap maximum rewards when combining forecasts.

It is a usual practice for representatives from different business functions within a firm to impart their opinion and engage in group forecasting – although much of the existing research has concentrated on how individual judgment is captured in forecasts. Group forecasting can be done in a variety of ways using a variety of techniques that are extensively used in industry. However, averaging each group member's forecast and using that number as the final forecast is the simplest and most frequently used approach (Wright & Rowe, 2011). The Delphi method has been widely applied as a means for group forecasting (Bolger & Wright, 2011). However, behavioral factors of the group members may impact the final outcome in the Delphi method (Wright & Rowe, 2011). Groups can be either helpful or destructive toward forecast accuracy, according to group dynamics and social psychology theory. Groups are more effective than individuals at bringing a wider variety of knowledge and skills to the forecasting process, but there are risks when members of the group tend to share the same opinions (Siemsen et al., 2019). Emergence of supply chain practices such as collaborative planning, forecasting and replenishment (CPFR), and sales and operations planning (S&OP) has meant that group forecasting is getting more attention in the industry than what the limited number of academic literature exploring this topic would indicate. Thus, it is imperative to build on the interesting findings of work of Janet Sniezek (1990) as well as other investigations on group forecasting (Önkal et al., 2012) to expand our understanding on its impact in the supply chain.

### Effect of Promotions and Other Special Events on Forecasting

One of the key challenges in forecasting is incorporating upticks or downticks in demand due to special events. For instance, retail promotions have been regularly cited as a key driver that leads to forecast adjustments (Arvan et al., 2019; Hewage et al., 2022; Perera et al., 2019). While normative research has focused on incorporating special events to forecasting using techniques such as artificial intelligence, there has been another thrust that has focused on understanding the behavioral constructs that go into forecast adjustments.

Numerous BSCM studies have explored how forecasters are enticed to adjust forecasts to capture the demand fluctuations that arise from retail promotions (Fildes et al., 2018; Hewage et al., 2022; Trapero et al., 2013). Incorporating "last like promotions" (i.e., data from the most recent promotions for the same SKU or a similar SKU) is a standard technique in the industry that has shown accuracy improvements (Trapero et al., 2013). The use of contextual information and the prevalence of biases in forecast adjustment in the presence of promotions have also generated recent interest (Fahimnia et al., 2022; Sroginis et al., 2022).

Another prominent area of discussion has been how the postpromotional dip (due to stockpiling during the promotion) is neglected/underweighted in forecasts. Literature has begun to address this gulf although there remains ample room to contribute (Hewage et al., 2022). Both practitioners and academics would benefit extensively from discerning how best to integrate judgment to improve forecast accuracy before, during, and after the promotion, as opposed to solely concentrating on the promotional period as an isolated event.

### Forecasting Support Systems

Information systems have become an integral part of modern business. Forecasting support systems (FSS) are a type of information system that focuses on providing forecasts to aid business decisions. Most enterprise resource planning (ERP) packages are embedded with FSS (Arvan et al., 2019; Perera et al., 2019). However, there are ample examples of standalone FSS that are customized to specific needs given the constraints faced by ERP (Arvan et al., 2019). The ever-increasing complexity in supply chains and the numerousness created by growing numbers of product families and stock-keeping units (SKUs) has made it exceedingly difficult to generate accurate forecasts. Thus, FSSs are becoming more prevalent, especially supported by the development of data science such as artificial intelligence and machine learning.

The prime focus of research in FSS is to develop bespoke or generic tools that are capable of improving forecast accuracy (Arvan et al., 2019; Perera et al., 2019).

This could either be delivered in the form of a fully automated FSS that has minimal human intervention and generates forecasts based on the data it is fed. However, this may lead to the "black box effect" where supply chain practitioners may feel left out and would have little clue of the forecasting process. The alternative is an autonomation-oriented solution where the FSS works in tandem with forecasting professionals. Several researches have been published in this domain, and many other works are afoot (Arvan et al., 2019). Majority of them focus on how information provision and guidance can enable the forecasters to work in symbiosis with the FSS to derive accurate forecasts (Arvan et al., 2019). This approach considers the school of thought that underscores the value of contextual knowledge of the forecasters who are more conducive to impacts on the supply chain than an FSS/ERP.

### Supply Chain Implications

Forecasting is often the trigger point of a supply chain that sets into motion other activities upstream/downstream (Perera et al., 2019). Therefore, the implications of how judgmental forecasting may affect the supply chain elsewhere are vitally important to study. This is especially true given the interconnected nature of modern supply chains that often rely on forecasting to plan the rest of its operations (Perera et al., 2020).

Forecasts have shown to have a ripple effect on inventory decisions of a supply chain. Companies are weary of maintaining the "right" level of inventory so as to avoid stockouts while simultaneously eliminating waste and cost (Perera et al., 2020). All stock control models require demand forecasts as an essential input (Syntetos et al., 2016). This has been further exacerbated by the COVID-19 pandemic which mainstreamed the concept of maintaining "just-in-case" inventory to tackle uncertainty in demand.

The drive to generate accurate forecasts at an SKU level to reduce inventory investments has meant that the interrelationship between forecasts and inventory models keeps growing (Perera et al., 2019; Syntetos et al., 2016). This is further underscored by literature that emphasizes the importance of sharing forecasting information to empower accurate inventory decisions (Sanders & Graman, 2016; Spiliotopoulou & Conte, 2021; Sterman & Dogan, 2015). However, only a few works have conducted a detailed investigation encompassing the interrelation between forecasting and inventory decisions (Rekik et al., 2017).

Intermittent demand items have infrequent demand with varying quantities and many zero demand periods (Nikolopoulos, 2021; Petropoulos & Kourentzes, 2015). While there is a rich body of literature that reports on various aspects of intermittent demand forecasting, there have not been expansive investigations on the impact of judgment on intermittent demand forecasting (Boylan & Syntetos, 2010). Thus, there is ample avenues for future works exploring the intersection of behavioral implications on intermittent demand forecasting.

### Multiple Adjustments to Forecasts

Multiple adjustments to forecasts relate to a single forecast being subjected to adjustments more than once during its lifecycle. It is an underreported issue that is widely observed in the real-world (Aruchunarasa & Perera, 2022; Önkal et al., 2008; Perera et al., 2019). Industry practitioners have often reported that multiple adjustments to forecasts are a serious pain point that reduces transparency within the supply chain (Aruchunarasa & Perera, 2022).

There are conflicting opinions with respect to how forecast adjustments improve forecast accuracy. It is widely agreed that adjusting for contextual information that are not captured in the forecast leads to accuracy improvements (Perera et al., 2019). Multiple adjustments bring the risk of excessive adjustment which can be counterproductive toward improving accuracy. It is also likely that multiple adjustments are applied in lieu of the same cause which leads to duplication (Aruchunarasa & Perera, 2022). Literature highlights the importance of providing guidance and information to empower forecasters while also informing of previous adjustments (Arvan et al., 2019; Hewage et al., 2022; Perera et al., 2019). However, research on this alley has been scant and it is fertile ground for further works.

## 3.2 Inventory and Ordering Decisions

How much raw materials/products to order, when to order them, and how much to keep in inventory have been an age-old problem that has riddled supply chain practitioners. While information systems have continuously developed solutions to aid ordering decisions, practitioners have imparted order adjustments for a variety of reasons. The prime reasons are to either attain ownership of the final order, to adjust for contextual information missing in the information system, or to calibrate for organizational goals/constraints (Perera et al., 2020). Although some of these adjustments lead to streamlining its supply chain, others lead to costly inefficiencies. Therefore, gaining a deeper understanding of the behavioral elements driving inventory and ordering decisions would help us to optimize the supply chain.

Research on inventory and ordering decisions can be primarily divided into two: single-period inventory decisions and multiperiod inventory decisions. The beer distribution game is an extremely popular learning exercise in classrooms across the world. The literature contains a rich body of literature inspired by lab experiments relating to the beer game. Lab experiments, and normative methods, dominate research in this avenue while field experiments, verbal protocol analysis, and vignette-based experiments too have a small but growing presence. A recent systematic review fleshes out further details on inventory and ordering decisions from a BSCM perspective (Perera et al., 2020).

From a behavioral perspective, heuristics and biases play a significant role in research on inventory and ordering decisions. Numerous theories have been tested within this paradigm with ample room for future works. One interesting observation has been a thrust to prove mathematical models through experimental research (Perera et al., 2020). The role of overconfidence and guidance has emerged as a key discussion point for inventory and ordering decisions.

### The News Vendor Problem

Single-period inventory decisions relate to the widely renowned news vendor problem where decision-maker places an order for a particular period which cannot be revised during the period. This implies that the decision-maker is running a risk of stocking out or having an excess during the period. Stockouts translate to a potential revenue loss while excess inventory incurs a loss. The premise of the news vendor problem is to minimize stockout costs and excess costs through optimal ordering (Perera et al., 2020).

Inspired by behavioral economics, a rich strand of research investigates the impact of utility on the news vendor problem. Risk or loss preference, prospect theory, mental accounting, inventory error, and impulse balance theory are some of the angles from which these studies are conducted (Becker-Peth & Thonemann, 2018). Literature indicates a correlation between risk preference and order quantities (Becker-Peth & Thonemann, 2018). Another finding shows that risk-averse decision-makers are willing to pay to obtain extra information before they order. The prospect theory posits that humans evaluate decisions against changes from a certain reference point rather than comparing the alternatives with one another. While there has been ample normative research along this alley, experimental investigations have been rare. This implies an opportunity for researchers to prove these theoretical findings in the laboratory through future works. There are ample opportunities available for future research on applications on mental accounting, inventory errors, and the impulse balance theory building on the contributions made along these lines over the past decade.

The critical ratio relates to the profit margin applicable in a news vendor setting (Bolton et al., 2012; Bolton & Katok, 2008). This is an avenue of research with a rich history and has given rise to the phenomenon known as the pull-to-center effect (PTC). PTC refers to the tendency for decision-makers to order less (more) than the nominal quantity when critical ratio is high (low). The presence of PTC is attributed to the anchoring and adjustment heuristic due to insufficient adjustment (Perera et al., 2020). Previous studies prove that the level of experience has no bearing on PTC. One explanation of this phenomena is the anchoring effect where decision-makers anchor on the mean demand and make an adjustment toward optimum order quantity (Bolton et al., 2012). It is also reported that unit price has a bearing on PTC with higher prices leading to increasing PTC. Learning, training, and decision support have been outlined as approaches to overcome decision biases in the news vendor model (Becker-Peth & Thonemann, 2018). There are many unresolved questions relating to the presence of PTC. It is vital to meticulously design experience as there is evidence that some experimental designs lead to PTC (Zhang & Siemsen, 2019). This further confounded by some works that question the existence of PTC (Lau et al., 2014).

A fresh thrust of literature focusing on the competitive news vendor problem has emerged over the past few years which examines a duopolistic market. The PTC effect has been reported in these settings too (Perera et al., 2020). Results suggest that more inventory is required in a competitive news vendor setting when compared with a monopolistic setting (Feng & Zhang, 2017). This burgeoning area requires further investigation, especially from an experimental lens. Similarly, researchers ought to consider news vendor settings for multiple products in a monopolistic setting as well.

The demand-chasing heuristic has been widely observed in the news vendor setting. This implies scenarios where decision-makers overorder to compensate for demand realizations in the previous period(s). Literature indicates that (i) change frequency, (ii) adjustment score, (iii) regression, and (iv) correlation are the primely used methods to compute the demand-chasing heuristic. More research on the demand-chasing heuristic can further our understanding of this effect (Perera et al., 2020).

Research on the behavioral effects of the news vendor problem should expand its horizons. There is a need for further investigation into the effect of decision support systems during disruptions, promotions, environmental issues, etc. It is also salient to explore with more realistic demand distributions as well as engaging nonstudent participants for experiments. The asymmetry of the PTC effect is another fertile topic for further research (Zhang & Siemsen, 2019).

### Multiperiod Ordering Decisions

Multiperiod ordering decisions concentrate on understanding individual decision behavior that extends beyond a single period. The presence of multiple periods brings about many complexities, especially since inventory needs to be carried forward. This makes multiperiod ordering much more replicative of many products in the real world. Despite its importance to real-world operations, the complexities of coding experiments have meant that the attention on multiperiod ordering from a BSCM lens is inadequate.

Comparisons between the news vendor and multiperiod setting indicate significant differences and outline the importance of transit delays and shelf life on the decision process (Bloomfield & Kulp, 2013). Order volatility is reported to be higher in multiperiod setting as decision-makers adjust considering inventory levels and backlogs. Literature also explores bracing behavior where decision-makers order with a negative event looming. The results show that the uncertainty in timing of the event is more troublesome than deciding the volume to order (Tokar et al., 2014). A recent study also reported the myopic nature of ordering decisions within budgeting cycles (Becker-Peth et al., 2020).

Lack of supply to meet the demand, delivery delays, and feedback are reported to inflate orders. Meanwhile, the importance of aligning forecasting and inventory-ordering targets to the overall supply chain objectives has also been highlighted to be crucial (Perera et al., 2020). A study reports that intelligence is the strongest personal trait affecting ordering decision while demonstrating significant but weak relations to knowledge, personality, and interest (Strohhecker & Größler, 2013). Future research can investigate the effect of traits on multiperiod ordering decisions.

The economic order quantity (EOQ) model has been one of the most widely used inventory methods in the world. However, this has only been scarcely explored through the literature. Given its prominence, further research on the behavioral effects relating to the EOQ model is long overdue (Perera et al., 2020; Stangl & Thonemann, 2017).

### The Beer Distribution Game

The beer distribution game is a classic supply chain learning tool used the world over to demonstrate the bullwhip effect. Initially a board game, this is now available online and alludes to a four-echelon (occasionally two- or three-echelon) supply chain that should collaborate to fulfill customer demand while minimizing overall supply chain costs (due to excesses and stockout). Experimental research on the beer game was catalyzed over three decades ago (Sterman, 1989) and has seen wide attention from the community ever since. The beer game has been used for research on supply chain contracting as well as in tandem with multiperiod settings (Tokar et al., 2016).

Seminal studies indicate that bullwhip effect arises due to (i) demand forecasting, (ii) rationing and shortage gaming, (iii) ordering batching, and (iv) price fluctuations (Lee et al., 1997). The prime focus of the beer game is to gauge the bullwhip effect and to systematically understand the effects of the above causes as well as on how to mitigate them.

Literature posits that a prevalent issue pertaining to this research thrust is supply line underweighting (SLU) where decision-makers lose track of goods in transit due to the lead time. This phenomenon has been reported as a cognitive limitation that leads to coordination risks in the supply chain that results in higher inventory/costs (Croson et al., 2014). Phantom ordering is another phenomenon that has gained the attention of the community which discusses the practical problem of customers placing orders and prematurely canceling them that lead to incorrect demand signals upon which the supply chain is triggered (Sterman & Dogan, 2015).

Information sharing through the beer game has achieved wide attention in the literature. It is reported that sharing downstream information with upstream partners is more useful to mitigate the bullwhip effect. Research also underscores the importance of information overload that might confuse decision-makers. Therefore, it is doubly important to select what information to share and when to share with supply chain partners to mitigate the bullwhip effect. Interestingly, the presence of disruptions or supply overweighting has been known to lead to the reverse bullwhip effect which has received scarce scientific attention (Perera et al., 2020). Although a proven experimental method, the beer game is challenging to code and implement primarily due to its interactions. It will still play a significant role in the future growth of BSCM research as it provides avenues to comprehend complexities relating to supply chain interactions.

## 3.3 Buyer-Supplier Interactions

Supply chains connect players located at different echelons. Thus, coordination and contracts are salient for an efficient supply chain. Theoretical research on supply chain coordination investigates how information sharing among supply chain partners and supply chain contracts (incentive alignment schemes) might lead to mutually beneficial outcomes. This strand of research assumes supply chain actors as self-interested optimizers strictly adhering to rationality assumptions within game theory. However, the reality deviates significantly from rational theories as decision-makers are handicapped by cognitive limitations (Chen & Wu, 2019). Game theory has many implications on this strand of research. Framing, context, and social manipulation play significant roles as environmental factors that affect supply chain contracts and coordination.

### Buyer-Supplier Interactions in the Beer Distribution Game

Supply chain decisions are often made in a decentralized manner with incomplete information. Supply chain partners might only have access to their own data. They might not be aware of each other's information sets and/or decision-making processes when they interact. Additionally, they could purposefully or unintentionally distort their own data. These informational restrictions contribute to coordination breakdowns and ineffective results seen in both real-world and laboratory research (Chen & Wu, 2019). A classic example is the bullwhip effect that persists in the beer game (Forrester, 1958; Sterman, 1989) where four echelons in the supply chain aim to optimize their individual outcomes at the expense of making the entire supply chain inefficient.

Literature has widely reported the behavioral causes that influence bullwhip effect while also highlighting supply line underweighting where inventory on hand is short of target inventory levels (Croson et al., 2014). Information transparency (of point of sales data) and learning and communications (Wu & Katok, 2006) between buyers and suppliers are presented as remedies to overcome the bullwhip effect. Maintaining coordination stock to mitigate for risk arising due to behavioral uncertainty has been proposed as another remedy (Croson et al., 2014). However, a lot remains to be understood in the context of mitigating the bullwhip effect as finding a holistic answer that entirely eliminates the bullwhip effect is far-fetched.

### Supply Chain Contracting

Modern supply chains cut across multiple continents connecting a diverse range of stakeholders scattered all over the world. This has necessitated the existence of supply chain contracts. Most BSCM work on supply chain contracting has revolved around the phenomenon of double marginalization. Double marginalization occurs when different stakeholders in the same industry at different echelons apply their own markup prices. This alludes to the concern of adding multiple markups leading to inefficiencies across the supply chain due to decentralized decision-making (Chen & Wu, 2019).

Extant literature in supply chain contracting concentrates predominantly on a two-echelon supply chain. The supplier often makes a take-it or leave-it offer with specific contract parameters. The buyer must either accept or reject the offer. The experiments involve a negotiation process structure as an ultimatum game (Chen & Wu, 2019). Essentially, supply chain contracting takes the form of a Stackelberg competition where, more often than not, the supplier takes the role of the Stackelberg leader while the buyer responds sequentially assuming the role of the follower (von Stackelberg, 2010).

Once a buyer accepts an offer, an inventory decision needs to be made. The inventory decision follows two approaches. The first revolves around the buyer facing stochastic demand subject to a cumulative distribution at the presence of an exogenous market price. The buyer must finalize an order quantity prior to demand realization. This approach mimics the conditions faced by a news vendor. The second approach follows a bilateral monopoly where the retailer experiences a sloping demand allowing the buyer to select the ordering quantity. The selected price in turn determines the corresponding quantity (Chen & Wu, 2019).

The bilateral monopoly setting is less complex when compared to the news vendor setting given the demand behavior. This implies that using the bilateral monopoly setting is advantageous in better comprehension of reference-dependent behavior and fairness preferences. Contrarily, the news vendor application offers the pathway to findings which are more relevant to the practical world (Chen & Wu, 2019).

Supply chain contracts can be examined as per their respective demand behavior, i.e., stochastic and deterministic. Several supply chain contract types are prevalent in the stochastic demand literature. In buyback (BB) contracts, the retailer pays the supplier a wholesale price for each unit ordered with the option of receiving a rebate from the supplier for unsold units. A revenue-sharing (RS) contract incentivizes the supplier since the retailer would pay the supplier a portion of its revenue for each unit sold. Both are risk-sharing contracts that aim to balance the utility of the retailer and the supplier. Literature has demonstrated that they are mathematically equivalent and capable of coordinating the supply chain (Cachon & Lariviere, 2005). Wholesale price (WP) contracts can be either push or pull depending on the nature of the buyer-supplier relationship. In a push scenario, the risk is transferred to the retailer while a pull scenario shifts the risks to the supplier and leads to better channel efficiency. Quantity discount (QD) contracts consider scenarios such as all unit discounts, sales target rebates, incremental discounts, and advance purchase discounts (Kalkanci et al., 2014; Wu & Chen, 2014).

Supply chain contract research embedded upon deterministic demand focuses on linear demand settings which provide the buyer to determine the sales price. Studies in this domain benefit from limited externalities while allowing human-to-human interactions. Deterministic demand-related studies also employ contract designs that align with those employed for stochastic demand with a bias toward QDs. Two-part tariff (TPT) is a common phenomenon studied under this context where the buyer should pay a lump sum amount in addition to the wholesale price (Ho & Zhang, 2008). Other studies examine whether the number of blocks in a price contract has any effect, as well as the effect of social preferences and fairness (Loch & Wu, 2008).

Given the asymmetry of information in the real world, there is a lot of focus on studying the effect of this on supply chain contracts. With imperfect information, the importance of perfect demand information has been proven through research

(Kremer & Van Wassenhove, 2014). However, this is a domain that has ample room for future work.

Meanwhile, bargaining is also an essential element in supply chain contracting that has received a fair share of attention. In the real world, there are back-and-forth offers and counteroffers that precede the finalization of a contract. Theoretically, this has some elements that connect to the ultimatum game discussed under behavioral economics. An initial study that aims to explain bargaining in a supply chain contract setting introduces a structured bargaining (SB) protocol that includes a "cheap talk" stage preceding the traditional ultimatum bargaining (UB) protocol that is inspired by theory (Haruvy et al., 2020). Bargaining has not been sufficiently explored in BSCM research and provides a valuable avenue of investigation that can enrich both literature and practice.

One must not neglect the importance of investigating noncontractual decisions which are a salient part of modern supply chains. These are primarily grounded on existing channel relationships which sometimes lead to one party benefitting due to an investment made by another party. Economic literature defines this as the holdup problem. There is a recent trend in BSCM literature where this problem has been reported through numerous practical angles (Davis & Hyndman, 2019; Davis & Leider, 2018; Eckerd et al., 2013).

## Contracting and Mechanism Design

BSCM literature features several contracting and mechanism design perspectives. The traditional rational perspective considers contracts with a real-world relevance that are slightly modified for the experimental setting. This allows the findings to have implications on real-world supply chain decisions.

The behavioral perspective extends beyond the traditional rational perspective in terms of discerning behavioral principles. Some of the initial works in this domain examine how decision-makers respond to specific ways in which the contract is presented (Ho & Zhang, 2008; Lim & Ho, 2007). Nonoptimizing behavior and loss aversion have prominently featured in these studies. The data are subsequently mathematically modeled to make inferences. A subsequent stream of literature has examined the behavior of the supplier in setting contract parameters (Kalkanci et al., 2014). Overall, the findings underscore the bounded rationality of human decision-makers and advocate the importance of designing simplified contracts (Chen & Wu, 2019). Another paper investigating BB contracts goes beyond this in arguing the importance of factoring in behavioral factors to the contract design as well as going a step beyond in calibrating contracts to focus on individual behaviors (Becker-Peth et al., 2013).

It is imperative to understand the importance of grounding theoretical and empirical information when designing contracts. Given the bounded rationality of decision-makers, calibrating contract designs targeting specific individuals or the aggregate population are tweaks that are likely to provide more practical results given the heterogeneity of supply chain decision-makers (Becker-Peth et al., 2013). Future research can examine the behavioral implications of bargaining and negotiating in developing contracts. In addition, understanding how and when behavioral elements (i.e., decision biases) affect decisions in the contracting process are also important to manage triggers in the contract design.

Future research can go beyond the assumption that behavior of supply chain decision-makers is rational by considering heterogeneity. This would imply that contracts could be customized based on the behavior of relevant stakeholders to nudge them toward more optimal decisions (Chen & Wu, 2019). Moreover, trust plays a significant role in supply chain contracts, and this can be further examined in the future. Further investigation into exogenous factors that affect contracting decisions such as heterogeneity, framing effects, and social preferences would be advantageous. It is also important to assess the interlink between such factors thoroughly. Further understanding the effects of loss/risk aversion and how various levels of incentives on supply chain contracts would be valuable. One should also underpin the dearth of literature investigating dynamic settings as most supply chain contracting literature focuses on static settings which do not allow the proper reporting of learning and reacting.

## 3.4 Trust and Trustworthiness

Trust and trustworthiness are especially important for any supply chain. Trust relates to behaving voluntarily to accept vulnerability due to an uncertain behavior of another expecting a positive outcome. Trustworthiness is to behave voluntarily to avoid taking advantage of the other party's vulnerabilities amid a self-serving decision that conflicts with the other party's objective (Özer & Zheng, 2019). One cannot find any business transactions that are devoid of at least some degree of trust and when people take decisions based on trust, which brings along a certain sense of risk. The primary purpose of contracts is to mitigate the risk as it is widely accepted that trust and trustworthiness are insufficient in getting you across the line (Özer & Zheng, 2019).

Ensuring transparent flow of demand data across the supply chain has been a primary focus of many supply chains. Initiatives such as vendor-managed inventory (VMI), collaborative planning, forecasting, and replenishment (CPFR), electronic data interchange (EDI), and radio frequency identification (RFID) have enabled such data flows in spite of challenges cutting across the interaction points of multiple firms in a supply chain (Brinkhoff et al., 2015). Results show that some relationships lead to trust and collaboration while others wither away. Although there are some arguments claiming that trust in supply chains cannot be researched through lab experiments, this claim is debunked by the literature (Özer & Zheng, 2019).

Quantitatively measuring trust and trustworthiness has proven to be a challenge toward effective BSCM research. Literature in economics that primarily thrive on the investment game use game-theoretic analysis to measure trust and trustworthiness. From a more supply chain-oriented standpoint, the forecast-sharing game has been used to understand trust. This game hinges on the willingness of the trustor to accept the trustee's information. Additionally, the trustee is to initially share the forecasts, which helps to develop trustworthiness following trusting behavior. However, the highlight of the forecast-sharing game is that it allows us to measure the impact of exogenous factors as both the trustor and trustee are aware of business uncertainties that are beyond the control of the participants. Moreover, unlike the investment game, the forecast-sharing game focuses on trust and trustworthiness with respect to information sharing as opposed to transfer of property.

Subsequent studies have built on this branch of study by deeply exploring the effects of trust and trustworthiness in BSCM using games such as the forecast-sharing game (Choi et al., 2020; Özer et al., 2014). The fundamental premise here is whether the vendor should assume a risk in accepting the forecast presented by trusting the downstream partner. The results of the studies indicate that there is a continuum of trust and trustworthiness that exists between the vendors and the suppliers.

The seminal authors in this domain themselves argue the importance of developing structurally new games and experimental designs to advance our understanding of trust and trustworthiness (Özer & Zheng, 2019). Such investigations will shed further light toward comprehending the role of trust in numerous supply chain interactions while also understanding the effect of various external factors on trust. Moreover, our understanding of trust in specific scenarios would provide some degree of transferability to similar scenarios.

### Building Blocks of Trust and Trustworthiness

Trust and trustworthiness are reliant upon how, when, and why it would be required. A framework containing four building blocks that relate to trust and trustworthiness is introduced (Özer & Zheng, 2016). The four building blocks are as follows:

1. Personal values and norms (e.g., aversion to risk, inequality, and betrayal)
2. Market environment (e.g., investment risk, market uncertainty)
3. Business infrastructure (e.g., culture, institution, and social networks)
4. Business process design (e.g., process of engagement, team decision dynamics, and reputation system design)

*Personal values* are a prime cause determining the willingness of an individual to trust someone else. This would assume three primary dimensions: risk of being worse off than before (risk aversion), risk of being worse off than the trustee (inequality aversion), and risk of being betrayed by the trustee (betrayal aversion) (Özer & Zheng, 2016). It is possible that personal values can also be shaped by the status of an individual in the supply chain as well as other background factors (Özer & Zheng, 2019).

*The market environment* plays a vital role in determining trust and trustworthiness in a supply chain. Entities would be somewhat reluctant to trust one another during a period of strife such as an economic crisis or a pandemic as opposed to a smooth business climate. Experimental works confirm that what is at stake has a significant role in determining the reaches of trust and trustworthiness (Özer et al., 2014).

The impact of culture on trust and trustworthiness is discussed under *business infrastructure*. For instance, research reveals that Asian cultures demonstrate a high degree of collectivism. This leads to an "us versus them" mentality creating an in-group bias toward trust whereas out-group members are seen with a hue of suspicion. Individualistic cultures observed in the western world have less of an in-group bias (Özer & Zheng, 2019). These observations are galvanized by the findings reported through a lab experiment connecting participants from China and the USA that consider the role of culture in trust and trustworthiness (Özer et al., 2014).

The final building block relates to *business process design*. Here, the focus is on building trust between the two parties through the presence of transparent processes. For instance, a buyer would compare ratings of a vendor before choosing to buy from them. Additionally, the salience of information sharing toward attaining high levels of trust and trustworthiness is highlighted.

Our understanding of trust and trustworthiness in BSCM remains limited at the time of writing. Therefore, this promises to be a very fertile research avenue due to its importance in modern supply chains that transcend both intra- and inter-organizational boundaries. While lab experiments are a proven method to advance our understanding, one must not discount the possibilities presented through mathematical modeling.

## 3.5 Competitive Bidding and Auctions

This strand of BSCM research explores buyer-supplier relationships within a competitive environment. While price is a key determinant of supplier selection, learning how to select and collaborate with the right suppliers is vital. Auctions have been widely studied under experimental economics specifically under two auction formats. Under forward auctions, the seller who wishes to sell one unit is the bid taker with many buyers in the picture. Reverse auctions occur when there is one buyer with multiple sellers. A setting where the buyers know the demand distribution and privately sets their prices is defined as an independently known private value (IPV) condition. Auction formats determine (i) the bid-submitting process, (ii) selection of the buyer, and (iii) price (Elmaghraby & Katok, 2019).

### Forward Auctions

Forward auctions entail four primary formats. First, sealed-bid first price (SBFP) requires all buyers to submit a sealed bid at a given time with the highest bidder winning. Second, Dutch auctions (descending price) imply a scenario where the seller begins at a high price and constantly decreases the price. The first buyer to agree on a price is the winner. The decreasing auction price is defined as the "Dutch clock" in this context. Third, English auctions (ascending price) relate to the price commencing at a reservation level and ascending constantly. The price ascension is termed as the "English clock." The winner is the last buyer left in the auction. English auctions can be conducted as open (dynamic) auctions as well. Last, sealed-bid second price (SBSP) only differs from SBFP where the winner is the buyer with the second highest price (Elmaghraby & Katok, 2019). Seminal work suggests that under perfect conditions all four auctions should yield revenue equivalence (Vickrey, 1961). This has been proven to be inaccurate when human behavior is involved (Elmaghraby & Katok, 2019). Thus, BSCM research on auctions has a bright future based on the rich body of works stemming from behavioral economics.

Revenue equivalence is an appealing research avenue which has registered many works in the past. Comparing different auction formats and understanding the interrelation between the "clock" and human behavior is fertile soil for future works (Elmaghraby & Katok, 2019; Katok & Kwasnica, 2008). The "sealed-bid effect" is another widely debated topic where sealed-bid auctions have registered more aggressive bidding behavior than the risk-neutral Nash equilibrium (RNNE) condition (Haruvy & Katok, 2013). While risk aversion has been flagged as an explanation, this does not justify such behavior in SBSP or third-price and random-price auctions. Interpersonal comparisons such as spite, learning, and regret have also been attributed as explanations for the "sealed-bid effect" (Elmaghraby & Katok, 2019). Mathematical and experimental proof suggest that regret has a special importance in auctions. Winner's regret (which occurs when the buyer feels she paid more) and the loser's regret (when the loser regrets her inability to buy the product) are interesting domains for future works (Engelbrecht-Wiggans & Katok, 2008). Another strand of potential investigation could be understanding auctions in the presence of asymmetric bidders which are more akin to the practical context (Aloysius et al., 2016).

### Reverse Auctions

While forward auctions tend to predominantly focus on price, reverse auctions consider a myriad of supplier attributes (i.e., quality, sustainability, reputation, proximity, etc.) in the buying decision. Reverse auctions generally tend to be nonbinding due to complexities in fully evaluating the suppliers based on the above conditions. This implies that the buyer might even switch suppliers after selection in case of any discrepancies. To this end, buyer-determined (BD) auctions are important to assess the nonprice attributes in the supplier selection process. There can be three settings based on this: (i) Suppliers are aware of their attributes and those of their competitors; (ii) suppliers are aware of their attributes but unaware of those of their competitors; and (iii) suppliers are completely unaware of their or their competitors' attributes. If condition (i) is met, the auction is a price-based (PB) open-bid auction. Ostensibly, the open-bid format has full transparency while the sealed-bid format has no transparency. However, in either case, the buyer surplus (difference between quality and the buying price) is what determines the buying decision.

Research indicates that the buyer profits from the suppliers having less information. Sealed-bids as well as the supplier being unaware of the attributes of competitors lead to aggressive bidding (Haruvy & Katok, 2013). This situation exacerbates when the supplier is unaware of his own attributes as well as his competitors' leading to a point where suppliers cease submitting bids leading to a collusive equilibrium (Fugger et al., 2016).

**Price-Related Issues in Auctions**

Prior research in marketing outlines the importance of the starting price on auctions as they form anchors. It is also argued that low starting prices encourage herding behavior that compels the bidders to escalate their commitment as the auction progresses (Elmaghraby & Katok, 2019). Similar to starting prices, reference prices that act as benchmarks for the bidders can also act as pricing anchors.

Marketing literature has addressed the effect of price in auctions while there is a growing body of literature in BSCM that is turning its attention to it. There are ample opportunities to contribute to the body of literature by inspecting price-related anchoring in auctions. Interested readers would benefit from reader Sect. 15.5 of The Handbook of Behavioral Operations (Donohue et al., 2019).

**Supply Risk**

Supply risk has become a salient concern in modern supply chains. Therefore, this is an important avenue of study within auctions. Prior research has investigated how supply reliability affects buyer decisions (Gurnani et al., 2014). The findings highlight that those in a laboratory setting tend to do multiple sourcing while normative results indicate the importance of single sourcing above particular probability levels for supply reliability. Despite the burgeoning importance of this mitigating supply risk, this area has not received adequate attention from a BSCM perspective. There are many opportunities to expand our understanding of how supply risk may affect behavior in auction from both forward and reverse perspectives (Elmaghraby & Katok, 2019).

In sum, research into auctions from a BSCM lens has ample room to grow. How bidders are affected by others' bidding behavior has always been an important area to understand further within this domain. Trust, trustworthiness, and the moral hazard problem are some of the emerging areas of focus within this study stream worthy of further investigation. Moreover, the role of negotiations (sequential or postauction) in auctions needs to be further explored. Settings where different types of auctions are employed to source different SKUs also need to be better understood. The decision process of how and when bidders enter an auction and on what information they make decisions is also a key question. Whether experience or long-term relationships change bidding behavior is another important question (Elmaghraby & Katok, 2019). Those who are interested in the finer details of auction design are encouraged to read Sect. 15.7 of The Handbook of Behavioral Operations (Donohue et al., 2019).

## 4 Current and Emerging Concerns, and Directions for Future Work

Diversity, inclusion, and ethics are perennially important in BSCM research. One of the main criticisms against the current body of literature is that the results are mainly based on responses from western, educated, intellectual, and rich democratic

(Henrich et al., 2010). This refers to the lab experiment participants being mostly from the USA or Europe. There are however exceptions as some studies have reported participants from countries like China, Colombia, and Sri Lanka (Castañeda et al., 2019; Hewage et al., 2022; Özer et al., 2014; Zhao et al., 2016). One cannot undermine the effect of culture in the decision-making process as reported in some studies (Özer et al., 2014). Therefore, it is important to encourage more research reporting behavioral results from participants distributed across the world to ensure a more holistic approach of BSCM research.

Ethics has also taken center stage in discussions relating to BSCM. Many universities have made it compulsory for researchers to obtain ethics approval to conduct behavioral experiments. This trend will continue. Another ethical dilemma discussed prominently in numerous circles revolves around ensuring that experimental designs do not mislead participants. Some journals are very specific about the design being straightforward so that no information is withheld from the participants (Katok, 2019). The focus of studies should also be confined to ethically acceptable supply chain contexts and should refrain from scenarios which promote unethical behaviors. Researchers must pay special attention in drafting the cover stories provided to participants to avoid misconceptions. It is pertinent that the participants are not biased toward a particular action by any form within the data collection process as that might taint the outcome. The development of incentives needs to be well-tuned toward what the researcher aims to measure as an erroneous incentive scheme could easily digress the participants from the task at hand.

Like many other fields, data must be treated with utmost secrecy in BSCM research as some studies are likely to include sensitive data. The storage and processing of data must be done conforming to the highest standards. Analysis and interpretation of data should also be done carefully to report the realities in the real world using parametric or nonparametric statistical methods conforming to the characteristics of the data that were collected.

There is emerging interest in understanding the behavior of different actors of the supply chain. More emphasis is afforded to understanding heterogeneity and gender biases in decision-making. While initial works mostly explored individual decisions of managers, the research agenda has evolved more to examine behavior of individuals and teams in different echelons of the supply chain (Donohue et al., 2019). Interactions between different echelons (Chen & Wu, 2019) and the cultural barriers are also gaining prominence (Özer et al., 2014).

The effects of behavior on sustainable decision-making were the focus of a recent special issue of the *International Journal of Production Economics*. This seems to be an emerging stream of literature exploring the behavioral implications on incorporating environmental and social sustainability in supply chain decision-making. Other emergent trends in BSCM research relate to the behavioral applications in product development, retail supply chains, sourcing and procurement, healthcare supply chains, warehousing, and logistics. The future holds many opportunities for BSCM scholars to continue developing this literature and further contribute to supply chain practice.

## 5 Conclusion

Research on human behavior in supply chain management has experienced ever increasing attention over the past few decades. Supply chain managers are increasingly more aware of and interested in understanding how individuals and their behavior can impact supply chain decisions. Collaborative research that engages practitioners would especially add value to this body of knowledge given the theoretical and empirical implications of BSCM research.

This chapter reviewed the key substreams of BSCM research. The aim was to condense the extant knowledge and highlight future research directions within the confines of the chapter. Researchers who are new to BSCM can dive deeper by perusing relevant review papers and handbooks (Arvan et al., 2019; Donohue et al., 2019, 2020; Perera et al., 2019, 2020). With numerous top journals opening their doors to BSCM research through special issues and dedicated departments, it is important for the research community to continue focusing on developing and testing new theories and extend the empirical investigations.

Supply chains are growing in terms of their global footprint by connecting vendors and customers scattered across the globe. This comes with increasing human touchpoints that require interactions between people with unique identities. Managers cannot simply rely on normative solutions provided by information systems. Proactive engagement of supply chain actors is imperative for effective design and operation of our supply chains. Further attention to industry-oriented research can provide new avenues for practitioners to rethink how they operate and find innovative solutions to pairing information systems and human intuition.

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# Part III

# Logistics and Transportation

# Air Cargo and Supply Chain Management

Rico Merkert

## Contents



**Abstract**

Due to the COVID-19 pandemic, geopolitical tensions, and global supply chain disruptions and also due to the boom in e-commerce, air cargo has gained in importance and visibility in supply chain planning and management. Typically, as a by-product of combination carriers, it has been the forgotten child in the aviation industry and not been managed well in many supply chains. Record high yields and profit margins have not just resulted in air cargo being taken more seriously but have also created an opportunity for the sector to set itself up for the future, including new business models, as well as horizontal and vertical supply chain integration. Questions around fleet renewal or reinvestment of the unprecedented cash flows into digitization and transformation of air cargo firms are shaping the future of international but also domestic supply chains. Sustainability concerns, a looming recession, physical and online disruptions to global supply chains, and the drone revolution all add to the changing environment where only one thing is certain, an increase of uncertainty and that needs to be managed well for supply chains to function.

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**Keywords**

Air cargo · International freight logistics · Global supply chain management

## 1 Introduction

At the Supply Chain Summit on Optimization through digital transformation in Sydney in June 2022 it was somewhat surprising to many that every panel and discussion session involved some element of air cargo. For many years, supply chain managers (apart from those responsible for air freight) would rarely involve themselves in conversations related to air cargo, which may have been due to capacity never really being an issue and freight rates sort of being affordable. Air cargo carriers have, as a result, traditionally been loss-making volatile businesses, not least because of substantial government intervention, inherent business model flaws, ever declining yields, a lack of a level playing field in the sector (Merkert et al., 2017), and also lacking recognition in global supply chains. This has, in many cases, led to air cargo divisions of combination carriers such as Lufthansa, Qantas, or Singapore Airlines being neglected and often disadvantaged through unfavorable joint-cost allocation practices within those airline groups (Morrell & Klein, 2020); exacerbating the financial weakness of the cargo arms of such carriers (Reis & Silva, 2016).

With COVID-19 hitting the aviation sector hard and concerns around the carbon footprint of aviation rising (Gössling, 2020), some commentators have been wondering whether the air freight industry will ever return to commercial viability and whether it may indeed have a future (de Rugy & Leff, 2020). No longer is it just cargo airlines who are seen as financially volatile, but due to the pandemic and resulting high debt and dwindling asset values, it is now also full-service carriers who are at risk, as they are overly reliant on high yielding premium passenger traffic. This is problematic for air cargo, as those combination carriers typically move substantial freight volumes in the belly-hold of their passenger aircraft (e.g., Merkert & Ploix, 2014). As a result, cost transformation and automation (i.e., non-contact delivery) programs have been implemented at many air cargo logistics businesses, putting pressure on jobs not just on the demand but also on the supply side. While air cargo used to be fast, reliable and reasonably affordable, during the pandemic it has often been disrupted due to border closures, travel restrictions, belly-hold capacity gone (due to passenger planes not being flying). And yet, it was still better than nothing or the alternative slow and often also severally disrupted ocean shipping. In the new normal of business operations of 2022/23, where air freight rates have started to moderate, air cargo remains vital for shipment of time critical and high value goods. A good example was 2022 boom of shipments of baby formula products from Europe and Australia to the USA, who experienced a manufacturing crisis resulting in severe shortages of infant formula and were hence reliant on sourcing expensive but vital global supply chain alternatives that had to due to the urgency of the supply shock involve air freight. What this shows is that despite its significant carbon footprint and cost premium, supply chain planners will most likely never be able to manage their supply chains without air cargo, be it on a routine or contingency/emergency basis.

This chapter attempts to introduce the wider supply chain management community to air cargo by first describing the industry and the business models it comprises. We then analyze the current (much brighter than first anticipated but increasingly volatile) situation and provide an outlook for the sector, which could potentially be the golden decade for air cargo logistics or alternatively going back to being the forgotten cousin that is poorly managed in procurement and supply chains. That outlook is based on a discussion of challenges and opportunities presented to the various players in the air freight industry, such as geopolitical tensions, volatility in demand (looming recession), aging infrastructure but then also technological advancement and sustainability expectations.

## 2 The Post COVID-19 Air Cargo Business "New Normal"

Before providing an outlook to what the air cargo logistics sector may look like in the future, this section is an attempt to take stock to assess what has happened since the beginning of the pandemic and to portray what is currently described to be the "new normal" for the air cargo business. While it has been shown that air cargo is resilient to exogenous shocks such as the global financial crisis (Alexander & Merkert, 2021), few predicted that COVID-19 would result in the sectors' strong financial performance during the pandemic and hence a resulting potential decade of opportunities (Merkert, 2023). As shown in Fig. 1, air cargo volumes have deteriorated immediately after the initial COVID-19 shock but then experienced a V-shaped quick recovery, similar to that following the global financial crisis that ended in early 2009. While the "new normal" had in its early days of 2021/22 the potential for a golden decade for the air cargo business (Merkert, 2023), in late 2022 and early 2023 global economic headwinds, increasing sureshoring and a general shortening of global supply chains resulted in uncertainty and softer demand.

Different to previous global shocks, the COVID-19 crisis and related travel restrictions (e.g., border closures) have resulted in a very significant decline in belly-hold capacity in passenger aircraft, while dedicated freighter capacity has increased by up to 20–30% on a monthly basis in 2020/21 compared to 2019. While at the global level, the total air cargo capacity had decreased (due to the loss of belly-hold capacity in passenger aircraft), it became apparent (in the data but also to the media and our students) that global supply and value chains are the backbones of many industries and economies. Contrary to capacity, global air cargo demand and output increased during the pandemic, as shown in Fig. 2. This was most evident in North America but also in all other regions par Latin America.

It can be argued that air cargo did benefit from the need of global supply chains to continue to function, the increased demand for urgent delivery of medical and personal protective equipment that could not be delivered on time by the shipping industry, the boom in e-commerce and from increasingly congested container ocean shipping supply chains (something that has worsened since, at least temporarily, on

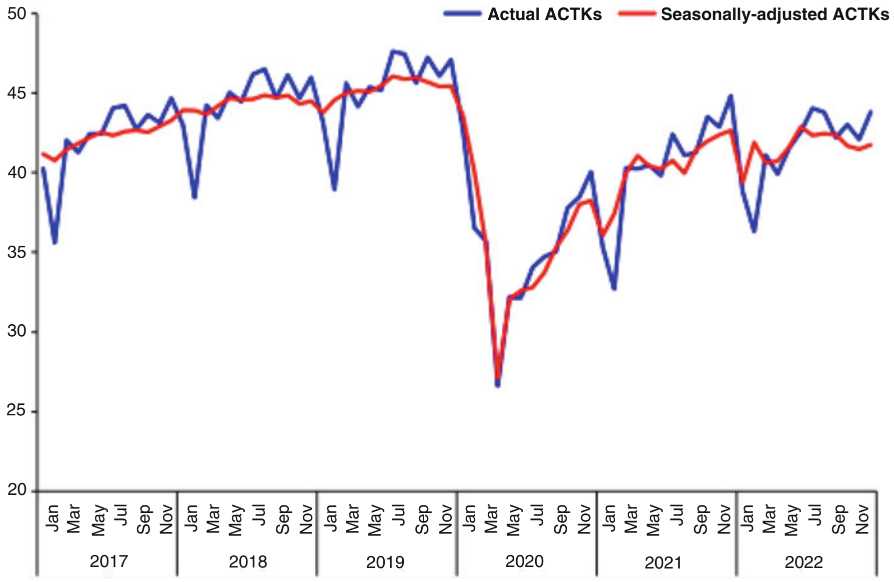


**Fig. 1** Industry-wide available capacity in cargo ton kilometers (bn per rolling 3 m period)

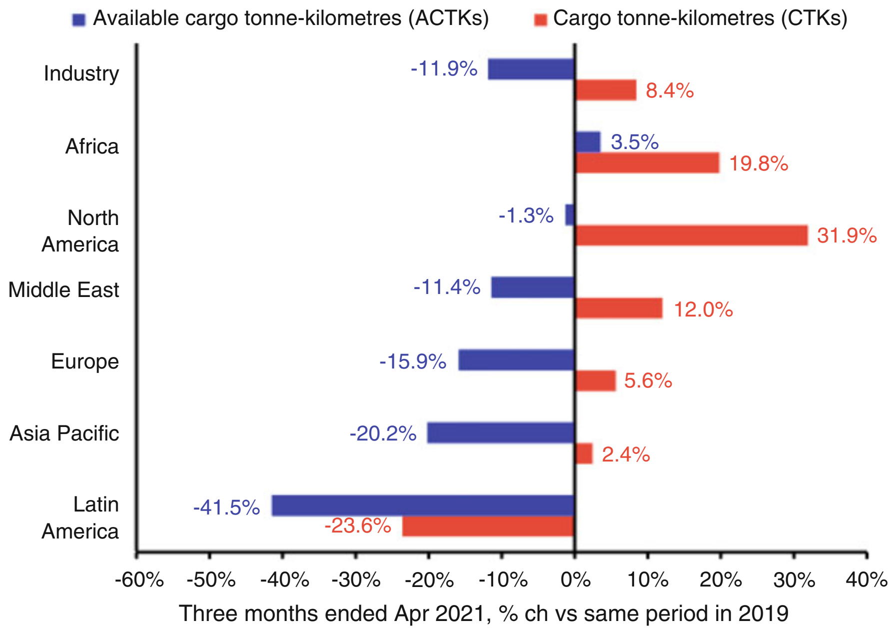


**Fig. 2** Global air cargo capacity and output

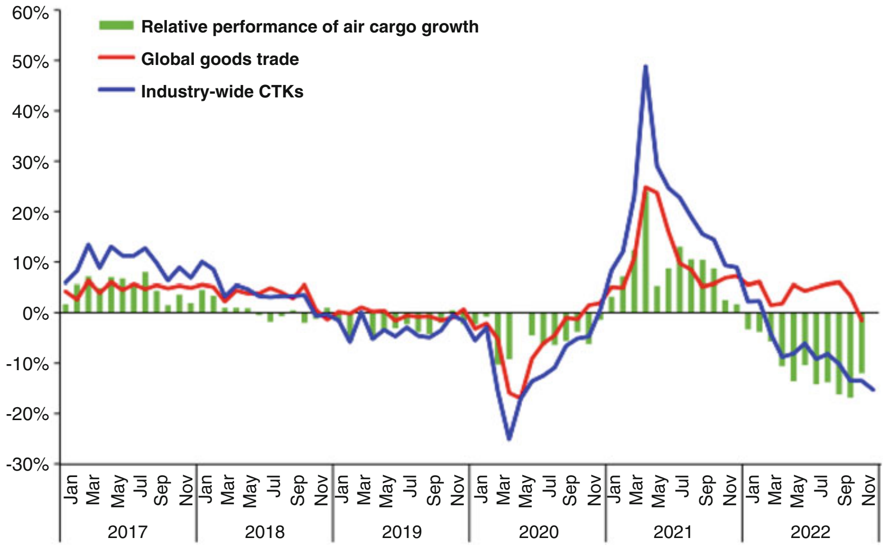


**Fig. 3** Industry-wide cargo ton kilometers (CTKs) and global goods trade

certain shipping lanes, most notably those affected by the chaos and shutdown of the port of Shanghai in 2022). With capacity decreasing and demand or output increasing at the same time, the industry experienced higher air cargo load factors than pre-COVID-19 and much higher air cargo yields. This has resulted in air cargo operators becoming financially more viable and for air cargo to become much more competitive against ocean shipping lines not only in terms of relative rates but also in terms of perceived value. However, this is not something all air cargo players in all jurisdictions have been able to convert into higher profit margins equally. It also does not tell us what is going to happen in the future.

In fact, things have become more challenging again since the end of 2021 and this time for both air cargo airlines and supply chain managers of companies that need to ship goods. Figures 3 and 4 show that air cargo industry wide output has sharply contracted since mid-2021 with a 15.3% year on year contraction in November 2022 which was also 7.4% lower than the CTKs) for the same month in 2019 (pre-COVID 19). What Figs. 3 and 4 also show is that air cargo performance (when measures in CTKs) is strongly correlated with a number of economic indicators and predictors such as global goods trade or the global PMI new export orders component. This makes prediction both the capacity and output of the air cargo industry much easier, as all a supply chain planner would have to produce is a forecast of those wider economic and business activity proxies which would then allow for relatively accurate air cargo growth forecasts. This in turn could be used for demand and cost planning in supply chains that rely on international and/or long distance freight transport.

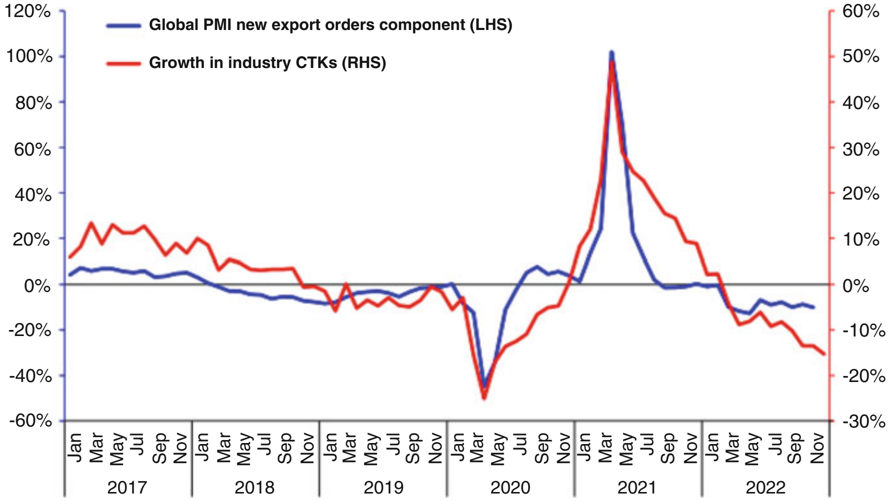


**Fig. 4** Relationship between CTK growth and global new export orders

In response to demand softening and jet fuel as well as finance cost rising (due to central banks starting an interest rate cycle), most operators have adopted "cash is king" as their mid-term strategy. This, of course, is a strategy that is not forward looking but more a means of surviving, which then also has knock-on effects on all other elements of global supply chains. It is very likely that volatilities are going to remain for the foreseeable future, agility will be a strength that will not only form firm competitive advantage for air cargo players but also global and domestic supply chains. What is also sought after is leadership and strategic foresight. While not all air cargo players have generated high profit margins, for many the pandemic has let to substantial profits and they are now asking themselves how to put those funds into good use; often in partnership with suppliers and/or customers such as freight forwarders. Should they purchase new freighter aircraft, invest in new technology or push digital transformation or just sit on this cash as a war chest for the recession that seem to have commenced globally? Is what strategists foresee next going to be another volatility event or going back to the unprofitable neglected days. Whatever it is, the less than one year ago predicted dawn of a golden decade for the air cargo supply chain industry (Merkert, 2023) seems increasingly unlikely.

In terms of early indications of what the future or "new normal" may look like, it appears that in most jurisdictions high value express shipments (e-commerce) have weathered the storm particularly well, followed by trucked cargo. International air cargo has had some good months but is much more volatile and often highly dependent on international passenger air services, which have suffered unprecedentedly and have taking much longer to recover. Those carriers solely depending on freighter aircraft have further experienced significant disruptions due to the Russia/Ukraine conflict, with many of them losing business or having incurred significant additional cost due to necessary detours or simply due to the substantial increase in fuel cost. A good example for this is Russian based Volga-Dnepr Group, a dominant player in the movement of oversized and heavy shipments. They have been sanctioned and while that may be justifiable, it resulted in much of their capacity no longer being accessible for global supply chains. While this will most likely be a temporary disruption, it shows how fragile and dependent some supply chains are on air cargo. As such, it is worthwhile looking at the different air cargo business models to gain a better understanding around which of those may hold the future for this sector and which are most important to supply chain management.

## 3 New Players and New Business Models

As outlined in the previous section, air cargo as the long forgotten and neglected child of combination carriers has experienced a revival since the COVID-19. The pandemic compounded with other disruptions such as semi-conductor shortages or geopolitical conflicts, have identified the reliance of global supply chains and entire economies on the functioning of air cargo logistics. Before the pandemic, air cargo typically used to be loss making (Alexander & Merkert, 2017; Morrell & Klein, 2020). Cargolux, for example, as one of the leading pure cargo operators is known for in the past having chronical financial issues and repeatedly requiring government support. That very same airline achieved record results in 2020 with an EBIT margin of 31.3% and then again a record year in 2021 with Earnings Before Interest and Tax (EBIT) of US$ 1.72 billion, an increase of 73% over 2020 (Cargolux, 2022) due to air freight being even busier and e-commerce booming even more in 2021.

Unsurprisingly, the unprecedented demand and profitability of air cargo has resulted in new players entering the market and novel business models being adopted. Especially the e-commerce boom combined with the lockdowns in many jurisdictions have accelerated the trend of air cargo becoming increasingly a door-to-door affair (Merkert & Bushell, 2021). While all air cargo business models, as summarized in Table 1, recovered quickly from the early COVID-19 demand shock and experienced an increase in profitability, going forward some may be better equipped for growth and profit margins.

For example, all-cargo carriers did benefit more during the first phase of the COVID-19 pandemic due to the sudden demand for personal protective (PPE) and medical equipment shipments and them having dedicated freighters available. This advantage was amplified by belly-hold capacity of combination carriers being substantially reduced or removed entirely due to travel restrictions and border closures grounding large parts of the global passenger aircraft fleet. As a result, all-cargo carriers have not only been highly profitable during the pandemic, but new market entrants have occurred, such as Aliscargo in Italy, ZFG Air in the UK, and Imex Pan Pacific Group (IPPG) in Vietnam.

Combination carriers have reacted to that operating environment and elevated air freight yields by chartering more dedicated freighter aircraft (which meant even more demand for ACMIs such as Atlas/Polar Air) and by using both the belly and above floor holds of their passenger aircraft for freight. The degree of converting of

**Table 1** Prominent air cargo business models

| Corporate objectives | Passenger/Cargo Operations | | Cargo Operations | | |
|---|---|---|---|---|---|
| | Belly | Belly flex/combination | All-cargo | ACMI/charter | Integrators/express |
| **Cargo strategy** | Value cargo as an important by-product of the core passenger business | View freighters to capture high market shares of core routes, leveraging belly-hold network | Airport-to-airport transport of cargo is the primary business task | Airport-to-airport demand (and matching supply) is the primary business task | Primarily provide express network capacity for premium air cargo products |
| **Customer marketing strategy** | Freight forwarders, some shippers, government mail contracts | Freight forwarders, shippers, government, other airlines and integrators | Freight forwarders, shippers, government, other airlines and integrators | Some freight forwarders, government, other airlines, integrators | Mainly direct shippers |
| **Network design strategy** | Centered around passenger gateway airports, mix of long, medium and short haul routes. Typically, member of an airline alliance | Similar to belly carriers, use of freighters as supplement on high-density routes. Some cargo only destinations | Cargo focused, including multi-leg or asymmetrical stages | No network. Routings are determined by clients | Hub and spoke, with distribution centers for sortation and processing |
| **Capacity management strategy** | Residual belly-hold capacity | Combination of passenger and freighter aircraft | Dedicated freighter fleet | Leasing of aircraft on short and long-term basis | Cargo aircraft as a link in door-to-door services |
| **Examples** | Japan Airlines, Delta, American, Air Canada, Air India | Qatar, Air China, China Southern, Air France-KLM Cathay, Qantas, Lufthansa, IAG, Korean, Emirates, Singapore | Cargolux, China Cargo, Air Bridge Cargo, Nippon Cargo, Polar Air Cargo, AirBridgeCargo, Cargojet, Avianca Cargo | Atlas Air, Volga-Dnepr Airline, ATI, Kalitta Air; SkyLease Cargo | FedEx, UPS, DHL, ABX Air, Blue Dart, Toll |

Source: Based on Merkert and Alexander (2018) those passenger aircraft (i.e., Airbus 330-200 or Boeing 777-200ER) to a “preighter” configuration varied, as a full conversion requires costly processes such as removing seats, retrofitting doors, toilets, galleys, etc. As such, many airlines have chosen instead to largely keep the configuration of their passenger aircraft but carry the freight in seat packs that strap into the passenger seats. As the seat packs may damage seats and their packing/unpacking being labor intensive and associated with safety risks it is unlikely that this practice will become a permanent future of the air cargo industry. Nevertheless, what this shows is that the different business models have different asset at their disposal which require different skill sets in terms of their finance, marketing, revenue, network, and capacity management.

Another strategic response of combination carriers to the pandemic has been to move away from wide-body to narrow-body passenger aircraft which has further reduced the global belly-hold freight capacity. Also, their ambition to provide more fuel efficient and flexible point-to-point services rather than hub-and-spoke networks is detrimental to belly-hold freight. The emerging business model of ultra-long-haul direct passenger flights might be the most extreme case of that business model development (Bauer et al., 2020) but it amplifies the lack of belly-hold freight capacity as potentially a longer-term phenomenon.

As such, it is interesting to see how all-cargo operators and integrators despite the early signs of an incoming recession and softening of demand (as of Jan 2023) keep growing their fleets. Due to the e-commerce boom, the latter have been complemented by online retailers building a chartered air cargo fleet presence themselves, most notably Amazon. Amazon Air, rebranded from Amazon Prime Air which transitioned into drone delivery services, is a virtual cargo subsidiary of Amazon Technologies. Amazon now owns a fleet of 11 Boeing 767-300 s freighter aircraft and leases nearly 100 others (Harrington, 2022) with freight services operated by Atlas Air, ATI (Air Transport International), and ABX Air (all ACMIs, as shown in Table 1). This gives Amazon a network of 200 flights a day out of 71 airports and has considerably reduced its reliance on integrators (i.e., FedEx and UPS).

A further blurring of business model boundaries appears to happen in a sense of airlines increasingly taking on roles of freight forwarders or ocean shipping companies now aggressively expanding their air freight activities. For example, Denmark based Star Air (basically an ACMI provider) is operating specialized cargo lift capacity under the roof of the largest shipping line A.P.Moller-Maersk Group. And it is not just Maersk who is using the cash treasure chest that they were able to build during the pandemic to acquire or expand their air freight businesses. Similar to Maersk’s acquisition of Senator International, Kuehne+Nagel acquired Apex International Corporation, both specialists in air freight forwarding. Kuehne+Nagel went even further by acquiring a 10% stake in Lufthansa, a move not too dissimilar from global shipping line CMA CGM’s emergence as an air freight disruptor as they first acquired CEVA Logistics, then launched CMA CGM Air Cargo and acquired 9% of Air France-KLM in May 2022. Finally, Europe-based ocean freight carrier MSC decided in September 2022 to launch their own cargo airline with the aim to integrate more and to offer a wider supply chain solution. Under the brand MSC Air Cargo, it has partnered with Atlas Air who will operate four Boeing 777-200 as part of their global ACMI deal.

These are seismic disruptions to a previously rather unspectacular and unprofitable sector. What these horizontal and vertical supply chain integration developments show is that the traditional air cargo sector and how to deal with it from a supply chain management perspective will not only be different in the future but is already today a management activity that is much less airline specific and much more diverse. This is likely to have significant implications on supply chain planning of shippers, as the negotiation and value adding position of integrated air cargo services is strengthening. In a sense, what freight forwarders and global shipping lines are doing is diversifying but more importantly also securing and further integrating their supply/value chains. While this is likely going to be beneficial from a value adding and visibility along the supply chain perspective (mimicking the business model of integrators such as FedEx, UPS, and DHL express), it may be less beneficial for competitors and Business to Business (B2B) consumers. Shippers and supply chain planners depending on shipping containerized freight but also for smaller, regional, and generally less-integrated forwarders could find themselves in a situation where for them it may become increasingly difficult to obtain capacity with the airline subsidiaries now controlled by larger forwarders and shipping lines, and where preferential access may be given to the own "in-house" entities of the now diversified parent companies.

## 4 Literature on the Future of Air Cargo

While not attempting to undertake an in-depth review of the extant literature, this section aims to briefly discuss observable trends in the literature that may allow us to portray the future of the air cargo sector in the supply chain context. Our Scopus search of papers that used the keywords "air cargo" or "air freight" or "air logistics" or "air supply chain" has yielded 625 documents, which shows that air cargo is still a relatively under researched niche area. As with Tanrıverdi et al. (2020), we used various bibliometric packages in R to create the keyword network map shown in Fig. 5.

What can be observed in Fig. 5 is that air cargo research appears to be rather quantitative involving integer programming, stochastic analysis, simulation, optimization, and mathematical models (for a more in-depth review, see Feng et al., 2015). The management of the causal relationship between aviation and economic development is also of importance (Hakim & Merkert, 2016) as is the value of air cargo to global supply chains (Shepherd et al., 2016), forecasting (Alexander & Merkert, 2017), contracting, and decision-making (Hellermann et al., 2013) and research on underlying drivers and future development of air cargo (Kupfer et al., 2017).

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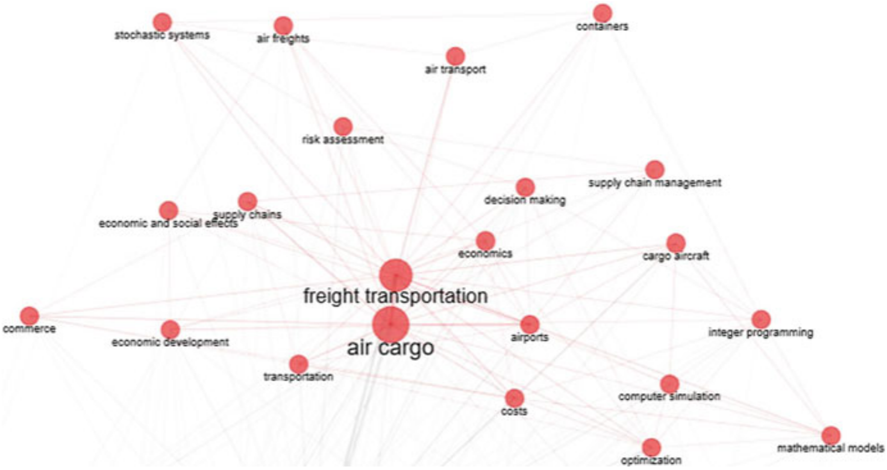


**Fig. 5** Keyword network map of all air cargo/freight papers (1960–2022)


**Fig. 6** Keyword wordcloud of air cargo/freight papers from 1960 to 2019

development is also of importance (Hakim & Merkert, 2016) as is the value of air cargo to global supply chains (Shepherd et al., 2016), forecasting (Alexander & Merkert, 2017), contracting, and decision-making (Hellermann et al., 2013) and research on underlying drivers and future development of air cargo (Kupfer et al., 2017).

Clustering the literature further into 564 papers that were published until 2019 and 61 papers that were published in 2020 and 2021 enabled us to show that traditionally revenue management (Lin et al., 2017) has been a popular topic with scholar, as shown in Fig. 6.

While risk assessment in air cargo logistics and supply chain management is not a new theme (e.g., Shang et al., 2017), in 2020–21 it has become notably more

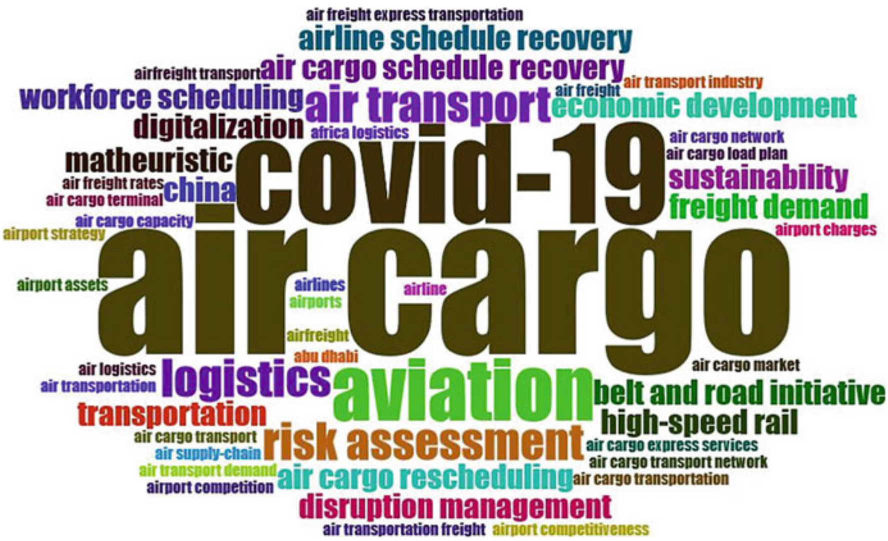


**Fig. 7** Keyword wordcloud of air cargo/freight papers from 2020 to 2021

prominent, as shown in Fig. 7. Judging by the literature, traditional risk management skills around pricing (Wen et al., 2020) as well as distribution channel and lane selection (Faghih-Roohi et al., 2020) are now enriched with skills more specifically related to disruption management (e.g., Feng et al., 2020) and schedule recovery, naturally often specifically related to COVID-19 (Shaban et al., 2021). Traditional areas, such as logistics, appear to be still of relevance, yet interestingly increasingly beyond just the air cargo airlines themselves and including airports as well as other elements of the air cargo supply chain (e.g., Hamdam, 2020).

## 5 Air Cargo Trends and What They Mean for Supply Chain Managers

Interestingly, our literature review has further revealed that keywords such as digitization, security, drones, and sustainability (e.g., Bartle et al., 2021), while being well established in the supply chain management literature (e.g., Choi et al., 2022), are now also increasingly popular in the air cargo literature. As typical for supply chain management across many sectors, air cargo is an industry that often still relies on transactions and B2B customer relationships being done via trusted and personal relationships (Tsai et al., 2021). Information technology and data do assist air cargo managers in their decision-making, but picking up the phone and negotiating with supplier and customers is still as important as it always has been and most likely always will be.

Before we discuss trends around technology and sustainability, it is important to note that air cargo carriers have traditionally suffered from a lack of *supply chain visibility* compared to integrators and a *skewed risk/reward profile* as well as *lack of negotiation power* when fronting freight forwarders (due to sheer size differences and the latter being able to not only consolidate consignments but often being able to dominate markets and talking to both air and ocean shipping companies when negotiating shipments). We feel that is an important characteristic of this market, which does influence yields, available capacity, service delivery, and as such supply chain management. Given that the boom in freight logistics and e-commerce has led to even further growth of freight forwarders, this negotiation power imbalance will remain a feature of the air cargo supply chain and it is possible to infer that negotiation skills and interpersonal skills will be crucial for a successful supply chain management. In fact, given the trend of air cargo integration with both ocean shipping lines and freight forwarders acquiring equity in air cargo businesses, it is very likely that the negotiation position of these now partially integrated air cargo players may improve in terms of bargaining power to the detriment of shippers (and their supply chain and transport procurement managers) and smaller, non-integrated competitors. Having said that, many large accounts are managed through interpersonal relationships and keeping them alive can break or make an air cargo airline. Being now dominated by a large stakeholder (e.g., freight forwarder) may upset some of the other larger clients and as such, the entire market may continue to be disrupted and dynamic for some time.

Of course, many managers will have worked for a cargo airline, freight forwarder and/or further up- or downstream (e.g., vendors) the supply chain in previous roles and as such will have specialist knowledge (e.g., revenue management) and quantitative skills (e.g., optimization, data analytics) as well as transaction knowledge which will be useful to for successfully maneuvering the entire supply chain. As disruptions and volatilities on both the demand and supply side are going to increase in the future, it can be argued that in addition to revenue and cost/risk management, loyalty and retention of B2B customers will matter even more than today (Tsai et al., 2020). As such, supported customer relationship management (potentially supported by data analytics and artificial intelligence but essentially still an interpersonal skillset) as part of marketing and procurement will therefore become an even more important asset. Managing interfaces of intermodal air freight (which nearly all freight is when looking at it from an end-to-end perspective) and then also along the supply chain well into shipper but also end consumer spheres, will become more important, too, as environmental, social, and governance (ESG) and cost pressures will increase and as technology and innovation will provide new opportunities.

As the *e-commerce* sector is growing fast, so are the volumes and margins of the integrator business model and with it the demand for *door-to-door services* and innovative last mile delivery solutions. As such, while air cargo airlines and even more so combination carriers are currently contemplating, whether they will soon become the ugly sister again (due to their lower volumes and traditionally lower yields than the passenger side of the aviation business and with global demand softening as of June 2022), integrators remain optimistic in terms of demand.

However, all air cargo business models but then also supply chain managers more generally need to adapt to constantly ecosystems. For example, mobile parcel lockers and drone delivery are no longer futuristic concepts but are happening today (Merkert & Bushell, 2020), as consumers are willing to pay for such alternatives (Merkert et al., 2022). As such, future supply chain management in the context of successfully incorporating an air cargo element into that supply chain will be more diverse (e.g., risk, financial, innovation, and strategic management) than the traditional air cargo tool set and in fact will extend far beyond air cargo airline management. Similar to passenger airlines, where loyalty programs play a decisive role, it is likely that loyalty programs beyond B2B relationships will become more prominent and become part of contemporary supply chain management.

As discussed in the introduction section of this chapter, *digitization and automation* of air cargo are increasingly implemented. Despite many airlines still relying on legacy systems (sometime DOS systems that have been patched over the years) and many processes still being much more labor intensive (and much less automated; e.g., ground handling) than those in other sectors, things are slowly changing. With the cash inflows (COVID-19 bonus) into the sector, it can be anticipated that in this current renaissance decade of air cargo there will be further investments into technology and hence a system and supply chain wide approach is needed. Electronic Data Interchange (EDI) and application programming interfaces (APIs) exist with most airlines these days but mainly with IATA, the global distributions systems (GDSs) and OEM manufacturers, such as Boeing, Airbus, Pratt & Whitney, and Rolls-Royce. Good examples of what is going to be the new normal in any air cargo company are IATA's CagoIS (Business Analytics) and Digital Cargo (data sharing and supply chain visibility) and e-freight/e-AWB/Cargo XML (digital customs and transport documents such as the digital air waybill). Implementation of such digitization of the air cargo supply chain has been slow pre-COVID but has been accelerated since then. Especially, suppliers to air cargo airlines (e.g., engine manufacturers and maintenance companies or spare part suppliers) collect substantial data of air cargo supply chains and whilst IATA always had strong system son the passenger side, they are increasingly advanced in the air cargo context, too. Still more system integration and joint dashboard development have the potential to enhance visibility, transparency, and efficiency.

The elephant in the room for air cargo supply chains is, however, not COVID-19 but *environmental sustainability* concerns (e.g., Bartle et al., 2021). In Europe, in particular, but with other regions likely to follow, there has been public and political pressure to not only green aviation but also to replace short-haul and intraregional flights with high-speed rail. While this is currently focused on passenger services, the loss in belly-hold freight capacity as well as a likely refocus that will include cargo flights is something that air cargo managers but also supply chain managers (at vendors, etc.) need to account for in their strategies today. As such, a deep understanding of environmental and social sustainability implications of air cargo operations will become increasingly important. Not only the measurement and monitoring of the carbon footprint, noise, and waste of air cargo but also the mitigation of residual exposure to environmental and supply chain disruption risks will be crucial for future air cargo management. That said, the various business models and elements of the air cargo supply chain will experience this differently and in each of those slightly different focus may be required. For example, the insurance business will become absolutely vital component for air cargo airlines and freight forwarders but may be less relevant in the warehousing and distribution context and hence important to integrator businesses. What will be required across all air cargo business models is strategies and management that develop and implement innovative and sustainable services.

Finally, we think that despite all innovation and disruption, a key competitive advantage of air cargo, in particular, when housed within combination carriers, will be *strategic enterprise leadership*. As air cargo yields will normalize over the next year or two, it is likely that air cargo arms of combination carriers will lose their appeal for group CEOs of those carriers which could result in air cargo going back to being by products in terms of revenue management and allocation of shared costs. This on the other hand may open up opportunities for shippers, who have been priced out of the market during the COVID-19.

## 6 Conclusions

Due to lockdowns and travel restrictions stemming from the COVID-19 pandemic and the accelerating e-commerce boom, the air cargo industry has been experiencing unprecedented demand and record profitability. As such, air cargo operators across all business models were suddenly confronted with the question of how to reinvest the welcome and in many cases substantial cash inflows, something they had not experienced before. Fleet renewals that will help with growing sustainability concerns are an option for consideration, as are growth and transformation programs that are going to assist the industry with adapting to disruption and technological change including digitization and automation along the supply chain. In particular the last-mile delivery sector which now includes aerial drone operations is an area that will see further growth.

However, with volatile oil and jet fuel prices and a considerable softening of demand for air cargo globally, more recent concerns are whether air cargo will return to being an unprofitable and not enough appreciated sector. Uncertainty around what next, creates tensions within and along air cargo supply chains. What is clear that ocean shippers and freight forwarders appear to be keen to further integrate and to widen their supply chain offerings thereby disrupting the air cargo sector. This means that management of the air cargo industry is continuously expanding its scope well beyond the traditional air cargo sphere as it is now including retailers and other supply chain stakeholders of the ever growing and diversifying air freight ecosystem.

The changing nature of the industry and growing concerns of its carbon footprint will require adequate measurement, monitoring, and management of emissions along the air cargo supply chain. Being able to collaboratively work with local but also international partners along the supply chains of air freight commodities will become even more important going forward.

Despite the accelerating digitization of the sector, the drone revolution, and emerging air cargo business models, traditional air cargo business models will continue to be relevant (as they offer unique/specialized solution for which there will always be demand). As freight rates continue to normalize, the complexities and power imbalances in the air cargo supply chain will, especially for managers of combination carriers (Hong et al., 2023), result in a return of the battles with not only the passenger divisions in their airline groups but also tough negotiations with the large freight forwarders. Being able to build trusted relationships with B2B customers and suppliers and leading air cargo divisions to commercial and environmental sustainability will continue to form part of the competitive advantage of air cargo businesses in and along the air cargo value chain.

Naturally, the focus of air cargo in the context of supply chain management has since the onset of the COVID-19 pandemic been very much on its role in supporting or disrupting global value/supply chains. However, it is important to acknowledge that air cargo airlines have their own supply chains, too. It is possible that sub-optimal aviation supply chain coordination (i.e., airlines not getting enough airport ground-handling resources, or not able to hire and schedule enough staff themselves to operate available aircraft to meet the demand), on top of the reduction in labor productivity and soaring cost of living, will create a major bottleneck to air-cargo capacity supplies. With increasing volatilities in both demand/supply and jet fuel prices as well as global economic headwinds, there is only one thing for certain, air cargo business will have to work and innovate collaboratively with their supply chain partners (up and downstream) to not only remain relevant in the public perception but also commercially viable whilst minimizing the ESG impact (i.e., decarbonization).

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# Coopetitive Urban Logistics to Decrease Freight Traffic and Improve Urban Liveability

Maike Scherrer

## Contents



**Abstract**

Urban space is scarce due to growing population and increased demands for goods, causing additional freight traffic. Private and freight mobility compete for urban space. Collaborative and bundled deliveries from logistics service providers are solutions to reduce freight traffic. Yet, logistics service providers refuse to collaborate with their competitors. This collaboration between competitors is called coopetition. This chapter will show that coopetition can be implemented if the city provides a scarce and valuable resource to logistics service providers and retailers – logistics space in the heart of a city. Cities can provide access to logistics space only to those competitors who collaborate and prove that they reduce the driven kilometers through shared infrastructure and shared delivery vehicles. Cities do not have to implement regulations that force competitors to collaborate but establish a system where collaboration between competitors is established on a voluntarily basis to get access to logistics infrastructure within

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city centers. The chapter introduces a three-echelon hub system, where the first echelon is in the outskirts of the city, the second is in the city center, and the third is in consumer neighborhoods. Through the provision of this three-echelon hub system to collaborative competitors, the city increases the motivation of competitors to collaborate and reduces the traffic burden of the urban setting.

**Keywords**

Horizontal and vertical coopetition · Urban logistics

## 1 Introduction

City centers face multiple challenges, many of which are linked to transportation and logistics. Traffic increases air pollution, noise, and even excess heat, which have a negative health impact on the urban population (Lagorio et al., 2016). Traffic also competes for rare space in the city centers, and overload causes congestions (Gössling, 2016).

While fulfilling customer wishes, logistics is supposed to be sustainable, should not harm city safety, and should be socially acceptable for inhabitants (Akyol & De Koster, 2018). Since logistics is noisy and valuable space in cities is more attractive to sell for housing or offices rather than logistics spaces, logistics activities have been pushed out of the city centers toward suburban or rural areas (logistics sprawl) over the last few years (Schmid et al., 2019). This situation has led to longer delivery routes, as products have to be brought from further away into city centers, causing additional traffic, congestion, air pollution, and noise.

The situation is expected to be aggravated in the close future. The United Nations (UN) forecasts that about 68% of the world's population will live in urban areas by 2050. Cities will be denser, more inhabitants causing more personal traffic, while traffic infrastructure cannot be extended any further. These forces result in a relative decrease of traffic infrastructure availability for logistics services.

In Switzerland, in 2019, 84.4% of the Swiss population lived in urban regions (BFS, 2020). The urbanization trend still increases. Due to this and the fact that online shopping has gained popularity (Becker et al., 2021), the traffic load on a city's infrastructure has increased dramatically. Currently, 10% of the transport performance (in vehicle km) on Swiss roads is caused by freight transport, causing 21% of transport related $CO_2$ emissions (BAFU, 2021; Becker et al., 2021). Due to e-commerce popularity, it is expected that the parcel volume will increase by another 75% and freight transport by 31% until 2040, leading to an extended logistics fleet of 37% (ARE, 2016).

In this situation, light commercial vehicles like vans are expected to have the highest growth rate of 53% (ARE, 2021b). This large growth is because products in the B2C (business to consumer) sector are to be delivered ever faster. It is expected that the situation will tighten further as forecasts predict that medication and grocery and especially fresh products such as fruits and vegetables are just at the beginning of their growth phase in e-commerce (Mazur et al., 2019). Medication and fresh


**Fig. 1** Challenges due to increased freight traffic in cities

products will further increase the requirement to deliver fast. Fast deliveries contradict bundling effects, optimal route planning, and the synchronization and harmonization of different flows of goods, leading to additional congestion, air pollution, and safety issues (Lagorio et al., 2016).

All this leads to challenges across the three sustainability dimensions – economy, ecology, and social dimensions – as shown in Fig. 1.

It becomes obvious that there exist contradicting requirements in terms of fast and convenient delivery to consumer homes against the request to reduce traffic in urban regions and the corresponding negative impact on the liveability in urban regions.

One possible solution for these increasing urban logistics challenges is seen in models where logistics service providers cooperate with their competitors by sharing vehicles. A common term for this is *white-label* or *multilabel logistics*. White-label means that no company logo is on the delivery van whereas in a multilabel approach, all company logos of all companies cooperating are displayed on the van. Despite the positive discussion, there are no cases known that really achieved benefits so that companies voluntarily engage in a white-label concept. Those systems that work are implemented through regulations, and companies are forced into a collaboration (Albeck, 2020).

An explanation for why the white-label approach does not work on its own might be that competitors refuse to collaborate voluntarily. To the best of our knowledge, city authorities can establish regulations that force competitors to collaborate. No cases are known where the city authorities implemented conditions that made the competitors collaborate on a voluntarily basis. Subsequently, we follow the research question *What framework conditions can a city implement to motivate competitors to collaborate?* This chapter gives an example of how voluntary collaboration between competitors can be fostered by giving the competitors access to scarce resources on the city ground, but only if they work in a collaborative manner – an incentivization approach.

## 2 Background

Collaboration between competitors is called *coopetition*. Coopetition is a game-theoretical concept in which the competitors are in a game with each other in which the decisions of both competitors influence their market success and the market success of the other competitor. The term coopetition was framed by Brandenburger and Nalebuff (1996).

Coopetition is explained as the coexistence of collaboration between two or more competitors. Over the last couple of years, coopetition has gained attention and was analyzed on an individual, intrafirm, inter-firm, and network level (Dorn et al., 2016). On the individual level, coopetition analyzed the complex psychological processes that an individual undertakes when expected to cooperate with team members, while, at the same time, having to fulfill individually set goals. Coopetition on the individual level is expected to facilitate innovation and creativity if the coopetition partners see benefits in the collaborative work (Baruch & Lin, 2012).

At the intrafirm level, the simultaneous expectation for collaboration between subunits in the same legal entity and competition for parental resources, power delegation, global position, or market expansion between subunits have been analyzed (Luo, 2005). On the inter-firm level, two things have been analyzed. First, companies cooperating with each other while competing in the same market for the same customer, and second, partners within a supply chain. On the network level, the similar cooperation and competition between firms working together in the same supply network have been studied (Dorn et al., 2016).

The direction of the relationship can be horizontal or vertical. In horizontal coopetition, competitors working at the same supply chain stage across different supply chains cooperate, while in vertical coopetition, buyers and suppliers or varying supply chain tier members cooperate (Bengtsson & Kock, 2014).

Each coopetition is characterized by tensions between cooperation and competition, as each coopetition member strives to maximize its own benefit, while, at the same time, trying to maximize the collaborative outcome. These goals can lead to trade-offs, as striving for one goal might hinder the fulfillment of the other goal, or by strategic incompatibility between the coopetitive partners (Bello et al., 2010). This situation can – in some cases – be overcome by defining common long-term goals, establishing trust between the partners, and a consequent untangling of strategic and operational tasks within and between the coopetition partners (Bengtsson & Kock, 2000; Tidström, 2014).

Overall, coopetition is considered ambidextrous – with advantages and disadvantages. On the positive side, coopetition can enable benefits from synergy effects which cannot be achieved by one partner alone (Pedreira & Melo, 2020). These synergy effects include access to complementary resources, increase of the knowledge base of both coopetition partners, shared costs, risk mitigation possibilities, and economies of scale benefits. Further, R&D activities can be pooled, external knowledge and resources can be accessed, innovation and technology development can be fostered, and complementary resources can be obtained (Bengtsson & Kock, 2000; Bouncken et al., 2015; Cygler et al., 2018; Luo, 2007).

On the negative side, coopetition also has risks. These risks include the following: a loss of flexibility and freedom; a knowledge drain toward the competitor with a loss of competitive advantages of the focal coopetition partner; a dependence on the partner with higher power and the danger that this partner develops expertise for its own advantage; and divergent aims and needs, or the prioritization of problems toward the partner with higher power (Bouncken et al., 2015; Cygler et al., 2018).

Coopetition can be externally pushed or internally pulled. Internal pull means that coopetition can be established through conscious action if the coopetition partners strive for common goals that one partner cannot reach alone. Another possibility for internal pull is an establishment by coincidence, not being strategically planned but happening out of a spontaneous reaction on environmental developments. Externally pushed means that partners can be forces into a coopetition trough regulatory forces or by law (Kylänen & Rusko, 2011).

In biology, coopetition can be found in different forms, ranging from commensalism to mutualism. In commensalism, two species are in a relationship in which one specie obtains food, protection, or other benefits from the other without either harming or benefiting the latter (Heim et al., 2021). Mutualism refers to an interrelationship between living organisms of two species from which, in contrast to the commensalism, both partners benefit from the collaboration with the other specie (Bronstein, 2015). An illustrative example is the relationship between the anemone and the anemonefish. While the anemone provides protection, the anemonefish cleans and defends the anemone. Both organisms benefit from the mutualism with the other. The mutualistic state is unstable. Through evolutionary pressure, the species need to adapt to the changing environmental conditions to stay in their beneficial equilibrium.

These biological characteristics can be transferred to a competitive environment in business. No matter how the coopetitive relationship was established, nor which supply chain depth or directions they contain, one still unanswered question is how coopetitive relations change over time (Dorn et al., 2016). A once established coopetition underlies mutual influences such as the market dynamism, the evolution of the coopetition partners including knowledge extension and strategy alignment, or the clockspeed of the industry, just to name a few dynamic changes.

One attempt to analyze whether coopetition partners are in a stable or temporal equilibrium state was conducted by Scherrer, Hollenstein, Stadler, and Heim (2021). In their work, they transfer the biological mutualistic relationship to the supply chain context. In biology, species have to constantly adapt to changing environments to stay in their beneficial equilibrium. To analyze the question of dynamism over time in supply chain coopetition, Scherrer, Hollenstein, Stadler, and Heim (2021) use the Lotka-Volterra formula, also known as the predator-prey relationship (Begon et al., 2017), and extend it to three partners, two being the coopetitive partners and the third the rest of the market. Similar to biology, they do not find stable equilibria, but only temporary ones. They arrive at a conclusion that coopetitive partners are – similar to living organisms in the natural environment – under evolutionary pressure, needing to constantly adapt to changing (market) conditions (Scherrer et al., 2021).

Pathak, Wu, and Johnston (2014) analyzed the evolution of network-level coopetition over time and derived four archetypes of coopetition, differentiating between low and high production/process complexity, and low and high institutional voids. To analyze how the companies evolve within or between the archetypes, they analyze microprocesses, such as managerial decisions of one of the coopetitive partners, and how these processes influence the dyadic ties within and between the networks. With this analysis, they show evolutionary partner paths within the archetypes.

Overall, coopetition exists within and between firms, and across supply networks. There are possibilities to enter horizontal and vertical coopetition forms. Coopetition partners need to adapt constantly based on market changes and changes of the coopetitive partners. These discussions are from a general perspective while considering coopetition partners from outside. Enablers for coopetition are also discussed from a partner's perspective, identifying prerequisites the partners have and bring into to coopetitive partnership (see Scherrer et al., 2021, for more details). What is less discussed is the possibility of external entities (i.e., authorities) to support mutualistic coopetition by offering scarce resources that no competitor has access to and how this provision of scarce resources can foster coopetition.

## 3 Current Concerns

As discussed earlier, companies tend to enter a collaboration with competitors if they are seeking for complementary resources, additional knowledge, or, for example, market access. One exception is the implementation of regulations and laws from authorities that, in consequence, force companies into a coopetitive situation. What is not discussed in literature is the question whether authorities have other mechanisms at their disposal rather than forcing competitors to cooperate. That is, whether it is possible to establish an environment where competitors voluntarily enter a collaboration.

To dig deeper into this question, we focus on the logistics environment, more precisely on urban logistics. Cities and logistics service providers have diverging goals when it comes to urban logistics. Cities aim for optimized routes with the lowest driven kilometers within the city to reduce traffic burden, congestion, air pollution, noise, and accident risks. Alternatively, logistics service providers aim at optimizing their routes in terms of driving one efficient tour through the city.

For logistics service providers, congestion time of the drivers is of lower importance than the avoidance of transhipment and cross-docking costs. Logistics service providers are not willing to collaborate with competitors in a city environment, as they claim the necessity of handing over the delivery that does not guarantee a high level of quality on the last mile distribution. This situation matches earlier findings in literature. As Fig. 2 shows, coopetition works far away from customers. The closer the activities are carried out to the customer, the more competitive suppliers act (Bengtsson & Raza-Ullah, 2016).


**Fig. 2** Relation between cooperation and distance to customer

Logistics service providers who are wary of coopetition: (a) fear cannibalization of customers through competitors, and (b) do not accept shipments to own customers delivered by vehicles of a competitor. Nevertheless, the noncooperative behavior leads to lost benefits from synergy effects, which cannot be achieved by one logistics service provider (LSP) alone (Pedreira & Melo, 2020).

## 4 Elements Known from Cities with Potential to Foster Coopetition

Each city has one scarce resource that the city administers. This is empty space within the city. As discussed earlier, logistics activities have been pushed out of the city center to the outskirts or even to rural environments. Getting access to scarce logistics spaces within a city center is an asset the logistics service providers can hardly get anymore. Subsequently, city authorities can use their space resources to motivate competitors to collaborate. This can be achieved by offering space to competitors that collaborate. The offered space cannot be accessed by a company alone, but only in a coopetitive manner. Next to space, other incentives for coopetition are granted to positively motivate competitors to collaborate.

Certain elements for shared space resources have been pilot tested and sometimes also implemented. France has been very active in testing different urban logistics elements (Boudouin, 2012), not with the goal to foster coopetition, but to reduce the freight load within cities. The tested elements have the potential to foster coopetition, if not considered in isolation, as done in France, but merged to a holistic urban logistics concept.

The elements discussed in France are depicted in Fig. 3 and include urban logistics box, goods reception points, urban consolidation, and urban logistics zones.

Taking a glimpse at the situation of Zurich, Switzerland, even though Zurich with its 440,000 inhabitants is not a big city compared to other cities in this world, the traffic situation in Zurich is challenging. In a 2012 referendum, the Swiss population approved the densification of cities and restricted the rezoning of farmland into

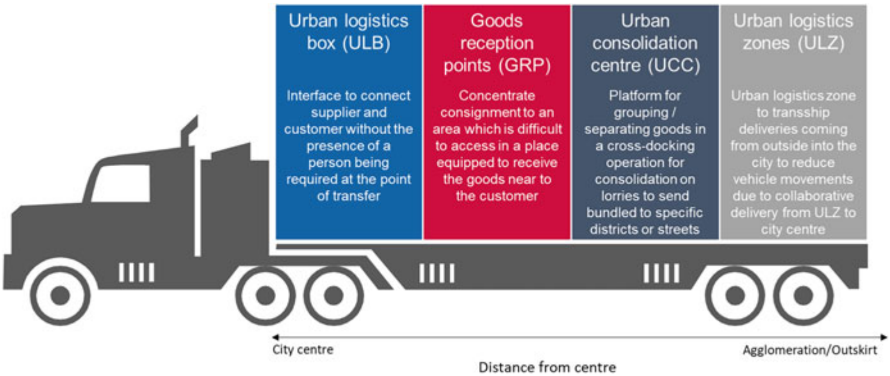


**Fig. 3** Possible urban logistics spaces

residential land in rural areas. If the population within the city increases, this will cause additional private individual traffic.

Alternatively, with e-commerce popularity and the need for ever faster delivery, freight traffic will increase as well causing greater congestion.

Overall, the relative traffic infrastructure availability decreases for logistics activities, as logistics and private mobility compete on the same street infrastructure.

Today, Zurich has a congestion belt encompassing the whole city center. If the assumed growth rate of delivery vans, parcel volumes, and the densification of the city by inhabitants becomes true, the situation will tighten even further. The daily traffic pattern does not show peaks anymore but plateaus, reaching several hours of rush hour time with congestions all over the city. The city of Zurich is concerned for the future development of congestion within the city and strives for a reduction in freight traffic. Coopetition between competitors with shared and bundled deliveries in a coopetitive approach is expected to be beneficial for the city of Zurich.

Logistics service providers do refuse this request from the city. They are not willing to engage in last-mile delivery coopetition, as the customer contact point is of utmost importance to guarantee deliver quality, and as the logistics service providers claim that they already have a high capacity utilization while delivering the goods into the city.

## 5 Proposition to Solve the Diverging Goals

The city of Zurich aimed at solving the traffic challenges within the city by establishing framing conditions that competitors can only access if they collaborate with their competitors. With this policy, the city of Zurich does not need to implement regulations, which are recognized as antecedents for coopetition (Dorn et al., 2016), but only needs to establish motivating framing conditions. Literature discusses that competitors are motivated to engage in a collaboration with competitors if they can benefit from collaborative synergies that cannot be achieved alone (Durach et al., 2020). These benefits are often discussed from a resource-based perspective, including technologies, capabilities, or market share, just to name a few dimensions.

The city of Zurich attracts competitors to engage in a collaboration by providing logistics space, if they cooperatively achieve freight traffic reduction. To be able to achieve this goal, several empty spaces have been defined as logistics areas – such as transhipment or cross-docking space. These areas are not rented out to a specific company but are offered in a pay-per-use model to logistics service providers and retailers to cross-dock their goods when needed to bundle the goods for shared delivery to certain neighborhoods. This means that only if the logistics service providers and retailers agree to ship their goods in a collaborative way, they can access the scarce logistics spaces at the outskirt of the city and inside the congestion belt in the city center of Zurich.

To identify whether this idea is beneficial for the city, a simulation was conducted. Two questions were asked. First: Is a hub beneficial to reduce kilometers on a city's ground and is it financially attractive for competitors? Second: Where should such hubs be located within the city? Four different scenarios have been tested.

As a setup, an abstract city model with a city center (dark gray), an agglomeration (light gray), and environs (white) (see Fig. 4) is used. In each corner of the city, a warehouse with different goods was located. The task in all four scenarios was to deliver the ordered items as efficiently as possible into the city. To facilitate the scenario, the logistics service provider 1 (LSP1) on the top left in Fig. 4, for example, had to deliver books and decoration articles, hence those articles that were left and right from LSP1, while the logistics service provider 2 (LSP2) on the right side had to deliver decoration articles and fashion, and so forth. Each lorry had a fixed capacity which could not be extended.

Scenario 1 (top left in Fig. 4) is the base scenario, where each logistics service provider had to deliver directly to the customer. The goal was to make a route optimization based on lowest driven kilometers.

In scenario 2 (top right in Fig. 4), each logistics service provider was allowed to freely position an own hub in the agglomeration or environs. In scenario 2, the

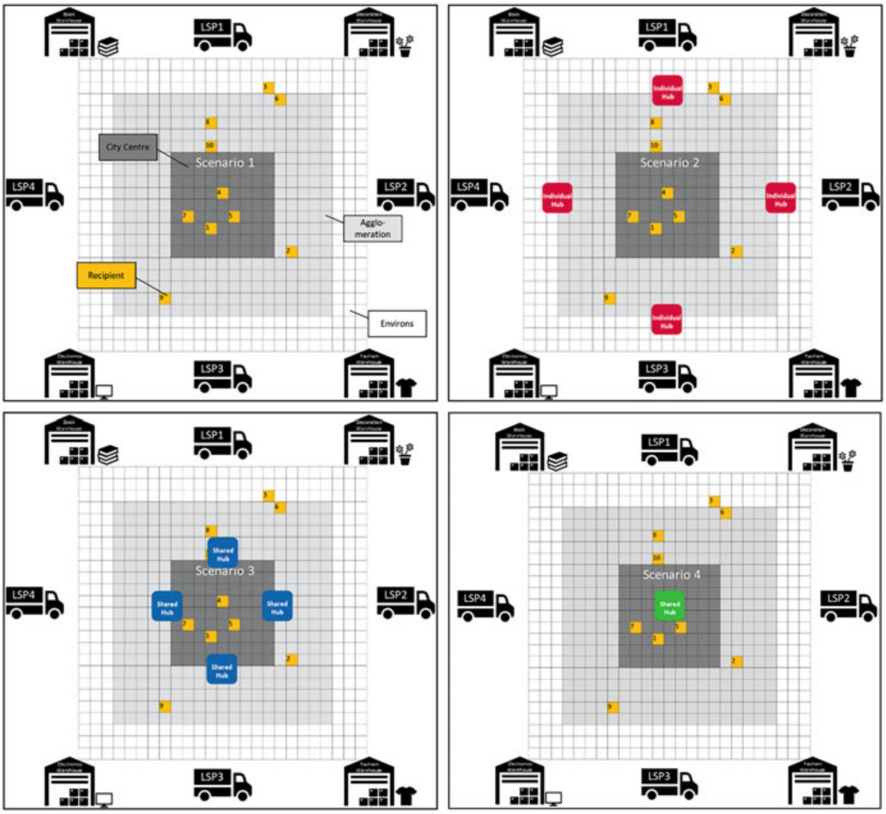


**Fig. 4** Four scenarios to simulate delivery efficiency in an urban logistics setting

logistics service provider was allowed, but not forced, to use the hub for cross-docking or transhipment. The goal was to make a route optimization based on lowest driven kilometers.

In scenario 3 (bottom left in Fig. 4), the logistics service providers were allowed to position shared hubs in the agglomeration or environs. The logistics service providers were allowed, but not forced, to use the hub for cross-docking or transhipment. It was also allowed to bundle the orders together with the other logistics service provider for bundled deliveries and higher load capacity utilization. The goal was to make an individual route optimization based on lowest driven kilometers. If the logistics service providers agreed to deliver together, transfer prices were set.

In scenario 4 (bottom right in Fig. 4), the logistics service providers were allowed to position one hub in the middle of the city center. The logistics service providers were allowed, but not forced, to use the hub for cross-docking or transhipment. It was also allowed to bundle the orders together with the other logistics service providers for bundled deliveries and higher load capacity utilization. The goal was to make an individual route optimization based on lowest driven kilometers.

For each scenario, three orders with ten suborders were provided to each logistics service provider, which all had to be fulfilled in full. While the capacity of the lorries was fixed, the number of lorries and the number of delivery rounds were not. At the end of each order, all lorries had to be brought back to their depot.

As Table 1 shows, scenario 4, with one hub in the city center, was the best scenario not only in terms of driven kilometers, but also by transport and transshipment costs, and costs per unit delivered.

In scenario 4, the individual logistics service providers organized their delivery tour as follows: They first picked up the goods at the warehouse and brought all goods that were on the way to the hub to the receivers (e.g., LSP2 brought fashion to target no. 2 before entering the city). In the hub, LSP2 picked up all goods

**Table 1** Achieved results of the four scenarios

| | Scenario 1 | | | Scenario 2 | | |
|---|---|---|---|---|---|---|
| | CHF | km | CHF/unit | CHF | km | CHF/unit |
| LSP 1 | 930.00 | 193 | 31.00 | 933.00 | 192 | 31.10 |
| LSP 2 | 969.00 | 211 | 32.30 | 876.00 | 190 | 29.20 |
| LSP 3 | 922.50 | 206 | 30.75 | 839.00 | 182 | 27.90 |
| LSP 4 | 1023.00 | 240 | 34.10 | 914.40 | 200 | 30.48 |
| Average | 961.15 | 212.50 | 30.05 | 890.60 | 191.00 | 29.67 |
| | Scenario 3 | | | Scenario 4 | | |
| | CHF | km | CHF/unit | CHF | km | CHF/unit |
| LSP 1 | 586.00 | 119 | | 352.50 | 56 | |
| LSP 2 | 810.00 | 174 | | 356.00 | 56 | |
| LSP 3 | 811.00 | 174 | | 303.00 | 51 | |
| LSP 4 | 666.00 | 150 | | 376.50 | 62 | |
| Average | 718.25 | 154.25 | 26.60 | 347.00 | 56.25 | 11.55 |

CHF = Swiss Francs

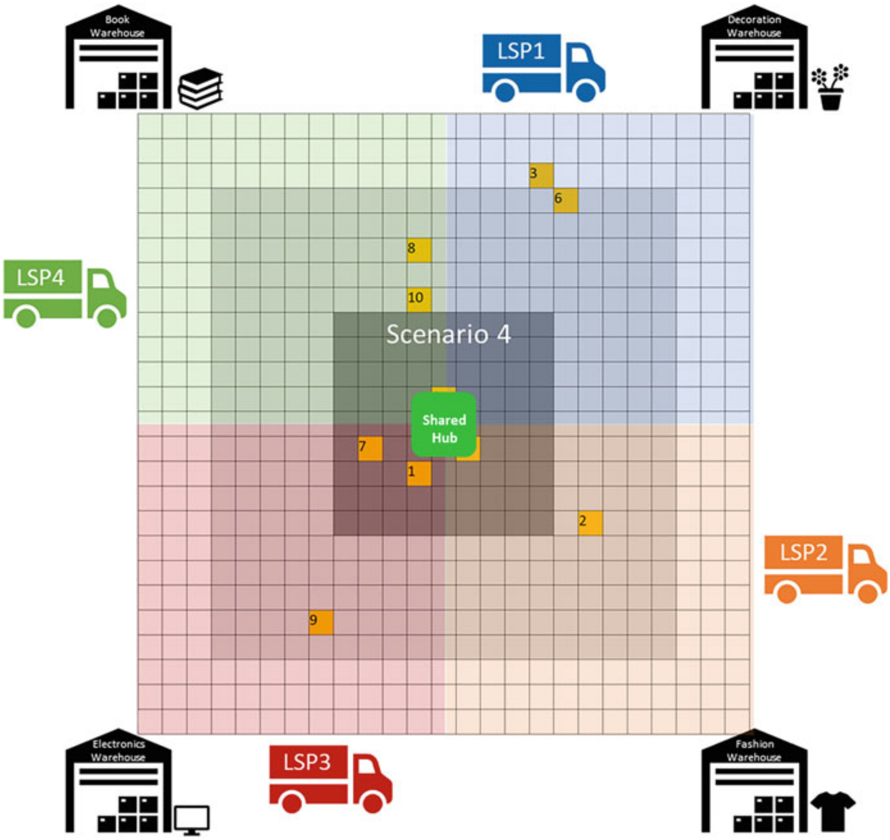


**Fig. 5** Area allocation to the logistics service providers for pick-up and delivery of goods

that had to be brought in the direction to the own depot – see Fig. 5 for the agreed area allocation.

This simulation shows that a hub system, in which competitors collaborate, can reduce the driven kilometer in the city and can reduce the unit costs for the logistics service suppliers, if the deliveries are coordinated and centrally planned for route optimization of lowest driven kilometers and maximum lorry capacity utilization. As a next step, pilot tests in the city of Zurich are planned with real hubs and deliveries.

## 6 Using Zurich as a Living Lab for Pilot Tests

To pilot test whether the hub system achieves the expected benefits in terms of lowered driven kilometers in the city and reduced costs for the logistics service providers, a hub in the city center will be pilot tested. Next to this central hub, which achieved the best results in the simulation, two other hubs shall be tested, as they have been discussed as being beneficial in France: one at the outskirts of the city, one in the neighborhood close to the customer. With this, a three-echelon hub system will be tested (see Fig. 6).

As optimization criteria, not the route-optimization of individual logistics service providers but the requirements of a city to achieve a liveable city with maximum comfort and invisibility of logistics solutions will be taken. By following the least-cost principle (Scherrer & Eberle, 2020), it is not the goal to build new logistics facilities but use empty spaces such as unused parking garages, exhibition grounds, or existing warehouses without full capacity utilization. If available, these facilities are used to establish the hubs in. If no empty space is available, space will be provided from the free zones that Zurich owns for logistics purposes.

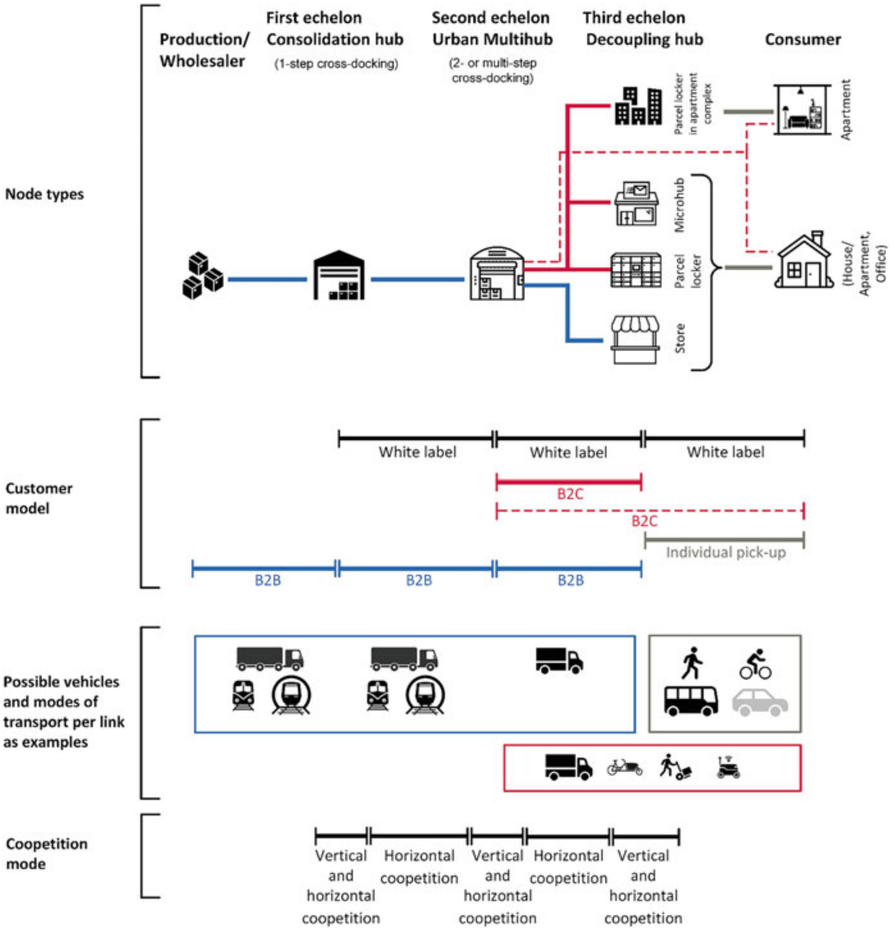


**Fig. 6** Schematic view of the urban hub concept

The goods that are delivered into the city vary in size, weight, delicacy to handle, safety issues, the necessity for temperature control, etc. It is expected that additional transhipment points are not appropriate for all types of products. Subsequently, it shall be tested whether certain goods require different hubs than others. In doing so, all 18 freight good categories based on the Nomenclature uniforme des marchandises pour les statistiques de transport (NST) will be considered.

While doing this, it needs to be analyzed where which freight good categories travel through, and which product categories can be handled together.

The *first echelon hubs* are located at the outskirts of the city and can be compared to the urban logistics zones (ULZ) of France. It is expected that especially bulky goods can be cross-docked for a white-label delivery to be delivered into the city, either direct or via the second echelon hub.

The *second echelon hub* is located in the core of the city center and is the main hub of the hub concept. This hub is close to the urban consolidation center (UCC) in the French system, even though the second echelon hub has additional functions than the UCC. It is located in a spot where freight not only from the street can be brought, but also from the train and, if built, from the planned freight metro. This hub is called the smart urban multihub. The smart urban multihub is a neutral and shared logistics space which is organized to serve multiple purposes, such as a disposition center for logistics service providers, a transhipment/crossdocking center for retailers and logistics service providers, and a center for consumer pick-ups and returns of goods.

This hub is dedicated to handle all different freight goods. It is in a layout that allows an easy and flexible adaptation of the space for dedicated requirements and product size. It does not matter whether the products are, e.g., fresh, cooled, with a short shelf life, or bulky. The smart urban multihub is designed to offer space for all kinds of products, dedicated for being supplied to the city. The smart urban multihub can be used for a 2- or multistep crossdocking to efficiently bundle orders so that they can be delivered efficiently to the same neighborhood.

The *third echelon hub* is located in the neighborhoods within the city and encompasses the goods reception points (GRP) and the urban logistics boxes (ULB) from the French system. These hubs are decoupling hubs in the size of microhubs. These can either be parcel lockers, neighborhood stores, or small post offices in the neighborhood. The idea of these decoupling hubs is to decouple logistics service suppliers and freight goods recipients in a timely and space-effective manner. If the logistics service supplier can deliver all orders from one neighborhood bundled to a decoupling hub rather than driving to every single address, the driven kilometers will be reduced, the delivery efficiency will increase, and, if no consumer needs to be home to give a signature for a delivery, the first yield delivery rate will increase to 100%, which will furthermore decrease the freight traffic within the city.

The delivery between the different echelons will all be organized in a white-label multilabel approach, which will reduce the motivation of logistics service providers to separately drive into the city, as they have to drive either anonymously without its own logo or with all logos on the delivery vehicle.

As seen in the simulation, the best results were achieved when the deliveries have been centrally coordinated.

To efficiently organize the hub concept that should be used by different logistics service providers to bundle different deliveries and ship them together with lowest driven kilometers on the city ground, a coopetitive digital platform needs to be in place. With this, the optimization of the deliveries into the city can be made, emphasizing routes with fewest driven kilometers and highest amount of delivered products within the respective city district. All logistics activities including administrative tasks (e.g., invoicing), commercial tasks (e.g., tracking), and financial tasks (e.g., payment) will be coordinated on a coopetitive digital platform that also allows the communication with the freight good receiver under the logo of the respective supplier.

## 7 Expected Results

The city of Zurich expects that the provision of the scarce resource space and the coordinative mechanisms, such as an information and communications technology (ICT) infrastructure that manages the orders, bundles the deliveries and commissions the orders to vehicles according to a geographic breakdown by district or street foster coopetition, since the provided space is only accessible for competitors – such as logistics service providers and retailers – that collaborate in urban logistics. Through the coopetitive approach, the city of Zurich expects benefits in terms of economical, ecological, and social sustainability, promoting the liveability within the city of Zurich.

Traffic and congestion cause, among other things, congestion, noise, local atmospheric pollution, accidentology, and negative externalities from which city's residents, but also the environment, suffer. The external costs of freight traffic for the region of Zurich alone sum up to 81 Mio. CHF (ARE, 2021a; BFS, 2019, 2021a, b, c). These include ecological, social, and economic elements.

Ecological value: In freight traffic in Switzerland, some of the negative externalities are internalized through a Pigouvian tax, i.e., performance-related heavy vehicle charge (LSVA) on highways. Other than this, there are no taxes or fees claimed for externalities due to freight traffic.

The hub concept has the potential to reduce the external costs by reducing the amount of driven kilometers within cities (see Fig. 7 for details of three freight traffic reduction scenarios based on the implemented hub concept).

Societal value: Urban social sustainability describes how communities and individuals live, including quality of life as one of the fundamental elements (Larimian et al., 2020). The Flagship aims at reducing traffic within urban areas while keeping existing comfort, and providing a high liveability in cities, adding to the social sustainability of a city (Table 2).

Economic value: Value is achieved by reduced costs and additional revenues, as shown in Table 3.

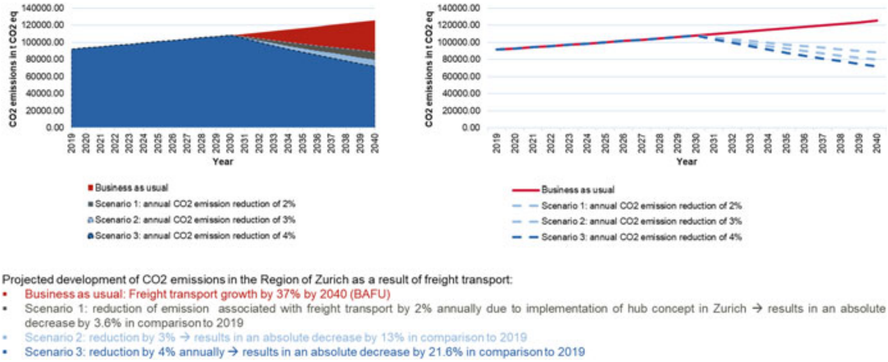


**Fig. 7** $CO_2$ saving potential based on percentages of freight transport reduction

**Table 2** Expected impact on urban social sustainability

| | Reduced negative externalities | Increased liveability in city |
|---|---|---|
| Consumers | Less congestion<br>Less pollution<br>Less noise | Increased safety in traffic<br>More space for recreation<br>More quietness and good air quality |
| Retailers | Less delivery traffic | Full availability of products with short delivery times |
| Logistics service providers | Less congestion | Reduced traffic through bundled deliveries |
| ICT/automation companies | | Created new jobs |
| Hub/decoupling hub owners | Less delivery traffic | Created new jobs<br>Bundled delivery traffic<br>High convenience for residents through pick-up and drop-off accessible 24/7 |
| City/canton | Less traffic, less infrastructure use | Higher satisfaction of residents |

## 8 Future Directions

The next step now is to pilot test the urban hub concept. Since the proposed three-echelon hub system is still on a conceptual base and pilot tests still need to be conducted, the effect on driven kilometers within the city and the reduced costs only based on simulations have not been operationalized and pilot tested yet. This will be done as a next step to be able to decide whether to skip the idea or the three-echelon hub system or whether to fully implement it into a running state within the city of Zurich. It is of special importance to find out which hubs and what number of echelons are applicable for which freight good category (NST) to be beneficial for

**Table 3** Expected impact on economic sustainability

| | Reduced costs | Additional revenues |
|---|---|---|
| Consumers | | |
| Retailers | Shared hub rent (Pay-per-use)<br>Bundled deliveries from hub to stores; less logistics costs | Additional customers due to sustainability label of urban multihub users |
| Logistics service providers | Less congestion costs (drivers being stuck in traffic jam)<br>Shared hub rent (Pay-per-use)<br>Service costs | Additional deliveries due the bundling between logistics service providers<br>Additional deliveries out of urban multihub |
| ICT/ automation companies | | Software licenses for urban multihub<br>Software licenses for decoupling services<br>Software licenses for disposition tool<br>Rent/revenue for technological and automation solutions within urban multihub |
| Hub/ decoupling hub owners | Higher capacity utilization | Rent |
| City/canton | Less infrastructure reconstruction | |

both, the city with reduced traffic and the involved companies through economic benefits. Only if it can be proven that the concept is beneficial for all involved stakeholders, it can be sustainably implemented. The logistics service providers are still skeptical but agreed to run the pilot tests.

It still needs to be tested for which products a three-echelon hub system makes sense and for which products this is too much, and a higher level of direct delivery still needs to be considered. The system aims at a mutualistic coopetition where both, the city and the companies (i.e., logistics service providers, retailers), benefit.

The above-described analysis is embedded in a broader logistics and supply chain context. The thoughts of the multiechelon structure and the question of how to motivate coopetition can also be discussed in a global logistics context. Existing studies on coopetition guide our work. Researchers have concluded that the level of cooperation between competitors is higher the further away the cooperation takes place from the customer of the competitors (Bengtsson & Raza-Ullah, 2016).

Trapp, Harris, Rodrigues, and Sarkis (2020) discuss that for the maritime sector, where containers are shipped, the decoupling point is the point of consolidation in secondary distribution centers (Chang, 2008). For the urban logistics with the three echelon-structure, an analysis needs to be run to analyze where decoupling points between coopetition and competition will be located. From an efficiency perspective in terms of financial and ecological benefits, decoupling needs to be as close as possible at the final consumers. Since the decoupling point in overseas cargo is positioned between general and individual cargo, the pilot study on the urban context focusses on the difference in handling of the freight, considering economies of scope rather than scale into consideration when analyzing possible decoupling points.

The economies of scope might differ between the 18 NST classes, leading to the assumption that different freight categories might have different decoupling points in their supply chain even to the point in the urban context that for some freight categories, a three-echelon structure makes sense while for others, only a two- or even one-echelon structure is suitable. This assumption can also be analyzed in overseas and long-haul distribution and not only in the urban environment to conclude for which product categories coopetition might be beneficial in financial and ecological terms.

Trapp et al. (2020) analyzed whether coopetition is beneficial in maritime container shipping. The researchers conclude that only in very specific situations, coopetition is beneficial over competition, as competitive organizations are already optimized to a great extent. The authors emphasize the role of regulations, concluding that an increase in carbon taxes does not have as high an effect as taxing fuel. In Switzerland, fuel is already taxed. Nevertheless, further research needs to be conducted to analyze whether additional incentives can be used to trigger coopetition, as discussed in literature (Gnyawali & Ryan Charleton, 2018).

Internal incentives are informal penalties to motivate coopetition partners to act in expected ways (Cao & Lumineau, 2015). Possible external incentives are $CO_2$ certificates for shared logistics, or labels for coopetition partners that show that they are more sustainable than noncoopetitive organization. The labels and $CO_2$ certificates can only be issued after a life-cycle assessment about environmental impacts of coopetition and competition in the context of urban logistics has been analyzed.

A third path to continue research is to test whether a platform, acting as a neutral intermediary, is able to positively influence efficiency gains in the distribution of freight in the urban context. Studies provide insights that a neutral intermediate fosters these efficiency gains in overseas supply chains (Trapp et al., 2020). To the best of our knowledge, the urban context has not been analyzed so far.

Furthermore, capacity constraints can also be discussed related to the existence of an intermediary platform, on which free capacity can be offered. Studies conclude that organizations with a high level of capacity are less aggressive in price competition than organization with low capacity levels (Fang & Wang, 2020). Subsequently, in both, the urban and global context, it would be interesting to analyze whether organizations with high capacity levels are willing to offer free capacities in terms of empty space and whether to take freight from coopetitive partners would be economically beneficial for low-capacity organizations in terms of cheaper shipping prices.

## 9 Managerial Implications

There are several stakeholders that need to be integrated in the concept. Subsequently, the concept cannot be implemented by one company alone but needs to be coordinated and implemented by a central unit. Based on the experience from


**Fig. 8** Target groups and beneficiaries of smart urban hub concept

France, such a stakeholder over spanning concept needs to have support from both, private and public, representatives.

The target groups of the smart urban hub concept are all companies that do business within an urban area. The beneficiaries of the smart urban hub concept are the residents and all those companies being involved in the smart hubs (see Fig. 8).

All involved stakeholders such as logistics service providers, retailers, space owner, and ICT infrastructure providers need to reconsider their business models, as changes will occur when implementing the urban hub concept. Since the concept aims at fostering coopetition, the business models need to change to a service-dominant logic, offering services (i.e., space inside a hub, bundled transport, access to a common ICT platform, etc.), which only need to be paid when used or through license fees.

This will change the business models of all involved partners. The digital transformation already showed this change in manufacturing environments. This transformation offers companies the possibilities to integrate their customers deeper in the own supply chains, enabling digital services and close collaboration between suppliers and customers, sometimes even integrating several supply chains steps (Deflorin et al., 2021). The pilot study introduced in this chapter shows that in urban logistics, a change needs to be conducted, going away from individual organizational perspectives toward a change of the whole urban logistics system with all involved partners. For managers, this means to work on a much higher level of external supply chain integration (Golini et al., 2016), letting company boundaries melt between organizations.

Regulatory bodies need to establish an environment in which the systemic change can take place. One incentive that cities have and can use to motivate coopetitive collaborations is land reserves. Cities could change the regulations and only allow the access to these land reserves through exclusive collaborative used, involving competitors to collaborate to access the land. Adopting this logic would mean to change regulatory basics toward mutual integration of organizations rather than developing policies dedicated to individual organizations.

## 10 Summary and Conclusion

Improvement potential in urban logistics is usually discussed based on single improvement suggestions that are not embedded in a broader system and effects that an implemented improvement has on the rest of the urban logistics system. The chapter at hand introduces a holistic urban hub system, encompassing hubs in the outskirt of the city, in the heart of the city, and in the neighborhoods of the city. This holistic urban logistics system is seen as the base to foster a coopetitive urban logistics system, in which competitors voluntarily collaborate, as they only can access scarce space resources that the city offers if the companies collaborate and prove that their shared transhipment/cross-docking and distribution activities reduce the traffic burden within the city. Since the competitors only agree to work in a collaborative manner with their competitors if they are not economically penalized, the urban hub system is beneficial for both, the city with its residents, and the participating logistics service providers and/or retailers.

The introduced urban hub concept turns the system of how urban logistics has been planned and analyzed. So far, the perspective of the logistics service providers and retailers have been core. Optimization purposes mainly focused on logistics service providers and are based on complex, mathematical models (Bergmann et al., 2020) that cannot be operationalized. We turn the perspective and put the residents' well-being at the center, derive their needs and develop a three-echelon hub concept, basing on digital solutions, fulfilling to be as invisible as possible and serving the customers at the best possible convenience. With this, we improve all sustainability aspects: economic sustainability of the logistics service providers and retailers through shared physical and digital infrastructure, ecologic sustainability through less traffic with lower emissions, less infrastructure use, and social sustainability through a better city life, less congestion, air pollution, and noise, and higher traffic safety.

In the proposed hub system, we have several coopetitive situations. Inside the hubs, retailers, even though being competitors, share infrastructure and services. Logistics service providers, being competitors, bundle and deliver freight together. Outside all echelon hubs, the logistics service providers also collaborate in delivering the freight goods from consolidation hubs (first echelon) to the urban multihub (second echelon), and on the last mile to the same districts in a bundled manner directly to receivers or to decoupling hubs (third echelon).

The smart urban hub concept combines shared physical infrastructure, a shared ICT platform for supplier and customer coordination, using a collaborative approach, and emphasizing sustainability not only through changed drive technologies but also in an approach, where existing infrastructure is not extended but activities are bundled, and optimization is done in the perspective of the needs of city residents rather than logistics service providers or retailers alone.

If cities have land reserves, they can be used to motivate competitors to collaborate. Following the coopetitive approach, city authorities can provide central space for logistics activities that is only accessible if the competitors collaborate. The space that is offered in the city center is designed to be multipurpose. The space cannot be rented by the individual stakeholders, as this is known by most urban consolidation centers (e.g., Aljohani & Thompson, 2016), but the space needs only to be paid for the time that it was used by a stakeholder. The multipurpose design emphasizes different requirements of goods, such as handling delicacy, temperature control, safety aspects, etc.

A city has the following possibilities to incentivize coopetition between logistics service providers and/or retailers:

1. Making space for logistics available in the outskirt and city center for collaborative handling and delivering
2. Offering a digital platform to coordinate the deliveries in administrative, financial, and commercial manner, ideally with end-to-end data
3. Providing additional incentives such as $CO_2$ certificates for saved driven kilometers due to collaborative delivery; a label for the city for those suppliers engaging in the coopetitive urban logistics concept to make the engagement for sustainability and liveability in cities through these companies visible; and reducing entry boundaries such as entry restriction at night-time in neighborhoods or entry restriction during the day in shopping areas

Overall, cities suffer from congestion, noise, and air pollution and seek to increase the sustainability and liveability in cities. The possibility to establish a system where horizontal and vertical coopetition will take place on a voluntary basis thanks to incentives and framework conduction from a city authority supports these goals. To be able to establish such a system, the stakeholders need to be willing to collaborate and to share their data. Only with the digital platform, the coordination and consolidation for lowest driven kilometers and maximum freight volume capacity can be achieved. If implemented, the sustainability and liveability of cities will be increased, making the cities ready to offer a comfortable life, even if the densification of cities will further progress.

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# Railway Transport and Its Role in the Supply Chains: Overview, Concerns, and Future Direction

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## Contents



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**Abstract**

Supply chain development has globally increased the importance of rail transport systems. This importance is mainly attributed to high speed, safety, reliability, lower cost, and being eco-friendly compared to road transportation. This chapter examines the overview of the rail freight network, its role in the supply chain, scientific literature, and current concerns. Rail network concerns are investigated considering six essential elements: environment, cost, optimization, operation, planning, and safety and resilience. Furthermore, a comprehensive causality network is developed to manage the railway network effectively. Finally, future directions, opportunities, and challenges in this domain are presented.

**Keywords**

Railway transportation · Rail freight transport · Supply chain · Safety · Security · Optimization

## 1 Introduction

Rail transport (RT) is one of the critical elements in a sustainable transport system and supply chain (Hao-dong & Shi-wei, 2010). RT importance is attributed to three critical factors (Lapidus et al., 2019). First, the low level of external costs leads RT to be an economical option for freight customers. Second, RT is environmentally friendly. RT is the most environmentally friendly method of land transportation for freight. Lower $CO_2$ emissions and energy consumption per tonne-kilometer compared to road transport or inland waterways transport have the least destructive impacts on the environment. Third, it provides higher capacity in the fastest possible time and less intercity traffic, making the railways a preferred way for transporting bulk goods such as solid mineral fuels and metal scrap.

RT is also known for transporting petroleum products and fertilizers. This importance is felt far more in North America and Asia than in Europe. In this regard, longer distances, shorter stops, and the possibility of running trains with much higher capacities are among the essential advantages of rail infrastructure in North America and Asia (Mohammadfam & Gholamizadeh, 2021).

The increased importance of RT in the supply chain has necessitated a comprehensive review of its characteristics, opportunities, and challenges. This chapter provides a comprehensive overview of RT and its contributions to supply chains.

The background section of this chapter presents the history of rail networks, their importance in the supply chain, and rail network infrastructure. The current concerns, emergent concerns, and special research section offer some research background on RT and its role in the supply chain. Concerns are presented in the future directions section. The summary and conclusion section discusses future directions and challenges based on current and emerging concerns.

# 2 Background

## 2.1 Historical Background of Rail Transport

Table 1 illustrates the evolution of rail transport since 1550 (SNCFT, 2010). The origins of RT go back to the invention of the fixed steam engine by James Watt. Extensive work on steam locomotives began only after his patent expired in 1800. Several inventors started working on improving the Watt design. Of course, some wagons' horses pulled on rails made of wood long before that. Under uncompressed pressure in the first few years of the nineteenth century, the first steam engines allowed engineers to build a new rail system. The invention of the train became one of the critical events in history for human progress in developing freight transportation. The first locomotive to run on a steel rail was a freight car built in the south of

**Table 1** The history of developments of the railway in the world (SNCFT, 2010)

| Year | Events |
|---|---|
| 1550 | The first frame invention was proposed for a moving cart on a mine rail in Alsace, Switzerland. |
| 1671 | Denis Papin presents the theory of the ability of vapor pressure in the development of railways |
| 1738 | Iron plates were created instead of wooden rails in a mine in the UK to reduce wear |
| 1789 | The invention of a rail system consisting of cast-iron rails and flanged wheels rolled into a pudding by William Jessop |
| 1804 | Construction and testing of the world's first locomotive with a carrying capacity of 10 tons (in 5 cars) by Richard Trevithick |
| 1808 | Design and build a more advanced locomotive than the first version |
| 1823 | George Robert Stephenson establishes the first locomotive plant in Newcastle |
| 1825 | Inauguration of the world's first passenger train with traction steam engine in the UK |
| 1828 | The operation of the French-saint Etienne Andrézieux railway was started |
| 1831 | Test of the first locomotives made in France by Marc Seguin |
| 1835 | Construction and opening of railways in Belgium and Germany |
| 1837 | Inauguration of the 19 km Paris-Saint-Germain railway |
| 1838 | Invent the rail-based postal machine to collect and move postal packages between Birmingham and Liverpool |
| 1839 | The inauguration of the Paris-Versailles and Netherlands-Italy railways |
| 1840 | The first train report in the UK by the telegraph |
| 1842 | Construction of the factory for the production of the world's first electric locomotives (with batteries) by Davidson |
| 1843 | The inauguration of the Paris-Rouen and Paris-Orleans railways in France. In this last line, the carriages are transported with their passengers on flat cars (the first combined attempt of the railways) |
| 1847 | The start-up of the first Crampton fast locomotive with a large driveshaft (over 2.2 m) and using it in many rail networks |
| 1851 | Rail transport of perishable goods in refrigerated ice wagons in the United States |

(continued)

**Table 1** (continued)

| Year | Events |
|---|---|
| 1853 | Introduction of the railway in India |
| 1855 | The usage of the Vignier device to prevent operator error in the signal box and prevent signaling by activating mechanical interlock |
| 1858 | Design and development of Gillard-type injectors to replace water supply pump in locomotives. |
| 1864 | Construction of the first railway line in Indonesia |
| 1868 | Researchers designed and operated the first steam locomotive with heavy oil heating by Sainte Claire Deville |
| 1869 | The constitution of a rail link between the Atlantic and Pacific oceans |
| 1879 | Design and commissioning of an electric tram in Berlin by Siemens and Halske |
| 1882 | The first application of electric lighting at a station in France (Saint-Lazare) for round-the-clock loading and unloading activities |
| 1893 | The trial of an electric locomotive connected to a battery in the northern network |
| 1900 | Design a high-speed locomotive in Belfort by Alsatian at a speed of 140 km/h |
| 1912 | Construction of the first diesel locomotive with 1200 hp. in Germany by Sulzer |
| 1918 | The establishment of a central control network in France to control the train's movement (dispatching) |
| 1922 | Creation of the International Union of Railways (UIC) in Paris |
| 1931 | Test Renault and Michelin cars at 107 km/h for cargo |
| 1937 | The tee of the two 4000 hp. diesel locomotives in the PLM network |
| 1955 | Set the world speed record by electric locomotives CC 7107 and BB 9004 with 331 km/h |
| 1961 | The tryout of freight trains in the United States with a starting load of 25,000 tons with six locomotives located in the front, middle, and tail and equipped with a telephone radio |
| 1972 | Record speed of 307 km/h based on self-propelled traction by the gas turbine of the French train TGV001 |
| 2004 | Launch of a new generation of regional high-speed trains (TER) by Bombardier transport company equipped with diesel technology for use in nonelectric lines |

England by Richard Trevithick. This move marked the beginning of the construction of the freight train and later the passenger train.

Throughout history, researchers have had significant concerns about the performance of rail freight systems, and they addressed many of them through advancements in technology. Timely delivery of goods and transportation optimization have supplied chain managers' most critical challenges. Delays in freight delivery, rail route interventions, energy optimization, and environmental protection have significantly affected the efficiency of rail systems in the supply chain. In addition, improving safety to prevent accidents is one of the concerns of supply chain managers. Life and financial losses have always been in the spotlight. The establishment of central control systems, mechanical interlocks to prevent operator error, and radio communication systems are some of the control solutions in this field.

## 2.2 Importance of Rail Transport in Supply Chain

RT plays a vital part in the logistics supply chain and third-party providers. RT has been recognized as a viable alternative to road transport. Moreover, RT is essential for future economic prosperity, so it plays a crucial role in ensuring continued competition and the creation of commercial wealth through its integration with the supply chain.

Figure 1 shows the volume of rail freight transported in the United States (US) and the European Union (EU) from 2006 to 2019 (Carlier, 2021a, b). The average transported rail freight volume between 2006 and 2019 in the USA (Carlier, 2021a, b) and EU (R FTS, 2021) was 2.4 and 0.385 trillion tonne-kilometers, respectively.

Statistics also present that the shares of rail transport in the supply chain in the USA are significantly higher than in the EU (R FTS, 2021). Alternatively, in 2019, goods were transported by approximately 3.1 billion ton-kilometers by rail in Europe and Turkey, slightly lower than in Asia, Oceania, and the Middle East – which had about 3.5 billion ton-kilometers transported by rail in the same year (Carlier, 2021a, b).

RT traffic has generally grown worldwide between 2018 and 2019 (Carlier, 2021a, b). The analysis of the share of RT in comparison with road and inland waterways transport is also significant. The share of RT has been approximately a quarter of the share of road transport in the EU (see Fig. 2) (FTS, 2021). On the other hand, the rail network has been used approximately three times more than the inland waterways to transport materials (FTS, 2021).

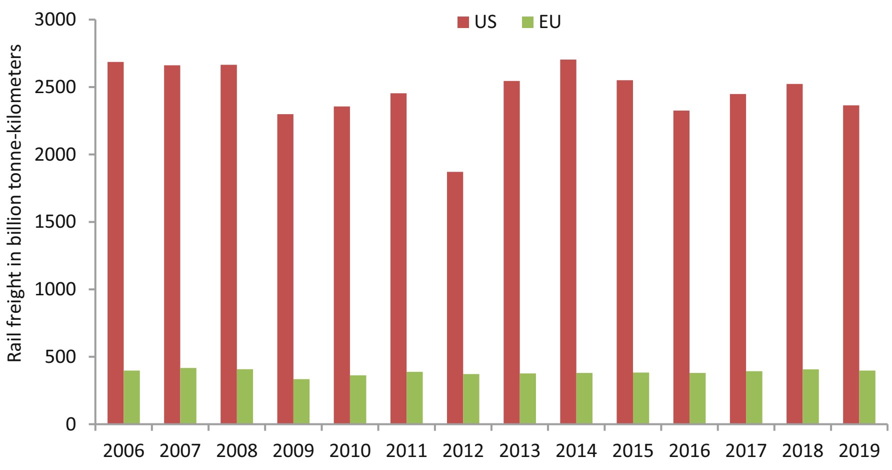


**Fig. 1** The volume of rail freight transported in the United States and the European Union from 2006 to 2019. (Carlier, 2021a, b; RFTS, 2021)

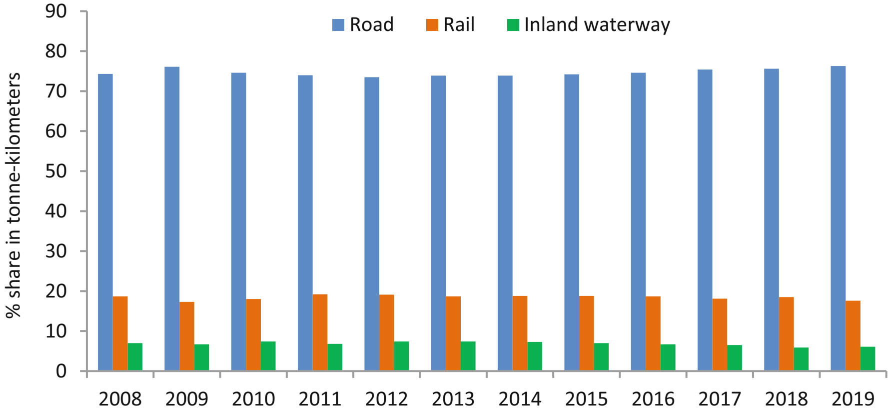


**Fig. 2** Modal split of inland freight transport in EU from 2008 to 2019. (FTS, 2021)

The cited statistics demonstrate the importance of railway networks in the supply chain and materials logistics. Railway networks are second only to road transport, and their importance is increasing every year.

## 2.3 Components of the Railway System

The railway is one of the most extended land transportation systems. Trains run on their own on a unique steel guide defined by two parallel rails using fuel or remote transmission force (electric traction) on movable steel wheels (Profillidis, 2016). Railways are designed to move passengers and cargo, and their excellent capability makes them deal with any distance in multiple geographical circumstances (urban, suburban, regional, and interurban). Its range for passenger transport is usually approximately 1500 km, while this distance can be much longer for freight transport. Figure 3 summarizes the components of the railway system (Pyrgidis, 2019).

We can divide rail systems into three aspects. In the first aspect, the railway system is divided into power vehicles, single vehicles, trailer vehicles, and engineering vehicles. These are, in turn, classified according to the type of fuel used and the type of use (passenger or freight). Secondly, rail systems may be classified according to the kind of route. Accordingly, tunnels, regular routes, bridge routes, overpasses, and underpasses are considered. The third category is related to the type of rail system trains. Push/pull trains, loco-hauled, and multiunit trains are part of this aspect, used to carry passengers or freight depending on the wagon type.

## 2.4 Research Literature

Studies regarding the rail network's role in the supply chain have been explicit since 1998 – the term supply chain was not as widely used in academic literature before

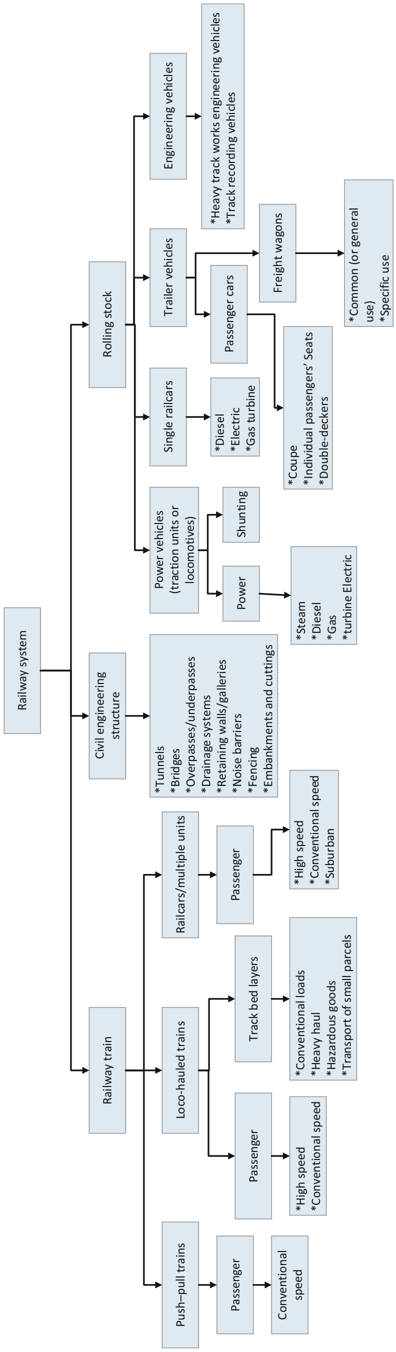


**Fig. 3** The components of the railway system. (Pyrgidis, 2019)

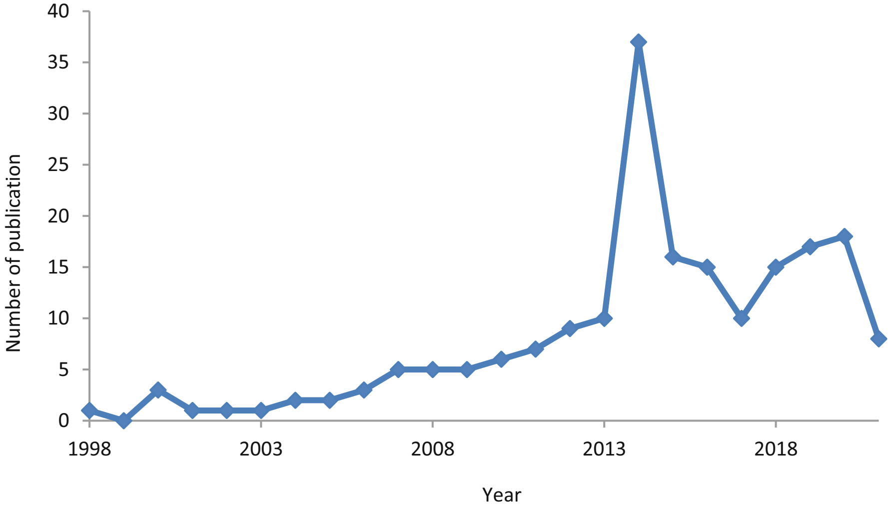


**Fig. 4** The trend of literature published in the rail network field and its role in the supply chain

this time. Lebedev and Staples (1998) indirectly investigated the role of the rail network in supplying coal from mines and transferring it to power plants. In this context, a comprehensive bibliometric search was performed using the Scopus database.

The results show that 197 documents have been published since 1998 on rail transportation and its direct or indirect role in the supply chain, as illustrated in Fig. 4. Increasing the number of studies was initially slow, but the number of documents published since 2013 has significantly increased. In 2013, 10 papers were published, and in 2014 this number increased to 37 papers. In recent years, the increasing growth in academic achievements is attributed to the tangible increase in the importance of the rail network and its role in the supply chain.

Findings related to the analysis of the subject area of studies also pointed out that most studies were conducted in engineering and social sciences – with shares of 23.7% and 15.3% of the total studies, respectively – see Fig. 5. On the other hand, economics, mathematics, and agricultural and biological sciences had the lowest shares with 2.6%, 3.3%, and 3.3% of the total studies. It is noteworthy that business and accounting comprise 10.3% of studies.

In addition, the findings of the analysis of the types of studies showed that 125 documents (63.5%) were journal papers (Fig. 6). Also, 51 documents (25.9%) were conference papers. The findings also revealed that China and the USA were countries having the most published documents, with 43 and 36 documents, respectively, followed by India, Sweden, and the United Kingdom with ten each.

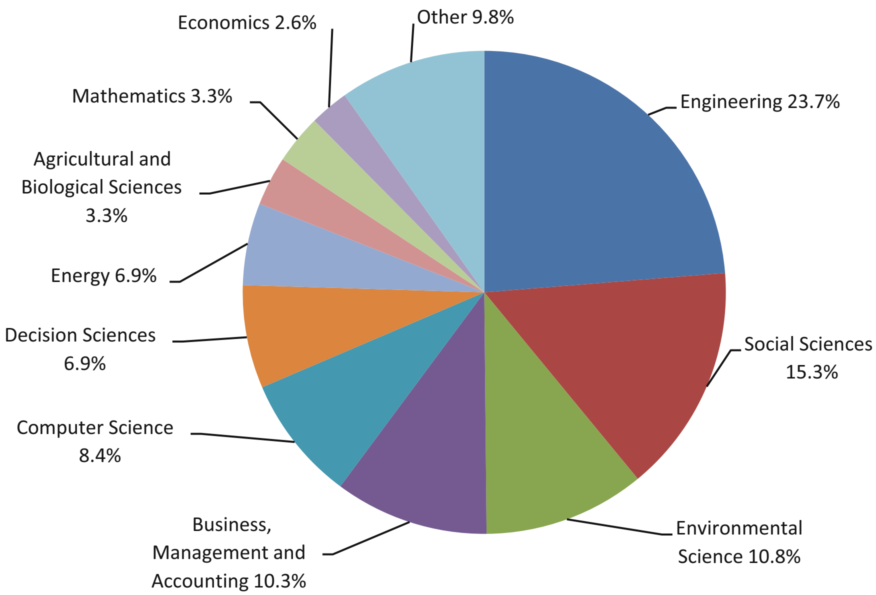


**Fig. 5** The subject of studies in the field of the rail network and its role in the supply chain

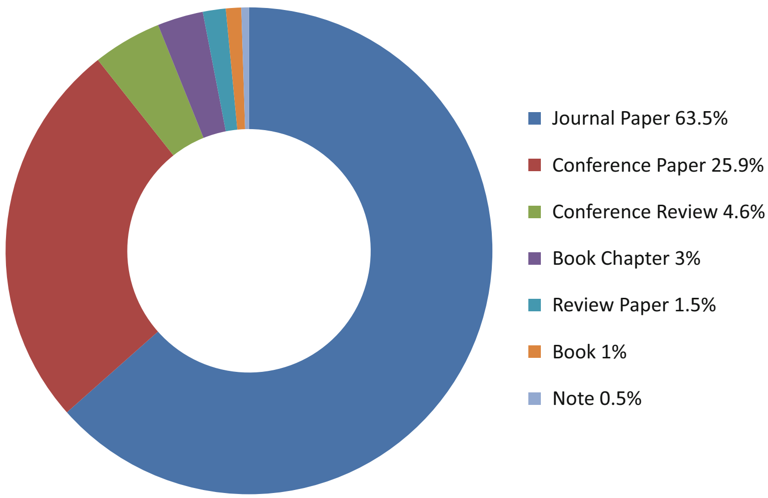


**Fig. 6** The type of studies in the field of the rail network and its role in the supply chain

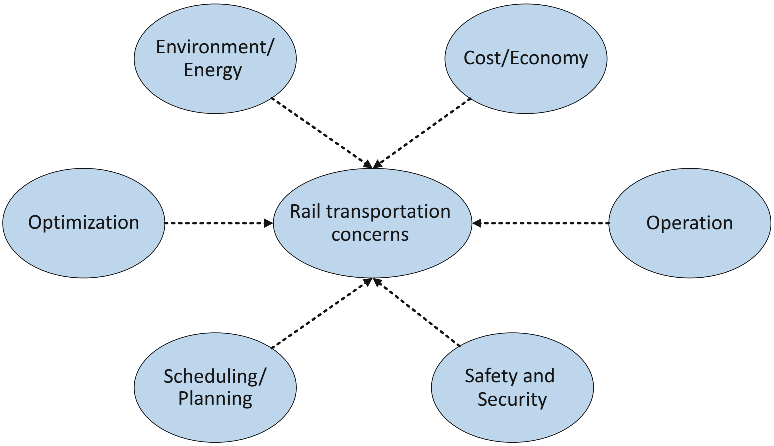


**Fig. 7** Primary Concerns in the rail transport & supply chain

## 3 Current Concerns, Emergent Concerns, and Outstanding Research

The identified studies did not focus directly on rail transportation and the supply chain. A close look at the direct studies revealed that they addressed six significant concerns – as presented in Fig. 7. In the following sections, these six concerns are discussed. These concerns include environment/energy, cost and economics, optimization, scheduling/planning, safety and security, and operation.

### 3.1 Environment/Energy

There is a close relationship between environmental impacts and the energy used by locomotives. As a result, locomotives that use diesel and other fossil fuels have more harmful effects on the environment. Therefore, in the last decade, due to the stricter rules of the Environmental Protection Agency (EPA) – in the United States – the willingness of railway network managers to use electric locomotives has increased. Alternatively, the concern of releasing harmful gases such as carbon dioxide ($CO_2$) and greenhouse gases (GHG) is gaining attention from researchers. Jäppinen (2014) examined the effects of local biomass availability and possibilities for train transportation on GHG emissions. The findings of this study proved that site-specific biomass availability and transportation possibilities should be considered in GHG emission management because there is an inverse relationship between the emission level of these gases and path characteristics. Jäppinen (2014) also examined GHG emissions of forest-biomass supply chains to commercial-liquid scale-biofuel production plants in Finland. The findings demonstrated that GHG release is significantly reduced through railway transportation from distant supply areas.

Moreover, Zuo (2013) used a "spatial decision support system (SDSS)" to investigate scenarios for reduced $CO_2$ emissions from the rail cars in Wales and the UK. Their findings demonstrate that replacing locomotives and using two new mines with a reduction of 260,000 tons and a reduction of 140,000 tons of $CO_2$ were the most effective control scenarios to decrease the environmental impacts in RT. Wanke (2015) demonstrated that carbon emissions should be considered in rail network planning. Accordingly, the inclusion of carbon emission costs in the planning of logistic networks is a critical point.

### 3.2 Cost and Economic Concerns

Profitability based on cost-benefit ratios plays a vital role in transportation management. Costs usually include maintenance, personnel, fuel, environmental pollution, and taxes. Generally, direct and indirect costs must be significantly less than the profit from freight or passenger transport (Abbas et al., 2013). Hence, transportation management has always welcomed low cost-high benefit approaches. They examined the coke-making supply chain and its costs using rail and road data in Shanxi, China. Researchers have also conducted studies in this field that adumbrate the superiority of the rail network over the road network in freight transport. Hendrickson (2006) demonstrates that transportation management should prioritize rail infrastructure budgets because the cost of the rail network is much lower than road transport.

There is a priority for rail transport costs, but not in all areas. Yuqian and Siping (2010) pointed to a "region" factor that plays a more critical role in cost-benefit in rail freight. They took into account the "region" factor and showed that in some regions, for geographical reasons, rail costs could be higher than road costs. It is worth noting that the prioritization of rail and road networks can differ depending on the area. In addition, the type of fuel used by locomotives also has a significant effect on the level of costs. Tahvanainen and Anttila (2011) revealed that at distances less than 60 km, freight movement by trucks is less expensive than locomotives using wood fuel (biofuel), but at distances of more than 130 km, the rail network is less costly.

Another economic challenge is large container businesses. Usually, in the supply chain structure of container trade, the containers are loaded in the country of origin, and the consignment is shipped to a large logistics center at the goel or a distribution center closer to the goel. However, this method may not be optimal for total logistics costs because the entire transport route is spent transporting cargo from one origin to one destination. Their study (Lin et al., 2020) suggested that in such cases, shipping is done in a branch to share several buyers in a shipment. Their findings point out that this solution could reduce monetary logistics costs: converting less than full container load (LCL) shipments to full container load (FCL) shipments and converting almost 20-foot FCL shipments to 40-foot FCL shipments.

### 3.3 Optimization

There is an interconnection between optimization and costs and environmental effects because optimization seeks to reduce or minimize these effects. Mathematical optimization or mathematical programming in mathematics, economics, and management refers to choosing the best member from achievable members (Rao, 2019). Mathematical experts endeavored to obtain the maximum and minimum values of an actual function by systematically selecting data from an achievable set and calculating the value of an actual function (Antoniou & Lu, 2007).

There are two assumptions in management: data availability and data constraints. The optimal value can be estimated using the first and second derivatives methods for continuous variables if we access the data. On the other hand, if we do not have access to the data, depending on the organizational and economic problems, models such as linear, integer, ideal, nonlinear, Lagrangian coefficient, defined or definite methods can be used. Therefore, an optimal point can be found using the available methods (Intriligator, 2002).

In optimization, depending on the conditions of the rail network, control solutions are provided, and then the optimal points can be calculated using the mentioned models. In simpler terms, the optimal points are the ideal state that can be implemented in the rail network. Studies in this area go to 2010 when Zang (2010) used the rail transportation joint optimization method to investigate the power coal transportation and inventory problem, and their findings showed that implementing the findings of this model could reduce total costs, transportation time, and fuel consumption, as well as increase rail system efficiency. In general, this is the ultimate goal of optimization programs. This issue has received considerable attention from rail transport management in the last decade. Ma (2014) also presented a freight train's operation diagram, a comprehensive optimization model, on high-speed rails and verified the proposed model using genetic algorithms. This model consisted of two parameters: economic profit and time consumption. The findings demonstrated that the model has led to economic benefits and reduced time consumption.

Like many management methods, we can use optimization methods depending on their capabilities and the model's objectives. Static and single-objective optimization models may not effectively support inter-firm collaboration to achieve optimal rail logistics. In this regard, multiobjective dynamic methods can be more effective. Palander (2015) (Palander, 2015) presented a model based on dynamic multi-objective linear programming, which supported inter-company cooperation because importing and exporting goods to the regional rail transport environment requires the continuous and integrated optimization of supply flows and railroad cars. Moreover, Shramenko (2019) used this optimization model to evaluate the railway efficiency. Their results showed that using optimal solutions, the efficiency of the railway reached 324.2 ton/h and the delivery interval reached 1.75 days. These signs of progress lead to economic benefits and lower time consumption.

Another primary problem involving rail manager input is the optimization of energy consumption to reduce costs and increase the efficiency of the rail system. In recent years, engineers have been working on nonstop power exchange systems and have developed optimal models in this area. Liu (2021) has proposed an optimal model for overcoming hydrogen fuel deficiencies in trains based on continuous power exchange using mechanisms of supply, consumption, and replenishment of multienergy forms (hydrogen energy, Photovoltaic, and electrical energy). Their study revealed that the benefits of using the introduced system are reducing the cost of energy, improving solar energy production, and increasing the capacity of energy carriers to solve the problem of distance-traveled anxiety in nonstop power exchange systems.

## 3.4 Scheduling/Planning

The transportation of goods should not be decoupled from the production cycle and assembly of goods, and therefore, the transportation schedule must be consistent with the production schedule (Hajiaghaei-Keshteli & Aminnayeri, 2014). This coordination is one of the elements of supply chain improvement, and if properly designed and implemented, it can reduce accident statistics and reduce transportation time and costs.

Rail network synchronization is no exception to this rule of coordination. Mathematical algorithms are used to develop rail chain-related synchronization. Due to the entanglement of rail networks and cargo movement in different lines, each wagon must pass through a rail joint at a suitable time to avoid catastrophic accidents. Hajiaghaei-Keshteli and Aminnayeri (2014) introduced a proprietary algorithm called the Keshtel algorithm. Their findings point out that the Keshtel algorithm is more efficient when the problem size is more significant and, conversely, it is better to use the genetic algorithm when the problem size is small. They suggested that researchers compare the performance of mathematical algorithms in future studies.

On the other hand, setting a schedule for the production and allocation of rail freight orders to optimize customer service at the lowest cost is another concern in rail synchronization. Different train destinations, train capacity, and different transportation costs are the main aspects of concern that need to be considered. Their study (Hajiaghaei-Keshteli et al., 2014) revealed that genetic algorithms provide more accurate findings in solving large-scale problems than simulated annealing. Another concern related to scheduling is the timing of trains arriving at stations. Another train on the same track is approaching the station when a train stops. This schedule is essential. Thus, coordination is necessary in this regard.

Zinder (2016) presents two polynomial-time optimization procedures for the train scheduling problem, where a single railway track connects two stations. They used dynamic programming and the Iterative algorithm for this purpose. The findings of this study showed that a combination of the two methods could be used to schedule the movement and stopping of cars.

## 3.5 Safety and Security

Although RT seems to have a higher safety level than road transport, it introduces serious hazards (Mohammadfam et al., 2020). Many factors together can cause rail accidents. The nature of rail accidents may be examined from two aspects. First, cargo overturned or colliding with another train could kill or injure personnel, passengers, or residents. Second, goods transported by a rail network can lead to catastrophic consequences such as fire, explosion, or the release of toxic substances. The latter is more hazardous and prevalent in chemical materials transporting, waterways, and railways.

Zarei (2022) proposed a dynamic approach to investigating the consequences of gasoline leakage. This investigation calculated the leak and propagation (escalated) probability of gasoline release from the rail cars using the Fuzzy-Bayesian network model. They also presented a dynamic model for analyzing domino effects risk in the rail network while capturing the time dependency. Their findings proved that fires and explosions caused by gasoline leaks involved radii of up to 18 m and 60 m, respectively, resulting in significant human, environmental, and financial losses. The research pointed out that the golden time to deal with the potential fire scenarios is around 5 min because the escalation probability to other rail cars (i.e., causing a domino effect) jumps dramatically after this moment. Therefore, it is necessary to meet the safety and risk-driven requirements in designing the railway systems, especially when they crisis residential areas.

In addition, Mohammadfam (2022) proposed a quantitative framework for assessing the risk of consequences related to the gasoline leakage from rail cars in the urban areas. Their findings showed that at 50.00, 53.00, and 54.50 m away from the gasoline leakage point, the individual risks of vapor cloud explosion (VCE) (per working year) are 1.00E-4, 1.00E-5, and 1.00E-6, respectively. As a result, they suggested that residential buildings and recreational and commercial areas should be built at a distance of more than 55 m from the leak point in urban areas where the risk is lower than 1.00E-6 per year.

Moreover, emergency response planning and crisis management are other vital challenges. Reducing rail accidents has recently become a vital priority for railway management. Reducing the rate of these accidents and crisis management when they occur are the effective parameters in creating sustainable development in the railway network. Although advances in technology have reduced rail accidents, according to the International Union of Railways (UIC), efforts to reduce rail accidents to zero are still challenges in managing rail transport. We can examine rail safety from four aspects, including risk assessment, emergency response management, human factors, and reliability engineering (UIC, 2019).

Despite significant progress, RT development is often accompanied by unpredictable disasters. In 2003, an arsonist set a train on fire in Daejeon, Korea, causing a severe fire that killed 198 people and injured 147 (Park et al., 2013). In 2005, another incident occurred in Japan. A train traveling between the suburbs and the city of Amagasaki derailed and collided with a building, killing 107 people and injuring 549 others. In mid-2011, a Chinese train traveling from Beijing collided with another train from Hangzhou due to a signal failure, killing 40 people and injuring 200 others (Dong et al., 2012). In Iran, the Neyshabur train accident was another clear example of a rail accident in history that occurred on February 18, 2004, killing more than 350 people and injuring 460 others (Jahangiri et al., 2018). As a result, emergency response has become a vital issue in developing rail systems. Designing and implementing effective strategies to reduce casualties and financial losses as much as possible is the main framework of the emergency response (Dong et al., 2012). Emergency management can reduce the number of people exposed to potential consequences by zoning the scene and improving the resiliency of supply chains.

The rail networks worldwide have always been directly and indirectly affected by natural disasters such as storms and earthquakes. Geologists have always considered landslides and floods in the safe routing of rail networks, therefore, less prone to distracted by natural disasters. For example, a storm caused extensive damage to rail and road networks in the UK on June 28, 2012. In this regard, Jaroszweski (2015) suggested that related experts should notice the safety and security measures to deal with natural emergencies on all relevant railway lines and stations. This approach is a constructive interaction between operations and system resilience.

Generally, it is vital to minimize the impact of natural climate disasters on rail network activities. Woodburn (2019) pointed out that the effects of climate disasters are short term and, at the same time, have meaningful economic and operational impacts. Consider a sudden storm that starts at 9 a.m. and continues until 11:30 p.m. In this case, we are facing a short-term natural disaster. Nevertheless, on the other hand, the effects of this storm can affect the railway network and supply chain for several weeks. Rail network cleaning, rail line repairs, treatment of potential casualties, substantial economic costs, etc., can be part of these effects.

On the other hand, the timely presence of emergency response forces such as firefighters and medical rescuers can also reduce casualties and financial losses. In addition, if it is at the right level of performance, the incident command system can prevent unnecessary gatherings at the scene and create proper coordination between different organizations. It is noteworthy that implementing the National Fire Protection Agency (NFPA) and EU standards can play a vital role in emergency management (Mohammadfam & Gholamizadeh, 2020).

The issue of theft is also essential in reviewing the security of rail networks. In general, in heavy industry, rail freight volume is indispensable. Thefts often occur due to the poor security of rail routes – usually passing through plains, mountains, and forests – and the significant volume of goods in rail transport. The main problem with securing rail transportation is predicting the location with the most potential for theft. Risk assessment with advanced engineering tools that can simulate human thinking is efficient. Lorenc (2020) predicted the risk of stolen sites in the rail network using artificial intelligence networks and machine learning methods. They had already identified the high-risk areas (based on the history of thefts) and then calculated the risk of those areas using the mentioned two methods. Their findings showed that machine learning (by identifying high-risk areas = 100%) performed better than artificial intelligence networks (efficiency = 94.7%). Thus, machine learning could be used as a reliable tool in developing rail infrastructure security.

Risk assessment is central to security and safety and overall supply chain and RT resilience. Risk assessment means identifying, assessing, evaluating, and controlling the hazards. Risk is the interaction of the two main parameters of probability and severity (Zarei et al., 2013).

Experts seek to answer a series of questions in most risk assessment investigations. What is the rate or probability of a rail accident, equipment failure, rail overturning, derailment, and consequences such as fire, explosion, injuries, and fatalities resulting from the accident? How severe are the consequences of a rail accident? What should be the safe distance from the railway networks? What should preventive control strategies be considered to prevent these accidents?

Safety engineers use various tools to answer risk assessment questions. Risk is usually calculated quantitative and qualitatively, and in the last decade, experts have paid more attention to quantitative risk because of its accuracy. For instance, to quantify the risk probabilities, we can use appropriate tools such as Fault Tree Analysis (FTA), Event Tree Analysis (ETA), and Bowtie analysis (Mohammadfam et al., 2022).

Bayesian networks, artificial neural networks, and fuzzy sets theories can be used (Gholamizadeh et al., 2022). Safety engineers can also use appropriate tools to calculate the severity. Severity calculation can begin with consequences modeling (Aliabadi & Gholamizadeh, 2021; Gholamizadeh et al., 2019). Simulation equations (Zarei et al., 2022) or specialized software can be used, such as PHAST and ALOHA software. This software estimates the thermal radiation caused by fire and overpressures caused by explosions and toxic substances concentrated at different distances from the center of the chemical leak.

PHAST software can directly extract the risk by entering the probabilities (Aliabadi & Gholamizadeh, 2021). Other methods can input thermal radiation and explosion pressure values into the probit equations, with the severity factor finally estimated (Mohammadfam et al., 2022). Quantitative risk can then be calculated by multiplying the probability of the consequences by their severity factor. The calculated risk should be compared with the risk criteria, and the degree of desirability of the risk should be evaluated. Finally, safe distances and control solutions are provided (Aliabadi & Gholamizadeh, 2021).

Human error plays a significant role in rail accidents. Welders, for example, are the most vulnerable component of railroads and can be easily damaged by the fault of designers, manufacturers, operators, or maintainers. Design defects caused by the designer, defective welded joints caused by the manufacturer, excessive speed or loads caused by the operator, and corrosion of railway lines due to poor inspection and maintenance could be the cause of defects. These errors are not related to a specific time and can occur at any time. Moreover, human errors can occur in all rail system parts (Mohammadfam et al., 2022): train controlling, rail planning, manual operations in the maintenance, loading, and unloading operations. Therefore, these errors must be evaluated using suitable tools (Gholamizadeh et al., 2022).

Humans and technical functions require extensive human-machine operations in the rail network. Although the mentioned technological advances have operationally improved freight transport, many activities such as control, repair, and monitoring are still operated by human resources (Wilson & Norris, 2005). Hence, it is necessary to pay attention to human factors. However, human factors analysis receives more attention in the safety and ergonomics domain. Rail human research has proliferated over the past few years, both in quantity and quality.

The continuing effects of safety concerns, new technical system opportunities, business reorganization, the need to increase the effective, reliable, and secure use of capacity, and the increasing interests of society, the media, and government have now significantly accelerated rail human resource research programs (Reinach & Viale, 2006). Future studies in this field could be performed to analyze human errors and study human behavior in rail systems. In this regard, the use of specialized methods such as HFACS (Human Factors Analysis and Classification System), HEART (Human error assessment and reduction technique), and THERP (The technique for human error-rate prediction) can be helpful, depending on the type of study (Gholamizadeh et al., 2022).

Hassan (2009) suggested that in assessing the risks associated with rail transportation, experts consider human errors and technical failures. They used the human error assessment and reduction technique (HEART) to assess human reliability in rail accidents. Baysari (2008) used the HFACS method to identify the factors influencing rail accidents in Australia. Their findings revealed that nearly half of the incidents resulted from equipment failure, resulting from inadequate maintenance or monitoring programs. In the remaining cases, slips of attention (i.e., skilled-based errors), associated with decreased alertness and physical fatigue, were the most common unsafe acts leading to accidents and incidents.

Also, Madigan (2016) used the HFACS method to analyze five types of rail accident reports. They proved that in the study of human error, experts pay more attention to operational failures, and in future studies, latent failures should also be considered. They also proposed a new category entitled “Operational Environment” for future studies on the use of HFACS. Other methods have also been observed in studies related to human error analysis in rail transport.

Safety experts pursue the goal to predict and analyze human error probability (HEP). For this purpose, researchers use specialized methods such as THERP, HEART, CREAM, and SLIM (Success Likelihood Index Method). Zhou and Lei (2020) used a combination of HFACS and SLIM methods to analyze the probability of human error in the railway driving process. They first used HFACS to identify links between human parameters related to 611 rail accidents and then calculated the human error probabilities using SLIM and network analysis.

In addition, researchers used FANP to handle the problems of interdependencies and interaction between EPCs and the uncertainty that exists in the experts’ judgment was used. Sun (2020) used the modified CREAM method to analyze human error probability in high-speed railway dispatching tasks. Like other methods of assessing human error, the traditional CREAM cannot calculate the probabilities with sufficient accuracy when faced with a lack of sufficient information.

Therefore, it must be combined with appropriate quantification methods. Sun (2020) used a 2-tuple linguistic term set to describe CPCs evaluation, combined weighted Common Performance Conditions (CPCs) by Evidential Reasoning (ER) approach, and adopted the multi-Attribute Group Decision-Making (MAGDM) method to calculate HEP.

The authors suggest that in future studies, third-generation methods of human error analysis – such as using a Bayesian network to evaluate the dynamics of human error in the rail system – could be used in sensitive parts of the rail network. These sensitive areas include rail line planning, movement and stop planning, and loading and unloading operations.

The concept of reliability is an essential indicator for measuring random network performance. Reliability is the ability of a system or component to perform its required functions under stated conditions for a specified period. In recent years, deteriorating urban traffic conditions and frequent traffic congestion have widened the gap between traffic conditions and passenger expectations, forcing transportation management to look at traffic problems more rationally. Reliability can be investigated in maintenance, planning, mechanical, and operation. Interested readers can refer to Vromans (2005).

Reliability, maintenance, and support of rail logistics address the concepts that must be considered in the design, development, and operation of a system. There is a deep connection between system reliability and safety. These parameters strongly affect the performance and costs of rail transportation and, in particular, should guide the choice of railroad managers in planning maintenance actions.

The traditional approach to maintenance planning has always been available for each case based on previous experience in maintaining the same equipment. This approach is now obsolete because it is not feasible if new technologies are used, and there is no historical memory or experience for new situations. So management must take a more appropriate approach based on a probabilistic estimate of system behavior and actual data. In other words, a dynamic prediction must be made during system operation. The so-called reliability-centered maintenance (RCM) policy meets this requirement.

The RCM must progress in three steps before achieving significant results. First, the RCM process must examine the performance of assets and, based on that, understand the goals of asset productivity. Second, look at how an asset can fail, including the impact of failures on systems and subsystems. Third, the RCM must develop mitigation strategies that can be implemented against potential failures.

Investigations have shown that when the RCM process is used in other industries, it has been able to increase the quality of the maintenance process, improve the reliability and safety of the equipment, and reduce maintenance costs. In this line, Creecy (2003) reports that some organizations have saved up to $ 147 million a year in RCM maintenance costs; others (D'Addio et al., 1997) have shown that RCM could reduce costs and increase the profitability of rail systems.

We can divide the safety and security events in the supply chain into three categories. The first category is events whose severity is insignificant or low, and the probability of their occurrence is known. These events are less important, and their prevention is not a priority. These types of events are called known events. The second category is rare events, but the consequences are predictable, events such as hurricanes in Los Angeles; although the probability of such accidents cannot be determined, the resulting damage can be estimated based on similar cases. These events are known as unidentified or gray solid events. The third category refers to events that have not been experienced yet. The consequences of their occurrence are severe. For example, an earthquake may occur in Oslo, but due to its nonoccurrence to date, its probability cannot be accurately estimated. These events will have severe consequences and are called unrecognizable or strong black events. The first category of events can be justified by the concepts of reliability, while to justify the second and third categories of events, a new concept called "resilience" is needed.

Resilience is originally derived from the Latin word *resilience* and means to return. Resilience is the ability of a system, community, or society at risk to resist, absorb, adapt, and recover on time from the effects of a hazard and maintain and rebuild the basic structures and functions of the system. Resilience applications observe in the multifarious supply chain, engineering, organizational, economic, ecological, and social domains (Hosseini et al., 2016).

In recent years, engineering resilience has been investigated in rail networks. These studies addressed four central challenges of topology, data-driven, simulation, and optimization. In rail systems where equipment is constantly exposed to breakdown, the root causes occur in various inherent, natural, human, and operational factors.

Equipment maintenance and repair are an essential part of the systems operations process. In such systems, rapid detection of resilience means reducing the duration and severity of disturbances. In other words, the ability to predict, tolerate, and adapt to different disturbances – meaning the disturbance of events with low probability and severe consequences. The resilience of rail systems can be defined in three parts before, during, and after the accident (Hollnagel, 2013):

***Before the Accident:***

- *Situational Awareness:* Awareness of the state of the system in the past, present, and future (extensive monitoring, protection, and control system)
- *Preparedness:* Prepared for gray and black events
- *Endurance:* Endurance against known events

***During the Accident:***

- *Adaptability:* the capacity of the system to adapt to a new network status
- *Durability:* The ability of the system to mitigate an accident

***After the Accident:***

- *Recovery and self-repair:* Return to regular operation, detect and locate the fault, and auto-recover
- *Speed of operation:* High speed to return to normal situation

It is expected that the rail system's performance does not decrease rapidly after the onset of the accident due to its endurance. This step is prevention. The duration of this step depends on the situational awareness and strength of the network. Naturally, increasing the duration of prevention leads to improving system reliability. This improvement depends on the design phase. On the other hand, after a specific time of the accident, the system's performance decreases. The durability phase starts from this moment and continues as long as the system remains at the maximum drop.

The recovery phase starts when the system performance improves and continues until the system returns to a stable state before the accident. Recovery time can be used as an indicator to measure the quality of the resilience system. A rail engineering system is usually designed to have the necessary endurance against common accidents so that its performance is not easily affected in such conditions. Nevertheless, at the same time, this system must have sufficient resilience to adapt to a severe disturbance without losing its function and recover quickly after the disturbance (Hollnagel, 2013).

## 3.6 Operation

Operations in the rail system refer to monitoring RT and human functions. Integrated monitoring of RT systems in the last decade has focused on the conditions of wagons on rail lines. Sharing data through wagon tracking systems provides traffic officials opportunities better to monitor the use of infrastructure. This tracking-based monitoring can improve maintenance procedures by shipping operators and, in addition, make it possible to track and trace the containers and pallets needed by shipping customers. These monitoring activities can reduce traffic levels, improve usage time, and improve the safety and security of cargo (Mirzabeiki & Sjöholm, 2012).

One of the most prominent aspects of implementing the information and communication technologies (ICT) system is attributed to automatic rail driving. There are significant challenges in implementing automated vehicles in the supply chain, but such a system's benefits are enormous. About 94% of transportation accidents are related to human error, which can be reduced through automation. Transportation accidents represent some of the most costly accidents in the world.

We can examine rail transportation automation from three dimensions. First, rail automation promotes safety by reducing the role of humans as the leading cause of accidents. Second, rail automation can reduce the economic impact by improving safety and reducing accident rates. Third, rail automation can reduce potential delays and improve transportation efficiency by directly monitoring rail schedules.

Automated driving systems (ADS) are among the safest and most profitable transportation systems globally. Due to the high efficiency of these systems, several

ICT systems have been developed with different sizes and capabilities. Huge development costs and a short asset life are deterrents to deploying ICT-based solutions in railways (Narayanaswami & Mohan, 2013). The inability to install and run simultaneously various ICT systems from different providers has caused a high cost of changing the railway infrastructure. However, there is still an excellent platform to use more capacity in designing and implementing these systems. In addition, the number and size of railway projects in terms of investment and turnover worldwide have increased dramatically in recent years. Future studies should be conducted on designing and implementing these systems in rail freight transportation in the supply chain (Narayanaswami & Mohan, 2013). For example, a system can quickly detect leaks in tanks carrying hazardous chemicals and notify the command control center.

Moreover, there is a problem with transporting short cargo distances – for example, the railway line between two small towns less than 20 km away. After loading, the train must change direction and return to the origin from another rail. In this regard, the use of a shuttle train service – a shuttle train is a train that runs between two round-trip points, especially if it offers frequent services on a short route – can reduce the costs and time used in the supply chain. In this regard, Hyland (2016) demonstrated that using this service over short distances increases the efficiency of rail operations.

Rail system electrification and digitalization have also seen recent challenges. In recent decades, the tendency to use electricity and replace fuels has increased. The main reason for this increase is the less harmful environmental impacts when using electricity compared to fossil fuels. In this regard, the use of computer models in the design analysis of rail logistics information management systems has been considered (Deng, 2014). The Collaborative Planning, Forecasting, and Replenishment (CPFR) model was used as a computer decision-making system based on data mining technology and an object-oriented data model. The findings proved that it is essential to build the proper infrastructure before electrifying rail systems. Before modeling to identify transportation's technical and economic benefits, it is essential to understand the relative functions and interrelationships of all transport nodes, logistics, electrification and digitalization, and rail engineering. Railway electrical engineering is valuable, and it is also a good reference and guide for future railway power supply.

It is noteworthy that digital control systems can introduce new ergonomic and safety risk factors in the control rooms. This system can reduce the alertness and situational awareness of the human condition and reduce human performance in emergencies. Moreover, changing regular control stations to digital stations due to new performance shaping factors (PSFs) causes new human errors. These PSFs include new procedures, alerts, decision-making, and communication (Gholamizadeh et al., 2022).

Another concern in digitization is the creation of large volumes of system information in the supply chain that operators are forced to analyze large amounts of audiovisual data quickly. This force significantly increases the volume of mental workload that can lead to human error. In addition, if operators suffer from a lack of proper situational awareness or face other issues, they may not provide an accurate and timely response. Hence, new methods of analyzing human error related to digital control systems need to be developed. The authors suggest that specific methods be developed to analyze the performance errors of operators in digital rail control rooms.

In addition to the concerns mentioned above, the rail transportation of perishable materials has also raised some problems in supply chain management. The total loading, transporting, unloading, and selling processes should be optimal for perishable foods such as meat, dairy, and agricultural products, which is possible in the destination cities and towns. In this regard, researchers and experts have proposed two strategies. First, rail transportation should be such that the areas of origin are as close as possible to the destination areas. Second, appropriate equipment such as large industrial refrigerators (for transporting meat), large isolated containers (for transporting dairy products), and suitable packaging (for transporting vegetables and other agricultural products from rural to urban areas) could be used (Yang & Tang, 2019). By implementing these two strategies, economic losses can be avoided.

The various studies and issues introduced in this section can form a causal network related to the rail transportation system in the supply chain (see Fig. 8). Managers can use this figure as a comprehensive strategic guide in future planning. As can be seen, there are many causal relationships between the parameters of the rail network. The effects of each of them cannot be examined without considering other parameters. Management approaches should also be designed and implemented based on this network. For instance, the economic management of the rail network must be such that, in addition to solutions with a direct economic impact, safety controls can also indirectly reduce economic costs by preventing accidents. Alternatively, for example, the deployment of maintenance systems can affect two factors: First, it can reduce the probability of equipment failure and, consequently, accidents. Second, by increasing the useful life of the equipment, it can increase the efficiency of the rail system. Consider a train carrying a chemical that passes near a river line and then passes near a village. Safety and environmental engineers can significantly reduce human and ecological exposure to rail accidents by using risk assessment findings and determining safe distances to rivers and village homes (Mohammadfam et al., 2022).

## 4 Future Directions

The need for rail transportation is steadily growing worldwide, especially in urban areas with growing populations. Even in Europe, where the population is slowly growing, forecasts suggest an increase in the share of rail transport in the supply chain network. There is an increasing trend in other continents. The demand for passenger and freight rail transport increases due to the rising demand for urban and intercity transportation. Integrated rail transport, which includes rail, metro, and tram transport, now has a larger market share in urban and regional markets, not only for commuting and leisure but also for freight, and researchers expect this trend to continue due to the acceleration of urbanization (Cheng, 2010).

The demand for long-distance rail freight is also increasing in many countries, and this growth is expected to grow with the further development of the express train

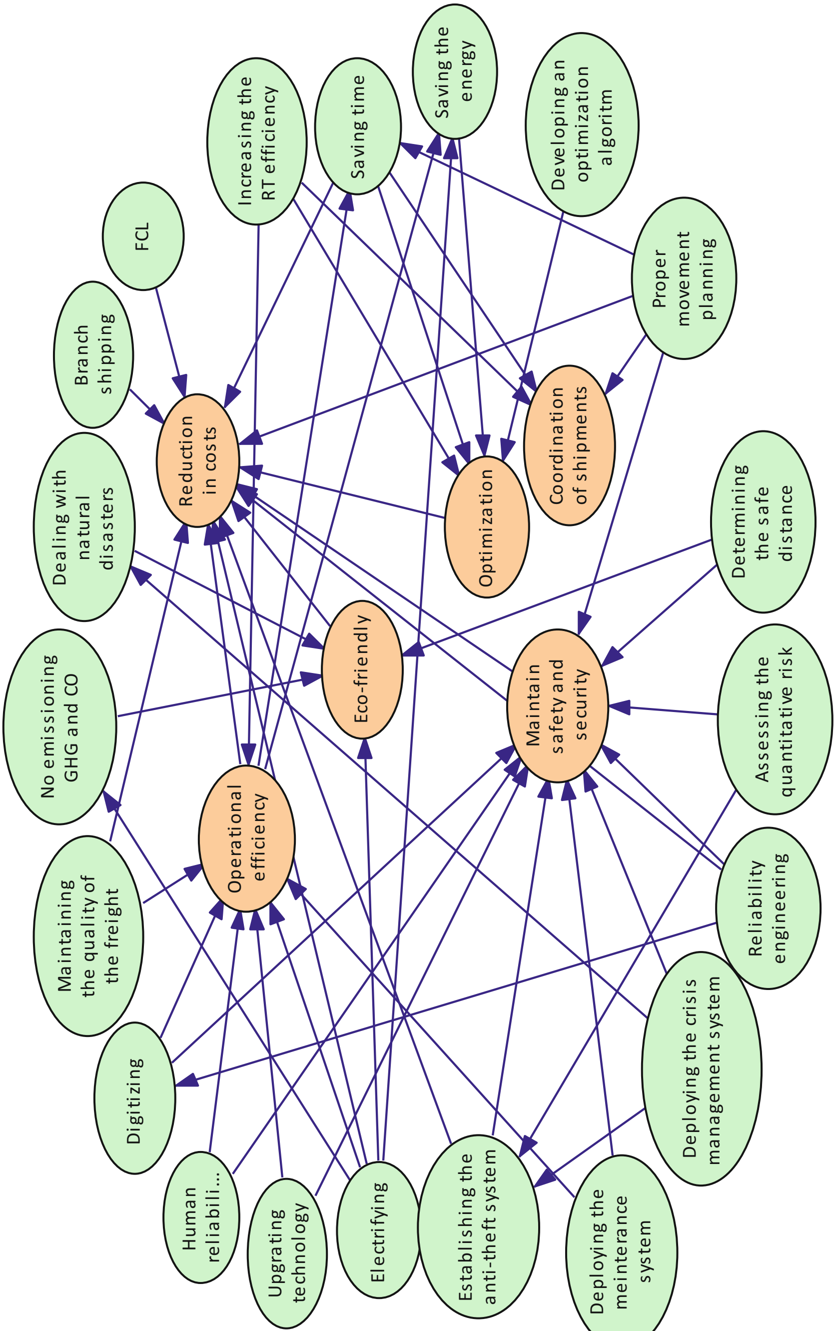


**Fig 8** A comprehensive causal network related to the rail transportation system in the supply chain

network in Europe, especially in the "Belt-Road Initiative" of China (Neumann, 2021). Shortly, specialists will design high-speed commercial ships to deliver goods needed by people and factories in a couple of hours at speeds over 300 km/h (Rungskunroch et al., 2020). According to railway experts, the golden key to the development of the railway network is to attract capital from private markets to strengthen further the infrastructure of the RT worldwide. With this practice, public budget costs reach the lowest possible, and as a result, the obtained profits are entered from rail networks to secret bases (Lapidus et al., 2019).

It is worth noting that competition in freight delivery markets tends to drive large corporations to use less energy, such as electrification and rail system optimization. This competition can also change supply chains' pricing and delivery quality policies (Bao, 2018). From a technological point of view, rail management welcomes energy-efficient systems and resources. The world rail system will move towards the "digital railway network." Integrated order registration system and customer information, guidance services, and minimizing delays are expected to be in place soon. From a safety and security engineering perspective, safety experts are expected that a global convergence of quality will exist.

Moreover, safety and security management systems based on the best performance and a global rail system with the maximum degree of interoperability are other strong customer expectations (Chester & Horvath 2012; Matsika et al., 2013). The primary innovation trend in the railway sector is based on integrated technologies, which can be seen in the digital rail network. Key customers and other rail supply chain stakeholders expect digital communications and complete data transmission via rail (Butakova et al., 2017). Today, almost all human populations have access to new generation mobile phones. In future digital network-based applications, customers will use GPS technology to monitor the delivery of their goods and receive information about the exact time of delivery of goods.

It seems that semi-autonomous or fully autonomous vehicle systems and their propulsion will become the main competitors of mass-electric rail transport by 2030 if they can reach an acceptable level of safety (Lapidus et al., 2019). However, restrictions on on-road vehicles for long-distance freight and passenger traffic will continue. This replacement can help reduce traffic levels and air pollution and reduce the rate of catastrophic accidents (Litman, 2007). Rail transportation will play a significant role, especially in highly dense metropolitan areas, in preventing congestion and outdoor consumption by reducing traffic and parking. Moreover, sustainable mobility measures, that is, local climate policies and planning to reduce carbon and GHG emissions in cities and suburbs, will significantly shift towards rail transport. These development strategies will increase rail services in the coming years. Also, experts will project more flexible infrastructure with improved emergency maintenance by 2050, including customer and freight information that, if disrupted, will provide possible alternatives to achieving destinations on time.

In addition, in the field of research, we should wait for specialized studies on various aspects affecting rail transport and the supply chain. Based on the discussion within the different sections of this chapter, future studies can address the following points:

- Designs of specialized engineering related to the upgrading locomotive power supply systems
- Optimization of fossil fuel consumption to achieve maximum energy-minimum consumption
- Optimal design of goods transfer
- Introduction of optimal systems at a reasonable cost and receiving the highest profit
- Digitization of rail systems
- Electrification of rail systems
- Design of specialized software for tracking goods shipped from the warehouse of origin to the warehouse of destination
- Introduction of specialized approaches to the safety assessment of railway systems in a dynamic framework
- Design of antitheft systems
- Introduction of mathematical algorithms for planning and scheduling
- Simulation of the consequences of hazardous material leakage and determining safe distances
- Development of a specialized method for analyzing the performance errors of operators in digital rail control rooms

## 5 Summary and Conclusion

This chapter introduces issues facing rail freight network transportation, its role in the supply chain, the current concerns, and the future direction of rail networks within the supply chain. The findings revealed that rail network concerns should be addressed considering six main aspects: environment, costs, optimization, operation, planning, and safety and resilience. Research has increased dramatically in the last decade, especially in engineering. In this regard, experts have conducted various investigations to address the challenges of the rail network. Designing optimal electrical power systems, introducing planning algorithms, investigating the safety, reliability, and environmental impacts, and introducing cost reduction and efficiency programs are the most prominent challenges researchers considered. Briefly, engineering designs are moving towards designing powerful and fast engines with low energy consumption, developing more efficient rail networks, capturing the industry, and including resilience potentials in system development.

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# Maritime Logistics

Kee-hung Lai and Dong Yang

## Contents



**Abstract**

The shipping market requires reliable and cost-effective cargo delivery in the globalized business and e-commerce development age. Maritime logistics, moving cargo through maritime-based shipping networks as part of the global supply chain, is an important part of the process because of the scale and scope of its large operations in moving cargo to physically complete economic transactions in trade. The concept, the elements, the challenges, and the trends for maritime logistics are examined, considering its unique role in integrating with the global supply chain for cargo handling and movement to facilitate international trade activities. This chapter offers researchers a quick overview of maritime logistics in the supply chain context and discusses trends in the field.

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**Keywords**

Shipping · Logistics · Port · Intermodal

## 1 Introduction

Shipping cargo to complete economic transactions between exchange parties is an important part of logistics management to coordinate the upstream and downstream requirements of the supply chain. Maritime logistics via ocean transportation carries over 80% of the international trade of goods by sea. The process involves the participation of different parties, including vessel management at sea and intermodal transportation with different shore-based operators such as port terminals, customs-clearing agencies, warehouses, and connecting inland freight in sea, road, and railway. Movement of cargo by seas covers different types of vessels, including container ships to carry container boxes for cargo-suitable movements that can fit into standardized stock-keeping units, e.g., 20 ft or 40 ft container boxes. For cargoes in bulk form, such as sand, wood, or iron ore, that are unsuitable for carriage in container boxes, they are carried by bulk vessels. For liquid bulk or energy shipping such as petroleum, tanker vessels provide shipping service for this cargo type.

For shore-based maritime logistics operations, port terminals are an important interface at land to upload/unload cargoes from vessels at sea. The supporting activities include berthing vessels, moving cargo for connecting freight, clearing customs requirements, handling documentation, and temporary storage for shipment transit. The role of the port terminal is essential to receive cargo shipment by sea transportation dispatched from the upstream and arrange timely cargo delivery to the downstream parties. It also involves cargo handling for uploading to/downloading from the vessels and temporary storage at the port for subsequent shipping instructions. Specialized equipment and facilities, such as quay cranes, forklift trucks, and conveyor belts, facilitate cargo movement in various types, including container boxes, dry bulk cargo items, and liquid bulk energy commodities.

Maritime logistics moves cargoes at sea with intermodal connections to service shipping demands in the global supply chain. As the ocean transport mode carries most of the international trade volume, management decisions for maritime logistics activities are challenging but crucial to enable user enterprises' cargo to meet the market demands in terms of cost, time, and reliability of cargo delivery. These decisions concern transportation costs, routing and scheduling planning, transit time planning, and compliance with regulatory requirements in the carriage of goods by sea (e.g., documentation, security and safety standards, import/export trade regulations, and environmental issues, e.g., emission and ballast water treatment, cleaner fuels, and energy-efficiency propulsion technologies for vessels) to ensure smooth cargo flows and timely delivery in the global supply chain.

At the industry level, managers must also understand the factors influencing the total capacity of the shipping industry and how the related maritime logistics activities (e.g., demand for shipping services, vessel price, and fleet size) are related to shipping demands in the market to formulate their action plans (Lun et al., 2013). The relatedness of maritime logistics with other maritime sectors: shipping-related, port-related, and maritime service businesses in various geographic locations such as the Greater Bay Area and the Yangtze River Delta in China, the Malacca Strait, the Panama Canal, etc., and their differences must be understood for better planning and development (Yang et al., 2022).

Achieving this end, there are also risk issues for maritime logistics to manage, which include unforeseen disruption in port and shipping operations (e.g., Covid-19 and other pandemic outbreaks and natural disasters) and vessel accidents (e.g., vessel collision, grounding: A grounded ship temporarily obstructed Egypt's critical Suez Canal in May 2023, resulting in a worldwide disruption to the global supply chain, fire accidents, and capsizing), cargo security (e.g., theft, piracy, smuggling, and terrorism), and regulatory compliance (e.g., 24 h rule, nonintrusive cargo inspection) (Bichou et al., 2007). These maritime logistics risk issues require proper management actions on emergency planning, insurance coverage, and security management (e.g., ISPS code). With the digital transformation trend in business, managers increasingly adopt digital technologies such as artificial intelligence, blockchain, cloud computing, and big data analytics to enable decision-making for greener supply chain operations (Lai et al., 2023). Maritime logistics activities also join the bandwagon to employ digital technology for performance improvements. Examples include cargo tracking and tracing, radio frequency identification systems, and blockchain technology to ensure transparency, visibility, and automation in shipping and port logistics operations.

## 2 Elements of Maritime Logistics

Logistics in a maritime network involves collaboration with other parties, such as intermodal service providers, container terminal operators, and auxiliary service providers, for customs clearance and storage services (Lun et al., 2023). Based on the liner shipping network by (Lun et al., 2009), maritime logistics can be analyzed in terms of the SHIPMENT model comprising the following elements, which are elaborated in the subsection below.

### 2.1 Space Management (S)

Shipping space is an asset for vessels, and sharing space can help reduce the risk of underutilized space and excessive financial investment in vessel capacity. Practices in space sharing, slot chartering, and schedule arrangements can also achieve better utilization of resources for maritime logistics activities. New technologies, such as digital platforms, are vital in assisting liner companies with space management. For instance, the online quote platform attracts many small shippers to book directly online, thereby assisting liner shipping companies in optimizing their space management capabilities (Han et al., 2022).

## 2.2 Hinterland (H)

It is the area where the shipping demands for cargo arise for sea-born shipment. The port-hinterland relationship is evolving with the global market's changing production and consumption patterns. New shipping demands emerge and grow in different geographic regions, such as the BRICS countries. Another notable example is the remarkable growth of Piraeus port in Greece, driven by the Belt & Road Initiative. As a result, establishing a railway system connecting Southern European hub ports to their inland regions is reshaping the existing shipping network. In this context, the port of Piraeus has emerged as a prominent hub port in Europe (Yang et al., 2018). Maritime logistics must couple with these developments to capture the opportunities with reliable and quality shipping services.

## 2.3 Intermodal Transport (I)

Maritime logistics needs connectivity with other intermodal transport operators in rails, truck, and barge service to arrange fast and responsive transshipment. Close collaboration with these operators in the network can save capital investments and time for equipment and facilities required to handle the connecting freight transport for the shipments from maritime logistics with better services of wider breath to meet the logistics needs of shippers. Dry ports, functioning as inland intermodal terminals affiliated with seaports, alleviate pressure on seaports by receiving cargo and vehicles, providing short-term storage, handling, and consolidating cargoes, and delivering efficient and swift transportation to the seaport (Chang et al., 2019).

## 2.4 Port (P)

As an important part of maritime logistics for exchanging cargo between the ship and the shore, the role of the port for transshipment operations is crucial to connect with different intermodal operators. The Port also serves as a transshipment place where feeder shipping routes are connected with trunk routes to arrange shipment in maritime routes. In their study on the ports in China's Great Bay Area (GBA), Yang et al. (2022) observed significant trends. They noted that Hong Kong is increasingly assuming the role of a transshipment port, serving as a feeder port for Southeast Asia in reexport trade activities. Additionally, they found that Guangzhou has become a transshipment hub for the South China hinterland, primarily catering to domestic and import trade activities within the GBA.

## 2.5 Management Information System (M)

Digital technologies enable shipping and logistics operations to gain performance (Shou et al., 2023). Their applications can promote the performance of various maritime logistics activities such as cargo tracking and tracing, customs response, vessel planning and scheduling, shipping space booking, and electronic shipping documents.

The lack of timely data and analytics can hurt the reliability of the shipping schedule and the vessel schedule recovery actions such as port-skipping (Li et al., 2022). Electronic integration of intraorganizational and inter-organizational processes can benefit the cost-efficiency of maritime logistics activities (Lai et al., 2008). Technological adoption and IT-enabled transport logistics support responsive product movement for global supply chain management (Wong et al., 2009).

In the maritime industry, the Internet of Things (IoT) has the potential to revolutionize operations by connecting the physical and digital realms. This connectivity offers numerous benefits, including a significant reduction in paperwork and the ability to manage the entire supply chain in a holistic, real-time, and data-driven manner.

With IoT technology linking all items within warehouses and ports, there is the potential for fully automated allocation of space and seamless transfer of goods as technology advances. Intelligent Transportation Systems (ITS) enable real-time tracking and monitoring of shipments, providing convenience to shippers and carriers aiming to minimize costs and delays throughout the supply chain. Blockchain technology plays a vital role by transferring the entire supply chain process to a secure and transparent blockchain platform. Radio-frequency identification (RFID) sensors also enhance the supply chain by effectively locating cargo and enabling real-time tracking and reporting.

## 2.6 Equipment Supply (E)

Equipment generally refers to container box availability in container shipping. They can refer to handling equipment such as cranes, conveyor belts, and pipelines for bulk and energy shipping. Equipment management is difficult; container boxes are expensive to purchase, rent, and repair. The maritime logistics network can coordinate among the operators to arrange empty containers to locations with demands at low cost. They can collaborate with intermodal operators in land, rail, and sea transport to enhance the efficiency of empty containers or other idling facilities for their repositioning for high utilization and economic efficiency. Technologies such as RFID have been widely used for maritime logistics activities for equipment management (Ngai et al., 2007).

## 2.7 New Agents (N)

To provide local support services, it is common for shipping companies to employ domestic agencies for handling related matters. As maritime logistics is broad in location coverage spanning different countries, it is usual for shipping companies to jointly appoint a domestic agent to provide local support services and coordinate with other intermodal transport operators to deliver more flexible and responsive shipping services meeting the shipping needs of import/export customers in their locations. Nevertheless, nurturing the commitment of local service providers to support logistics operations can be challenging (Wong et al., 2012).

### 2.8 Terminal Operators (T)

Port logistics in maritime terminals include cargo loading and discharging, cargo storage, and cargo movement operations. Coordination with maritime terminals can improve logistics efficiency and avoid schedule disruption (Zhang et al., 2023). In Hong Kong, three major terminal operators, Hutchison Ports HIT (HIT), COSCO-HIT Terminals (Hong Kong) Limited (CHT), and Asia Container Terminals Limited (ACT), have announced a collaborative effort aimed at achieving effective and efficient management and operations.

This collaboration between HIT, ACT, and CHT facilitates streamlined facilities management and optimal allocation of resources, ultimately leading to reduced operational costs and shorter logistics times within the supply chain. The coordination among terminal operators can also impact shipping alliances and potentially lead to supply chain reorganization (Liu et al., 2020).

## 3 Challenges of Maritime Logistics

These eight maritime logistics elements elaborated with the SHIPMENT framework are evolving with many management challenges. One challenge is port congestion and disruption due to inadequate port planning and management for infrastructure requirements. Congested port and shipping operations can cause cargo delays or damages if they are perishable merchandise. Port congestion leads to significant time losses, increased fuel consumption, and even cargo damages for shippers, causing disruptive effects on the maritime supply chain.

Due to the interconnected nature of port networks, port congestion is not confined to a single port but has a propagation effect, leading to congestion in other linked ports (Peng et al., 2023; Bai et al., 2023). Unforeseen events, such as natural disasters (e.g., hurricanes, earthquakes, and storms), man-made incidents (e.g., cyberattacks, human errors, labor strikes, and technical sabotage), and public health crises, can lead to significant port disruptions. The propagation effect of port disruptions leads to decreased port calls in other countries due to the implementation of lockdown policies (Bai et al., 2022). To alleviate the damage caused by port disruption, port skipping is widely used in the Covid-19 pandemic to facilitate recovery of vessel schedules (Zhang et al., 2023). Therefore, ports must enhance their resilience to manage shocks effectively, absorb disruptions, and swiftly recover and restore operations.

Maritime security is another concern because undesirable events such as piracy and cargo theft damage the cargo and the personnel involved in the processes.

Without proper security measures, the caused damages can disrupt the global supply chain operations, resulting in shortages, cost increases, and lost sales in the market. It is also crucial that maritime logistics develop the ability for supply chain resilience, particularly considering that the activities are vulnerable to different types of disruption caused by extreme weather, labor strikes, pandemics, and trade wars. Such events can lead to cargo delays and damages, shipping and port operations rescheduling, and supply chain disruption.

Security is a topical issue in supply chain management due to its importance in preventing, mitigating, and recovering from undesirable security events with studies investigating different areas, including (1) supply chain security conceptualization and application, (2) security management systems, (3) transportation security, and (4) terrorism (Tong et al., 2019). Research has also examined the relationship between supply chain resilience and firm performance in the shipping industry, with findings that risk management culture, agility, integration, and supply chain reengineering are beneficial for developing resilience in shipping operations (Liu et al., 2018). There are also studies on voluntary security standard adoption, such as the Customs-Trade Partnership Against Terrorism (C-TPAT) certification and their performance value for shippers (Tong et al., 2022). As the risk factors for maritime logistics continue to increase, given the issues of geopolitical tensions and climate changes, managers must be more proactive to mitigate the risks of disrupting maritime logistics in port and shipping and the broader supply chain operations (Lai et al., 2020).

Going green continues to be challenging for the maritime industry due to the need for compliance to reduce its environmental impact. In shipping operations, green shipping practices can be performed in six dimensions, covering (1) company policy and procedures, (2) shipping documentation, (3) shipping equipment, (4) shipper cooperation, (5) shipping materials, and (6) shipping design and compliance (Lai et al., 2011). Green shipping practices are widely adopted for maritime logistics to ease public concern about the damages brought by shipping operations to the environment, and the relativity with shipping firm performance is found (Lun et al., 2015b).

There are stricter regulations to control emissions, cleaner fuels, and waste treatment. Even for large shipping companies, complying with the developing regulatory requirements, such as investing in new vessels, equipment, and processes, is costly. These challenges also apply to compliance with customs and trade regulations on documentation requirements and procedures, particularly considering that different countries have different trade policies and laws for maritime logistics. Research has found the value of green practices in shipping design and compliance on the financial and service performance (Lai et al., 2013) and the green capability of shipping firms (Lun et al., 2014). Nevertheless, the time and cost investment in staff training and handling procedures for maritime logistics can be demanding to meet the regulatory requirements in different countries.

The global supply chain becomes lengthier and more complex due to the intensifying internationalization of productive and market activities of enterprises to acquire the factors of production and the market. The increased length and complexity of the global supply chain make it difficult to coordinate the different involved parties for cargo movement in maritime logistics. Managing maritime logistics activities is difficult if timely information for cargo tracking and tracing is not available to mitigate uncertainties such as congestion, which, when they arise, will cause delays and disruption in the supply chain. Even if the cargo transparency and visibility issues for maritime logistics are solved with digitalization, managers must pay attention to cybersecurity threats, which can pose risks to the sensitive data of the shipments, the cargo security, and the information network connectedness to control the IoT devices and automated processes and coordinate with the different upstream and downstream partners in the supply chain.

## 4 Trends of Maritime Logistics

There are several trends in maritime logistics concerning digitalization and sustainability developments in recent years. With digitalization, shipping and port operations are increasingly automated for cargo handling, tracing, and tracking the cargo movement processes (Lu et al., 2007). Adopting digital technologies can enhance operational efficiency, improve accuracy with fewer human errors, and increase timeliness in cargo delivery in shipping and port operations (Lu et al., 2006). In adverse situations like the Covid-19 pandemic, deploying digital technology assets across the supply chain can alleviate operational damages (Ye et al., 2022).

Increased visibility through digital technologies such as blockchain can enhance supply chain integration and performance (Tan et al., 2023). Data-driven technologies and applications benefit supply chain design, planning, coordination, decision-making, and performance improvements (Singh et al., 2023). Due to the higher availability of data for analytics, managers of maritime logistics can make better and more informed decisions, such as routing and scheduling of cargo shipments, utilization of space for vessels and shipment transit, maintenance alerts, and cost control with better shipping services. Digital technologies can also be deployed to monitor and manage security risks in maritime logistics, enabled by surveillance systems to identify and address vulnerabilities in the activities.

On sustainability aspects, the United has developed 17 goals for sustainability development, which guide achieving a more sustainable future. Many goals are relevant to maritime logistics, including affordable and clean energy, responsible consumption and production, climate action, life below water, and partnerships for the goals. There is also the Sustainable Shipping Initiative, which aims to develop a more sustainable maritime industry covering six areas: (1) ocean, (2) communities, (3) people, (4) transparency, (5) finance, and (6) energy. In the literature, sustainability issues have been widely discussed in different domains of maritime logistics about shipping performance, port selection and management, shipping markets, and the environment (Vejvar et al., 2020).

While the economic aspect of sustainability is the main focus, such as developing a decision model for shipping operations (Parthibaraj et al., 2018), the holistic view of sustainability also emphasizes the other environmental and social dimensions. In practice, managers of maritime logistics activities encounter growing pressures for greener operations beyond economic considerations (Vejvar et al., 2018). These pressures arise from regulations, marketing, and productivity gains (Lun et al., 2015a).

Particularly, there are several international regulatory organizations governing the operations of maritime logistics in sustainability aspects. These organizations include the International Maritime Organization (IMO), part of the United Nations regulating maritime logistics activities with conventions and regulations. Safety of Life at Seas (SOLAS) is an example of IMO's regulation that establishes minimal safety standards for vessels specifying the requirements for construction, equipment, facilities, and operations in terms of safety for fire, navigation, and emergency response.

Research has also examined human failures in shipping container shipping concerning seafarers' national cultural characteristics, with observations that few human failures have resulted when low-power distance and collectivism and uncertainty avoidance are high (Lu et al., 2012). Managing the safety of maritime logistics is important because the activities are performed across country borders with varying safety performance and standards for compliance.

The International Convention for the Prevention of Pollution from Ships (MARPOL) is an example of IMO's Convention to prevent marine pollution by shipping operations. MARPOL sets emission and pollution limits with standards for control covering pollutant discharge into the seas, such as chemical (e.g., sulfur oxides and nitrogen oxides), oil, and sewage wastes. Furthermore, maritime logistics increasingly emphasize shipping decarbonization and different carbon cap-and-trade application schemes are being explored (Xue & Lai, 2023b). Given the growing public worries about the environmental implications of shipping operations, responsible shipping is also increasingly emphasized to design, plan, and implement responsible practices in servicing international trade and global supply chain activities (Xue & Lai, 2023a).

The revised IMO's GHG strategy adopted in 2023 has set up more ambitious targets to accelerate the sustainability process in maritime logistics. It envisages net-zero GHG emissions from international shipping near 2050 with two checkpoints for 2030 (a reduction of GHG emissions by 20% compared to 2008) and 2040 (a reduction of GHG emissions by 70% compared to 2008). Specifically, the revised strategy aims to decrease the carbon intensity by 40% by 2030. The uptake of innovative technologies and alternative fuels are new enhanced ambitions, expected to account for at least 5% of energy share in international shipping by 2023.

Supporting the IMO's GHG strategy, there are three primary categories of measures taken by shipping companies: technological measures (e.g., exhaust emission disposal devices, cleaner fuels, and alternative fuels), logistics-based/operational measures (e.g., speed optimization, route planning, and efficient supply chain management), and market-based measures (e.g., Emissions Trading Schemes) (Psaraftis, 2016). Notably, practitioners in the maritime logistics industry face sustainability issues such as logistics system optimization, sustainable supply chain design, and service quality management (Lee et al., 2019). From the perspective of maritime logistics, the IMO's GHG emission limit can significantly increase the supply chain cost, reducing trade. However, the investment in the supply chain performance is considered beneficial in emission control and trade growth via indirect mechanisms with larger and more fuel-efficient vessels (Randrianarisoa & Gillen, 2022).

## 5 Concluding Remarks

Maritime logistics is a key global supply chain process, where most trade items, particularly containerized cargoes and those in bulk and liquid form, are delivered via maritime carriage to physically complete international trade exchanges. Managers must understand the maritime logistics elements in the SHIPMENT model to strive for better productivity and higher-quality shipping service. They must also tackle the challenges and risks and grapple with the trends in digital transformation and sustainability development to excel in maritime logistics.

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# Facility Location Modeling in Supply Chain Network Design: Current State and Emerging Trends

Yasel Costa and Teresa Melo

## Contents



**Abstract**

Facility location decisions play a critical role in the design of supply chain networks. This chapter outlines key features of facility location problems and their integration with various logistic operations in the context of network (re)-design. Modeling approaches and solution methods are also discussed for these challenging combinatorial optimization problems. In addition, we examine five emerging trends that will continue to drive research in this area, namely, sustainable development, the transition to a circular economy, data source-related issues,

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disruptive events and resilience, and omnichannel distribution in the retail sector. We review and classify recent contributions, identify research gaps, and provide directions for future research.

**Keywords**

Facility location · Sustainable network design · Circular economy · Data scarcity · Resilience · Omnichannel

## 1 Introduction

A supply chain is a network of facilities comprising, for example, production plants, distribution centers, and warehouses, which perform several operations. These range from the acquisition of raw materials and their transformation into intermediate and final products, to the distribution of finished goods to customers to meet their demand. Designing a supply chain network is a complex undertaking that involves making a number of interdependent decisions. In general terms, network design decisions concern the selection of suppliers, the location of the facilities to be operated (e.g., plants and warehouses), the choice of technology and capacity size of each facility, the allocation of products to the facilities, the selection of transportation modes, and the determination of material flow through the network. Furthermore, decisions may also concern the collection and recovery of products, depending on the context. The goal is to identify the network configuration with minimum total cost or maximum total profit, subject to side constraints related to resource availability, technological conditions, and customer service requirements. Figure 1 shows an example of a supply chain network with three facility tiers. The first tier comprises suppliers who provide raw materials to the production plants. These, in turn, transform the raw material into finished products that are distributed

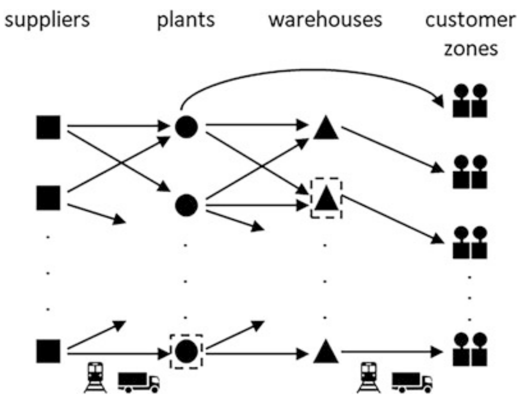


**Fig. 1** Example of a supply chain network with three facility tiers

to warehouses. Finally, the warehouses serve the demand of the customer zones. As highlighted in the figure, the latter can also be supplied directly from the production plants. Two types of transportation modes (i.e., road and rail) are available for moving raw material and end products through the supply chain.

Supply chain network design (SCND) problems are triggered by changing market and business conditions, often coupled with rising costs (e.g., materials, energy, labor, and transportation), variations in the pattern of demand or its spatial distribution, and changes in trade policies. Depending on the specific situation, either a new network is established (greenfield approach) or a network that is already in place is redesigned (brownfield approach). Figure 1 depicts an example of the latter case, highlighting by dashed squares those facilities that are operating at the start of the SCND project. In this case, one issue to be addressed is whether to retain these facilities, to close them down, or adjust their capacity through expansion or downsizing. Mergers, acquisitions, and strategic alliances also trigger the reconfiguration of a supply chain network in order to exploit the benefits and synergies that result from the integration of the acquired operations. Compared to greenfield initiatives, the need for the revision of the structure of a supply chain network is far more frequent.

At the strategic planning level, SCND has been an active research area for many years. Early modeling approaches focused on relatively simple facility location problems (FLPs) with limited scope as they did not consider the supply chain as a whole. Subsequent research has evolved into the development of more comprehensive mathematical programming models that integrate facility location decisions with a range of supply chain operations such as supplier selection, raw material procurement, production planning, technology acquisition, inventory management, transportation mode selection, and product collection and recycling, to name just a few (Melo et al., 2009).

This chapter focuses on FLPs and their relevance in the design of supply chain networks. Our intention is not to conduct an exhaustive review of the literature on FLPs and SCND problems, but rather to describe how various emerging trends have been addressed by the scientific community in Location Science in a structured way. Furthermore, we will also identify research gaps and suggest further research directions.

The remainder of the chapter is organized as follows. Section 2 focuses on the role of facility location planning within a SCND context, providing a broad classification of features captured by FLPs. Section 3, at the core of this chapter, is devoted to five emerging areas and how current modeling approaches address them. We discuss the challenges posed by growing sustainability concerns, the need to consider circular economy principles, data scarcity issues, the occurrence of disruptive events and the creation of resilient supply chains, and the more specific requirements pertaining to omnichannel retailing. In Sect. 4, the managerial implications related to recent developments in these five emerging areas are discussed. Finally, conclusions are provided in Sect. 5.

## 2 Facility Location Planning

One of the most important strategic decisions when designing a supply chain network is the location of facilities such as production plants, warehouses, and retail stores. Key literature reviews have highlighted the true value of location decisions. According to Farahani et al. (2019), facility location is not only one of the very first and most prominent strategic decisions, but one which has a profound effect on tactical and operational decisions within any organization. In addition, Celik Turkoglu and Erol Genevois (2020) argue that location decisions are increasingly crucial because they serve the profitability and sustainability of firms.

There is no doubt that Location Science is a well-established area of research (Laporte et al., 2019); in fact, it can be considered a century-old science if we review Alfred Weber's studies on the location of a warehouse, to minimize the total weighted travel distance between the warehouse and its customers (Weber, 1962). The truth is, despite its long tradition, many renowned authors believe Location Science still to be a valuable research area, with a wide range of applications (Laporte et al., 2019), and their derived mathematical models are ever-increasingly attractive (Laporte et al., 2019; Melo et al., 2009).

It is no trivial matter to categorize all the variants and extensions of FLPs. In this sense, Laporte et al. (2019) propose that FLPs can be classified according to different aspects such as the location space (continuous, network, and discrete), the type of objective functions (e.g., median, covering, and center; the interested reader is referred to the comprehensive review and classification in Farahani et al., 2010), the application context (telecommunications, logistics, transportation, healthcare, etc.), and the nature of the data (deterministic, stochastic). A recent review by Celik Turkoglu and Erol Genevois (2020) proposes a framework for the classification of location problems in which the authors identify some key characteristics, such as purpose, space, distance, time, parameters, capacity, number of facilities, facility type, number of objectives, competition, and type of location models. In this section, we provide a comprehensive classification of FLPs based on key and recent literature. Table 1 shows the main features of FLPs. Recent contributions addressing them can be found in the supplementary material**.

Moreover, the mathematical structure of FLPs falls into the class of NP-hard combinatorial problems and has proven to be a fruitful area of research for the development of solution methodologies (Ortiz-Astorquiza et al., 2018). Certainly, there has been a vast variety of solution methods, but in general, we can easily distinguish between exact algorithms and approximate approaches. Among the exact methods that have been used to solve FLPs, we can highlight the recent proposal of a specially tailored branch-and-bound method (Beresnev & Melnikov, 2018) to address the capacitated competitive facility location problem. The authors have dealt with a bilevel location model in which two competing parties open their facilities intending to maximize their profits for serving customers in a Stackelberg game. Benders Decomposition and branch-and-cut methods are other well-known exact approaches. These methodologies have been successfully applied to a wide variety of location-related problems, such as emergency response network design,

**Table 1** Comprehensive classification of FLPs

| Key feature | Aspect |
|---|---|
| Number of objectives | Single objective (total cost/profit)<br>Multiobjective (e.g., total cost + responsiveness) |
| Type of objective function | Covering (set covering)<br>Median (p-median)<br>Center (p-center)<br>Hierarchical (successively inclusive)<br>Flow capturing<br>Hub location<br>Dispersion (p-dispersion)<br>Anti-median and anticenter |
| Number of facilities | Single facility (no demand allocation)<br>Multiple facilities |
| Decision space | Continuous (points of a continuous space)<br>Discrete (finite list of potential sites)<br>Graph (located on vertices/arcs) |
| Number of commodities | Single commodity<br>Multicommodity |
| Planning horizon | Single period<br>Multiperiod |
| Input parameters | Deterministic<br>Probabilistic<br>Possibilistic |
| Capacity configuration | Static (unlimited and limited capacity)<br>Dynamic setting (expansion and contraction) |
| Supply chain structure | Single echelon<br>Multiechelon |
| Facility typology | Single type (e.g., warehouses)<br>Multitype (e.g., warehouses, stores) |
| Competition and cooperation | With interaction (multiple players)<br>Without interaction (single player) |
| Integration with other decisions | Location-routing models<br>Location-inventory models<br>Location-inventory-routing models |

humanitarian relief operations, agricultural supply chains, and reverse logistics. Some other notable exact methods used to address FLPs are branch-and-price (Ni et al., 2021), cutting plane algorithms (Castro et al., 2017), and dynamic programming (Puerto et al., 2014).

Undoubtedly, much work has been carried out on approximate algorithms (see Fig. 2). Some of the most used heuristics methods are Lagrangian-based heuristics (Kheirabadi et al., 2019), two-phase procedures (Sauvey et al., 2020), variable neighborhood search (Ahmadi et al., 2015), and local search heuristics (Brimberg et al., 2014). However, when it comes to the use of metaheuristics, we observe much richer literature. Here one can see the frequent development of genetic algorithms (Biajoli et al., 2019), tabu search (Melo et al., 2012), simulated annealing (Coll et al., 2022), ant colony optimization (Ting & Chen, 2013), particle swarm optimization

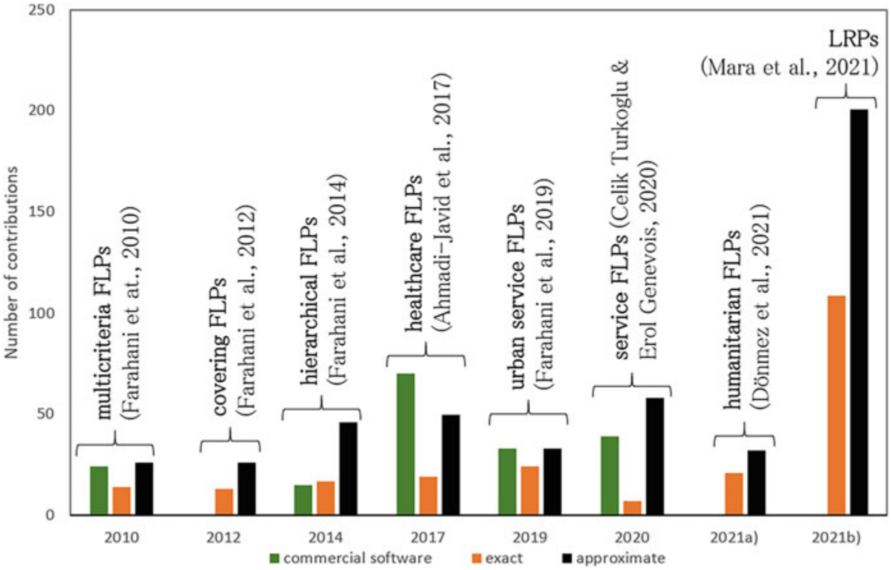


**Fig. 2** Key review articles that provide comprehensive analyses of solution methods for FLPs

(Peng et al., 2022), artificial bee colony algorithm (Lin et al., 2018), and adaptive large neighborhood search (Wu et al., 2022). Closely related to the above, Fig. 2 shows the analysis of eight relevant reviews that present a comprehensive analysis of solution methodologies applied to different FLP variants (e.g., healthcare, humanitarian, urban service, and multicriteria FLPs). These review articles differ from other FLP studies since they provide a comprehensive census (up to the time of their respective publication) of all solution methods (exact and approximate) used to address a specific location-related problem.

From Fig. 2, the following reflections can be made: (i) The application of an exact method is less frequent compared to other solution approaches; (ii) the use of commercial software (e.g., CPLEX and GAMS) is very popular among researchers studying FLPs; (iii) the largest number of contributions is related to the application of approximate methodologies; and (iv) healthcare facility location and location-routing problems have received greater attention concerning other extensions of FLPs.

Despite the growing number of contributions to studying FLPs, very few deal with brownfield analysis (e.g., facility location decisions included in a supply chain network redesign problem). Most of the articles reviewed in this chapter assume that a network is designed from scratch (greenfield approach). This can be verified after analyzing the four quadrants in Fig. 3. The majority of the contributions (more than 150 articles in the two upper quadrants) address FLPs, within the design of supply chains, under the assumption that a network of this type had never been designed before. Therefore, it is clear that greenfield analysis is predominant for both types of problem scenarios; one in which the network is created from scratch assuming a

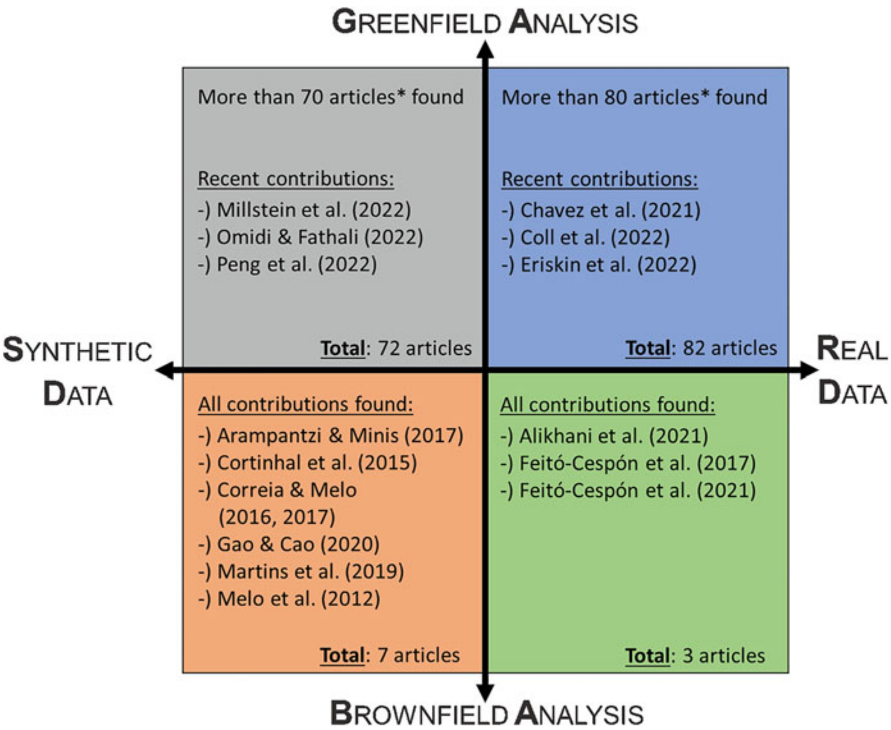


**Fig. 3** General approaches and data sources used in the reviewed articles; *see supplementary material** for a complete list

synthetically generated data set, and the other scenario in which the authors design the network for the first time considering realistic input parameters. Looking at the lower right quadrant, it can be deduced that brownfield analysis is closely linked to solving realistic supply chain network redesign problems.

In summary and to the best of our knowledge, we can state that FLPs are described by multiple features (at least 12 found) and that approximate methods are the most commonly used to solve this type of problem, and not least important, these methods are mostly proposed following a greenfield approach for self-generated or benchmark problem instances.

## 3 Emerging Trends

Recent global events have had a significant impact on the efficient functioning of supply chains. The truth is that planners are faced with unexpected difficulties and events, causing them to constantly rethink the strategic configuration already established for supply chain networks, including facility location decisions. This section analyzes and discusses the imminent challenges that a decision-maker (DM) is likely to face when addressing a facility location problem within the context of SCND. Five emerging challenges are discussed, based on a comprehensive literature review. We address sustainability concerns, the transition to a circular economy, the impact of data scarcity, the occurrence of disruptive events and the creation of resilient supply chains, and the specific requirements posed by omnichannel retailing. Most importantly, the identification of these five emerging trends is inspired by recent events (e.g., the COVID-19 pandemic) that have changed the economic and social dynamics throughout the world.

### 3.1 Sustainability Concerns

*Triple bottom line* is a business concept based on the three pillars of sustainability: economic, environmental, and social. Organizations that adopt this concept are committed to focusing not only on financial performance, but also on integrating the generation of environmental and social values into their corporate strategy (Elkington, 1997). Growing awareness of environmental and social issues within society and more stringent regulatory policies are driving organizations to include sustainability considerations in their supply chain management practices (Brandenburg et al., 2014; Brandenburg & Rebs, 2015; Rajeev et al., 2017). Based on a selection of 37 research articles (reported in the supplementary material** of this chapter), we examine how this trend is addressed by the literature dedicated to SCND problems. Table 2 summarizes the main features of these articles regarding various performance indicators associated with each of the three dimensions of sustainability. The increasing academic interest in this area is evidenced by 78% (29/37) of the selected, recently published articles (2017–2022). Moreover, the concern with modeling and solving real-world problems is also worth mentioning (32 articles or 86%). A broad application context is also observed, e.g., in the electronics industry (Arampantzi & Minis, 2017; Moheb-Alizadeh et al., 2021), bioenergy and biofuel production (Fattahi et al., 2021; Ghaderi et al., 2018), food sector (Jouzdani & Govindan, 2021; Varsei & Polyakovskiy, 2017), and tire industry (Gao & Cao, 2020; Sahebjamnia et al., 2018), among others.

Regarding economic performance, Table 2 reveals that the majority of the SCND problems studied focus on identifying the network configuration with the least total cost. By contrast, profit maximization has received far less attention, which is in line with the findings of previous studies, e.g., Melo et al. (2009) and Correia et al. (2013). The availability of models that allow quantifying the environmental impact caused by logistic activities (e.g., production, transportation) is gradually making it possible to integrate environmental metrics into SCND models (Alumur & Bektaş, 2019).

Methods based on Life Cycle Assessment, such as Eco-Indicator 99 and ReCiPe, have become popular (Eskandarpour et al., 2015) as they enable scores to be calculated which are then fed into the mathematical formulation of the SCND problem (e.g., Fattahi et al. (2021), Feitó-Cespón et al. (2017, 2021)). A classic method for considering environmental criteria is to measure the greenhouse gas

**Table 2** Performance indicators of SCND models addressing all dimensions of sustainability

| Performance indicator | Key feature | Selected contributions |
|---|---|---|
| Economic | Cost | 27 articles[a], e.g., Biuki et al. (2020), Govindan et al. (2019) |
| | Profit | 10 articles[a], e.g., Fattahi et al. (2021), Rahimi et al. (2019) |
| Environmental | Impact of . . . | |
| | facility location | 15 articles[a], e.g., Arampantzi and Minis (2017), Govindan et al. (2019) |
| | procurement | 8 articles[a], e.g., Allaoui et al. (2018), Gao and Cao (2020) |
| | production | 26 articles[a], e.g., Biuki et al. (2020), Sherafati et al. (2019)[b], Tirkolaee et al. (2022) |
| | material handling | 16 articles[a], e.g., Fattahi et al. (2021)[b], Guo et al. (2021), Moheb-Alizadeh et al. (2021) |
| | transportation | 33 articles[a], e.g., Budak (2020), Fattahi and Govindan (2018)[b], Martins et al. (2019) |
| | recycling/ disposal | 5 articles[a], e.g., Arampantzi and Minis (2017), Gao and Cao (2020) |
| | energy consumption | Feitó-Cespón et al. (2017), Feitó-Cespón et al. (2021), Mehrjerdi and Shafiee (2021) |
| | waste generation | 7 articles[a], e.g., Guo et al. (2021), Zhang and Jiang (2017) |
| | water consumption | 7 articles[a], e.g., Allaoui et al. (2018), Sherafati et al. (2019)[b] |
| | other indicators | Jouzdani and Govindan (2021), Pishvaee et al. (2012), Rohmer et al. (2019) |
| Social | Job creation | 21 articles[a], e.g., Sahebjamnia et al. (2018)[c], Moheb-Alizadeh et al. (2021), Zahiri et al. (2017) |
| | Impact of . . . | |
| | accidents/ damages | 8 articles[a], e.g., Rahimi et al. (2019), Sahebjamnia et al. (2018) |
| | regional development | 6 articles[a], e.g., Anvari and Turkay (2017), Budak (2020) |
| | equity | Anvari and Turkay (2017), Govindan et al. (2019), Martins et al. (2019) |
| | other indicators | 14 articles[a], e.g., Fattahi et al. (2021)[b], Tirkolaee et al. (2022) |

[a]See supplementary material for a complete list
[b]Indicator embedded in one or several constraints
[c]Consideration of fixed and variable number of job opportunities

(GHG) emissions associated with the various stages of the supply chain (e.g., Martins et al. (2019), Tirkolaee et al. (2022)). Meanwhile, the information needed is relatively easy to access through carbon emission calculators and similar tools provided by a number of public and private organizations. Only a few authors use energy consumption as a gauge for GHG emissions (e.g., Feitó-Cespón et al. (2017, 2021), Mehrjerdi and Shafiee (2021)). As shown in Table 2, transportation factors are taken into account by most authors, followed by production and material handling factors, with the latter resulting from the storage and/or processing of intermediate and final products. Interestingly, the environmental impact caused by the construction of facilities along with the type of technology deployed is also receiving growing attention. In contrast, less emphasis is placed on the negative effects of waste generation and water consumption.

While economic and environmental performance are studied extensively, the social dimension is underrepresented in the SCND literature. This is because social factors are comparatively more difficult to quantify and incorporate into a mathematical framework (Bubicz et al., 2019; Eskandarpour et al., 2015). The International Guidance Standard on Social Responsibility ISO 26000 (International Organization for Standardization, 2010) outlines recommendations for private and public organizations to operate in a socially responsible manner. Of the seven core themes addressed by ISO 26000, labor practices received prominence in SCND modeling. Employment opportunity generation is the primary way to account for this criterion and is typically modeled by the number of jobs created through establishing facilities and operating them. Some studies (highlighted in Table 2 by "c") account for both the fixed number of jobs (e.g., management positions) and the number of variable jobs created, whereas the latter depends on the level of capacity utilized at the open facilities. Work conditions are considered through the number of accidents that may occasionally occur during the construction and operation of the facilities. This factor is usually modeled by the number of workdays lost. Both metrics are affected by the type of technology deployed at the facilities. Labor practices and conditions are also closely related to regional development, an aspect addressed by some studies (see Table 2). In this case, a score is assigned to each facility favoring those locations in which a greater benefit can be achieved by attracting business operations. Depending on the context of the problem, equity issues are also modeled (e.g., equitable job opportunities in Anvari and Turkay (2017), equitable access to food items for charitable agencies in Martins et al. (2019)). The category "Other indicators" at the bottom of Table 2 comprises additional social metrics such as the work conditions in manufacturing plants (Arampantzi & Minis, 2017; Sherafati et al., 2019), the effect of traffic congestion (Jouzdani & Govindan, 2021), the risk to public health caused by uncollected waste (Zhang & Jiang, 2017), the number of undelivered products to customers (Feitó-Cespón et al., 2017, 2021), and access to medical and educational services (Anvari & Turkay, 2017). The diversity of the measures adopted shows that there is no consensus on the definition and quantification of appropriate social metrics for designing a supply chain network, in sharp contrast to indicators commonly used at the economic and environmental levels. Some authors rely on expert opinion and resort to methods such as the Analytic Hierarchy Process to decide on the scoring of the social parameters they use in their mathematical formulations (e.g., Allaoui et al., 2018; Varsei & Polyakovskiy, 2017).

The importance of the social dimension will continue to grow due to stricter legislation, such as the German Supply Chain Due Diligence Act, which comes into force in 2023 (German Federal Ministry of Labour and Social Affairs, 2021). Accordingly, large companies must ensure the protection of Human Rights and the

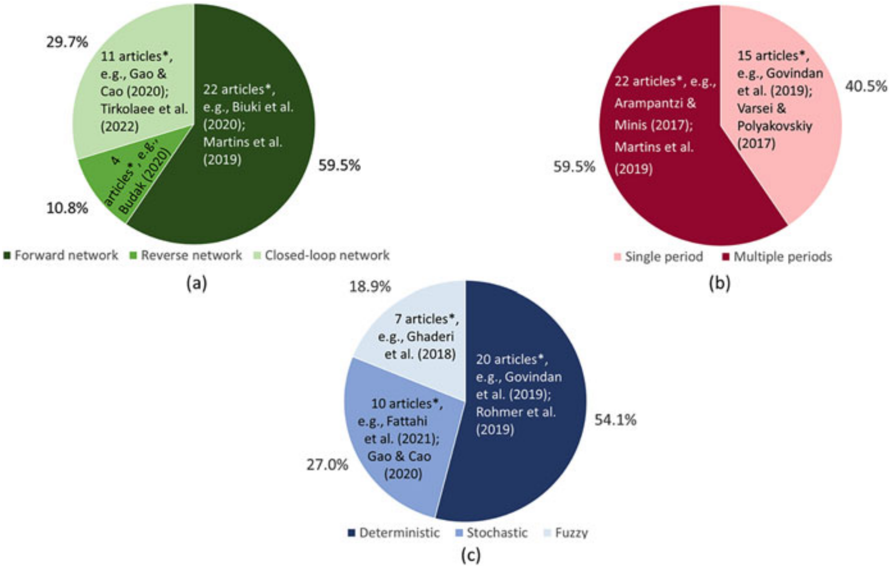


**Fig. 4** Selected features of sustainable SCND models: (**a**) type of supply chain network; (**b**) planning horizon; and (**c**) type of modeling approach;*see supplementary material** for a complete list

environment in their global supply chains. This law will affect the selection of suppliers and other contractual partners, and as a result, the design of supply chain networks. Thus, more research is needed to standardize and quantify social metrics, which requires the development of new assessment methods.

Figure 4 summarizes additional features of the 37 articles reviewed. Interestingly, problems addressing the configuration of forward networks received the greatest attention, followed by problems focusing on the design of multiechelon closed-loop networks, in which downstream and upstream product flows are coupled. Furthermore, for almost 60% of the contributions the SCND problem is considered in a dynamic setting concerning making location decisions and planning the various logistic operations so as to obtain a network whose configuration can respond to demand fluctuations and cost variations over multiple time periods. A deterministic modeling approach has been the preferred avenue for most authors. However, the growing interest in accounting for uncertainty about future conditions (e.g., customer demand, resource availability, and costs) when modeling SCND problems that integrate the triple bottom-line perspective is to be welcomed.

Holistic approaches to sustainable SCND problems are methodologically challenging due to the conflicting nature of the three dimensions of sustainability. Depending on the network typology, the length of the planning horizon, the number and type of logistic operations modeled, and the consideration of stochastic parameters, it is extremely difficult to identify Pareto-optimal solutions in reasonable computing time, especially for large-scale problems. Some authors address this difficulty by imposing thresholds on environmental or social performance, thus avoiding multiple objective functions (this case is highlighted by “b” in Table 2). Nevertheless, further opportunities for developing efficient and effective solution methods still need to be explored.

## 3.2 Transition to a Circular Economy

The circular economy entails sharing, leasing, reusing, repairing, refurbishing, and recycling materials and products to extend their life cycle and increase their usage intensity. At the strategic planning level, SCND decisions are at the core of setting the foundation for the development of practices in line with this paradigm. In particular, the design of reverse logistic networks and closed-loop supply chains is directly related to the circular economy. Research in this area started long before this concept gained popularity (Melo et al., 2009).

Several reviews have been devoted to the challenges posed by SCND problems in this domain and how they have been addressed in the scientific literature, e.g., Akçalı et al. (2009), Govindan et al. (2015), Islam and Huda (2018) (with a focus on managing waste electrical and electronic equipment), Melo et al. (2009), and Van Engeland et al. (2020) (with a focus on waste management). Rather than detailing these contributions in this section, we concentrate on how the transition toward the circular economy is being approached by the research community in SCND.

The integration of reverse logistics-related operations into conventional supply chains is challenging, not least because of uncertainty in the quantity, quality, and timing of returned products. This integration often leads to redesigning a supply chain network already in place, rather than pursuing a greenfield approach (Alumur et al., 2015). The recent comprehensive review of Mahmoum Gonbadi et al. (2021) identifies and categorizes a number of research articles dealing with FLPs in the context of different types of reverse flows, namely, recycling, dismantling, remanufacturing, refurbishing, repairing, reselling, refining, retreating, reconditioning, reusing, and donating (see Mahmoum Gonbadi et al. (2021) and references therein). Each of these reverse flows affects decisions about where to open facilities, the choice of technology to deploy in each location, as well as the sizing of the facilities. When the planning horizon is divided into multiple time periods, other actions can also be planned, such as the temporary adjustment of capacity in the network through facility expansion and/or facility contraction, the relocation of certain facilities, or even their closure.

The relevance of circular economy practices to achieve sustainable development is indisputable. However, Fig. 4a in Sect. 3.1 reveals that there is a limited number of studies that integrate the triple bottom-line perspective into the design of supply chain networks dealing with reverse flows. This finding is also supported by Calzolari et al. (2022) and Mahmoum Gonbadi et al. (2021). Furthermore, the degree to each supply chain is “circular” and is not measured by any of the contributions indicated in Fig. 4a. The development of one or several metrics to assess the level of circularity is certainly an avenue for future research, thereby helping promote the transition to the circular economy. A first step toward achieving this goal was recently taken in Calzolari et al. (2022) for closed-loop supply chains. The authors developed two composite indicators, each comprising several performance measures across the three dimensions of sustainability. The selection of the metrics was guided by the frequency with which they appear in the academic literature and in industry practice. A composite indicator is defined by the weighted sum of its metrics, where the weight of each sustainability component represents its relative frequency either in the literature or industry. The composite indicator obtained from the academic literature assigns a relative importance of 49% to the economic component, 40% to the environmental component, and 11% to the social component. In the case of the composite indicator calculated from industry practices, the weightings are 27%, 67%, and 6%, respectively. This wide disparity indicates that there is not yet a general understanding and that further discussion is needed to pinpoint the principles of the circular economy.

Servitized business models are also enablers of the circular economy (Agrawal & Bellos, 2016; Bressanelli et al., 2018). Servitization involves selling the use or the function of a product instead of the product itself. Leasing, renting, sharing, and pay-per-use are among the most popular servitized business models (Tucker et al., 2020). In particular, shared mobility systems have long attracted the attention of the Location Science community. Facility location decisions taken at the strategic level are intertwined with operational decisions involving vehicle repositioning strategies and rebalancing incentives offered to users. Mathematical models and solution approaches for bicycle and car-sharing system design problems were reviewed in Laporte et al. (2018). The additional challenges posed by designing and operating car-sharing systems with electric vehicles were discussed in Brandstätter et al. (2020), Çalık and Fortz (2019), and Yao et al. (2022), while facility location and capacity-sizing problems for bicycle stations were studied in Chou et al. (2019), Lin and Yang (2011), and Muren et al. (2020). Unlike the extensive stream of research devoted to network design problems within reverse logistics and closed-loop supply chains, we were unable to find a single article within the context of implementing a pay-per-use business model. According to Agrawal and Bellos (2016), servitization has structural and operational characteristics quite distinct from a classical business. Economic and environmental superiority can only be achieved in this innovative way of conducting business by designing and operating a logistic network appropriately. For example, when the service provider manages the relationship with the customers, and is neither the manufacturer of the products nor responsible for their maintenance, repair, replacement, and distribution, the viability of his business depends solely on interaction and collaboration with the various stakeholders. A multiple-tier network (e.g., production plants, distribution centers, repair shops, and recycling facilities) needs to be in place and aligned with downstream and upstream material flows. Potential economic and environmental benefits may be gained by resource pooling, which reduces the volume of new products to be manufactured and resources to be used. However, and as discussed in Agrawal and Bellos (2016), servitized business models do not always achieve higher environmental sustainability. Hence, one promising research avenue is to investigate under which conditions (including the design of the underlying supply chain network) can this type of business model have a positive environmental and social impact, while also being economically viable.

Finally, we point out that circular economy is a topic with growing popularity both in practice and in academia, which has sometimes prompted the use of this term in a less comprehensive context than that associated with its meaning. In addition to the directions for further research aforementioned, it should be noted that current SCND models are still far from contemplating a true consideration of circularity, a view advocated in Mahmoum Gonbadi et al. (2021) and that we also share. For example, reducing the consumption of virgin resources or avoiding the use of raw materials are issues that have not been explicitly addressed in the literature so far.

### 3.3 Data Source Issues

The overall performance of a supply chain network depends to a large extent on its level of coordination. In this regard, supply chain actors essentially need to have access to high-quality information in order to mitigate coordination failures. There is no question that the Industry 4.0 era has brought major technological advances in the field of information systems (Tang & Veelenturf, 2019); however, the recent COVID-19 pandemic (Rozhkov et al., 2022) and other unexpected natural catastrophes (e.g., the 2003 SARS outbreak in China, the 2004 tsunami in the Indian ocean, and the 2011 devastating earthquake in Japan) have exposed the necessity of supply chain planning in an environment where information systems completely lack historical data (Omar et al., 2022). Having restricted information about the different operations of a supply chain network certainly causes uncertainty in making important strategic decisions related to their configuration (e.g., facility location decisions). The decision-makers (DMs) should be aware that the "data-scarcity" and "lack of data" environments will become increasingly prevalent and as such they must be prepared to deal effectively with problem settings in SCND.

Academic literature reveals that different environments of information availability are directly related to a particular type of uncertainty. For instance, when randomness is the main source of uncertainty in the input data (Govindan et al., 2017), we can assume that historical information is abundant and DMs can identify the probability distribution or generate scenarios for each random parameter. According to Torabi et al. (2016), the use of stochastic programming (SP) is the most suitable modeling approach for those decision-making environments characterized by sufficient availability of historical data and random variables related to business-as-usual events (Naderi et al., 2016). Based on the taxonomy proposed by Naderi et al. (2016), the randomness uncertainty has the least negative impact on businesses, the greatest likelihood of occurrence, and the lowest degree of impact. The above clearly indicates that this type of uncertainty (under abundant data availability) is the simplest to address; however, the SP modeling approach has two major drawbacks. First, historical data are insufficient in most realistic network design problems, i.e., it is very difficult to perform goodness-of-fit tests in order to obtain adequate probability distributions for the uncertain parameters. Second, the number of decision stages in scenario-based SP increases, which raises the computational complexity of the original problem considerably (Correia & Saldanha da Gama, 2019). Despite these disadvantages, recent applications of SP for dealing with FLPs under randomness can be found in Correia and Melo (2021) and Guo et al. (2022).

Data-scarce environments are linked to the so-called hazard uncertainty, which is characterized by a low likelihood of occurrence yet high-impact of extreme events (Naderi et al., 2016). In this case, DMs do not have enough information to estimate the probability distributions of random parameters. The literature indicates that robust optimization (RO) is a suitable modeling approach to cope with FLPs when the worst-case performance of the supply chain network is to be optimized (Govindan et al., 2017; Sadghiani et al., 2015; Torabi et al., 2016). RO has been successfully used to model realistic FLPs in recent contributions such as closed-loop supply chains in the melting industry (Gholizadeh & Fazlollahtabar, 2020) and healthcare supply case (Shang et al., 2022).

In many real-life situations, DMs have to face supply chain network (re)design problems where they inevitably lack historical data. For instance, it is difficult to use SP or RO to address the configuration of a network when new products are launched because historical data are nonexistent. Accordingly, it is difficult to forecast consumer demand accurately or to conduct a goodness-of-fit test. A similar decision-making environment in SCND can be found in humanitarian relief (Nakao et al., 2017), all kinds of "scarce resources" caused by global pandemics (e.g., COVID-19), wars (e.g., Ukraine war in 2022), and natural catastrophes (e.g., earthquakes). Under these problem settings, the DMs usually rely on judgmental data extracted from experts for uncertain and fluctuating parameters such as customer demands, resource availability, facility capacities, and fixed/variable costs of logistical infrastructures. DMs use their subjective opinions and, in some cases, very scarce objective data (but often even inexistent) to adopt a suitable possibilistic distribution for each imprecise parameter. The unavailability of information about the likelihood of future plausible events is defined in the literature as deep uncertainty (i.e., epistemic uncertainty) (Naderi et al. 2016). To deal with this type of uncertainty, fuzzy/possibilistic-based programming approaches are usually used to model impreciseness in input data arising from a lack of knowledge about their exact values (Torabi et al., 2016). In this case, fuzzy mathematical programming (FMP) handles the planner's expectations about the level of objective function, the uncertainty range of coefficients, and the satisfaction level of constraints by using membership functions (Govindan et al., 2017).

Figure 5 shows a decision tree where we gather all decision-making environments (abundant, scarce, and unavailable information) and the modeling approaches (SP, RO, FMP, and Hybrid) used to deal with each type of uncertainty (randomness, hazard, and epistemic). This decision tree branches to illustrate a deeper analysis of modeling approaches and model components for all found contributions in which FLPs under epistemic uncertainty are addressed. As mentioned before, addressing FLPs under scarcity/unavailability of historical data is certainly an emerging concern

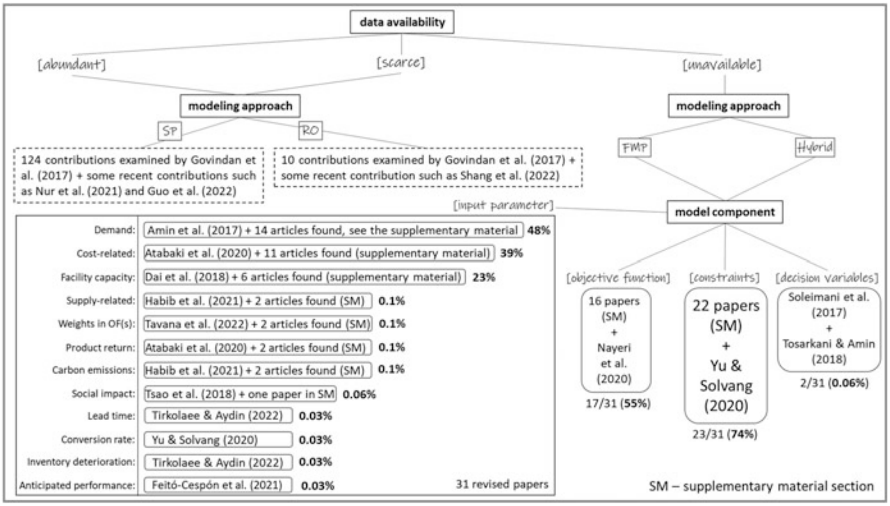


**Fig. 5** Decision tree summarizing the DM environments and their respective modeling approaches

that merits more attention. To this end, we developed our decision tree not only to identify research gaps within the fuzzy/possibilistic-based programming approaches, but also to explore other approaches that can be potentially used to address this emerging concern.

As shown in Fig. 5, we rely upon the information reported by Govindan et al. (2017) where the authors collected 124 papers and ten contributions that used SP and RO modeling approaches, respectively. Besides these articles (134), other recent contributions (5 applying SP and 3 using RO reported in the supplementary material**) are additionally revised in the present chapter. Furthermore, we could identify 31 papers addressing FLPs (within the context of SCND), where authors confront the lack of historical data. All these figures related to the number of reviewed articles clearly indicate that the decision-making environments associated with "abundant" and "scarce" data availability have received much more attention compared to contributions addressing SCND problems (usually multiechelon FLPs) under epistemic uncertainty.

Moreover, we can also identify the following research gaps within the application of fuzzy-based modeling approaches:

- The majority of prior research addresses the epistemic uncertainty in input data related to customer demand, profit/cost components, and facility capacity. Surprisingly, very few contributions study the deep uncertainty associated with scarce supplies/resources (3 papers out of 31). Again, this is a major concern because there are, and will continue to be, multiple critical situations (e.g., pandemics, wars, and natural disasters) where the DMs have to deal with deep uncertainty in resource availability that significantly influences the performance of their supply chains.

- A few studies consider impreciseness, due to a lack of historical data, concerning environmental (0.1%) and social (0.06%) performance indicators. It is clear that most authors in this research area investigate economic-related aspects, even though they constitute only one of the three dimensions of sustainability (see Sects. 3.1 and 3.2).
- The revised contributions mostly adopt fuzzy-based formulations in the model constraints and objective functions. Two notable exceptions are Tosarkani and Amin (2018) and Soleimani et al. (2017). In Tosarkani and Amin (2018), fuzzy decision variables are used to describe different stages of material flows (including inventory level) through a closed-loop supply chain set up in Vancouver, Canada. In contrast, Soleimani et al. (2017) propose two types of fuzzy decision variables to express membership degree related to social impact (i.e., missed working days due to occupational accidents) and demand fulfillment.
- Only one article uses a fuzzy modeling approach other than FMP (or any hybrid variant of FMP). In Feitó-Cespón et al. (2021), a fuzzy inference system is implemented to cope with the lack of historical data for scenario generation for the redesign of a real-life reverse supply chain network.

Although the deep uncertainty of input parameters in FLPs has been treated exclusively with fuzzy-based modeling approaches, researchers remain concerned about the great computational effort (Mula et al., 2006) required by the fuzzy equivalent models, especially when these mathematical models represent realistic large-scale instances of FLPs (Aranguren et al., 2021). Another major shortcoming of fuzzy approaches is that they often require the application of nonlinear membership functions (Chhibber et al., 2021) and complex operators (Mula et al., 2006) to adequately characterize deep uncertainty. In this case, DMs face additional computational difficulties in solving the nonlinear equivalent models that better describe the fuzzy phenomenon (Moradi et al., 2019; Rizk-Allah et al., 2021). All of the above indicates that much remains to be done when dealing with FLPs under deep uncertainty (notably, lack of historical information). In this regard, it is interesting to observe that other solution approaches have been successfully applied to similar problem settings. For instance, a system dynamics approach has been used to develop a decision support system for new product launch (Cui et al., 2011; Khajavi et al., 2015) and disaster management (Mishra et al., 2019). However, to the best of our knowledge, this modeling approach has not been employed to directly address location decisions in the presence of deep uncertainty.

## 3.4 Disruptive Events and Resilience

In recent years, it has become clear that supply chains rarely perform in a stable steady-state (Wieland, 2021). Key studies show that nearly three quarters of the companies experience a disruption in their supply chain operations each year (BCI, 2018), resulting in limited flow of goods, lower revenue, delivery delays, loss of market share and reputation, reduction in stock returns, and even sudden demise of businesses (Craighead et al., 2007; Hendricks & Singhal, 2005; Ivanov et al., 2021).

Disruptive events affecting supply chains are very diverse. For example, Tang (2006) introduced definitions of various types of disruptions. The author states that disruption risk is related to a specific type of event that may occur as a result of a natural catastrophe (e.g., earthquake, flood, and tsunami) or through intentional/unintentional human actions (e.g., war, terrorist attack, epidemics/pandemics outbreak, and labor strike). Other authors, such as Scholten et al. (2020), claim that the origin of disruptions can be found within the supply chain (e.g., production line break down, IT problems, sustainability issues, or quality problems) or externally due to labor strikes, legislation changes, demand fluctuations, weather conditions, financial turbulence, terrorism, and counterfeiting. The truth is that scientific literature proposes several categorizations of supply chain disruptions. However, we strongly believe that the recent review carried out by Shekarian and Mellat Parast (2021) comprehensively covers all types of disruptions that a supply chain can experience. According to this review, the source of risks that lead to supply chain disruptions is internal to the firm (all risks related to firm processes and its control activities), external to the firm but internal to the supply chain network (demand and supply side risks), and external to the network (all forms of environmental risks). With this in mind, in this section we have identified key contributions addressing supply chain disruptions that directly or indirectly affect the supply chain network structure and their respective location/allocation decisions.

Table 3 presents a comprehensive classification of 30 relevant research articles. We examine the type of disruption(s) addressed and in which application context each disruption was originated. Clarifications of each acronym are shown at the bottom of the table. It is important to note that some acronyms are never included within columns 2 and 3, namely, IT-driven problems (PD3), labor strike (PD4), all categories within CONTROL (CD), forecasting errors (DD5), unusual customer payment delays (DD6), sudden supplier demise (SD2), supplier quality problems (SD4), terrorism and war (ED2), political instability (ED4), and technology changes (ED5). This indicates that we could not find any contribution that addresses the corresponding disruption, i.e., it is indeed a knowledge gap based on our literature review and deserves further analysis.

A closer look at Table 3 reveals that supply and environmental-related disruptions have been much more extensively studied than other types of disruptive events. In this regard, most of the revised contributions analyze the effect of supply market shortage and natural disasters (generally earthquakes) on the performance of supply chain networks. We also observe a wide variety of case studies, including some recent contributions addressing the ripple effect caused by the risk of disruption from the COVID-19 pandemic (Sawik, 2022). Among the 30 articles reviewed, we found only two contributions (Haeri et al., 2020; Pariazar & Sir, 2018) that studied the sources of risk related to internal disruptions (process and control) in firms. Surprisingly, we have not found any articles that address the SCND problem (including facility location and capacity allocation) in the event of disruptions caused by IT problems or labor strikes. In this respect, we are convinced that some recent events

**Table 3** Classification of articles that use optimization methods to deal with supply chain disruptions

| Article | Source of risk | Disruption | Application context |
|---|---|---|---|
| Readers can see 30 articles (e.g., Taleizadeh et al. (2022), Kungwalsong et al. (2022), and Sawik (2022)) and a detailed version of the present table in the supplementary material** | DD, SD, and ED | DD1, SD1, and ED1 | Glass sector |
| | DD | DD4 | Automotive industry |
| | SD | SD1, SD3 | Agri-business |
| | DD, SD | DD2, SD1 | |
| | ED | ED1 | Humanitarian logistics |
| | SD | SD1 | HP case study |
| | SD | SD1 | Filter manufacturer |
| | ED | ED1 | Dairy industry |
| | DD, SD | DD4, SD1 | Automotive industry |
| | ED | ED3 | COVID-19 vaccine supply |
| | PD | PD1 | Pharmaceutical sector |
| | ED | ED1 | Medical device manufacturer |
| | DD | DD2, DD3 | Tire industry |
| | ED | ED1 | Glass sector |
| | ED | ED1 | Dairy industry |
| | SD | SD1 | Printers-cartridge manufacturing |
| | PD, ED | PD2, ED1 | Humanitarian logistics |
| | ED | ED1 | Humanitarian logistics |
| | ED | ED3 | |
| | SD | SD1 | Electronic manufacturing industry |
| | ED | ED1 | Humanitarian logistics |
| | SD | SD1 | Plastic sector |
| | DR, SD, and ED | DD2, SD1, and ED1 | Pharmaceutical sector |
| | ED | ED3 | |
| | DD, SD, and ED | DD2, SD1, and ED1 | Humanitarian logistics |
| | ED | ED1 | |
| | ED | ED3 | COVID-19 vaccine supply |
| | SD | SD1 | |
| | ED | ED3 | Food sector |
| | SD | SD1 | Pharmaceutical sector |

**PROCESS** (PD): product quality problems (PD1), equipment failure (PD2), IT-driven problems (PD3), and labor strike (PD4). **CONTROL** (CD): safety stock policy (CD1), ordering quantity policy (CD2), asset management policy (CD3), and transportation management problems (CD4). **DEMAND** (DD): volatile demand (DD1), unanticipated demand (DD2), market changes (DD3), competition changes (DD4), forecasting errors (DD5), and unusual customer payment delays (DD6). **SUPPLY** (SD): shortage in supply market (SD1), sudden supplier demise (SD2), variability of lead time (SD3), and supplier quality problems (SD4). **ENVIRONMENTAL** (ED): natural disaster (ED1), terrorism and war (ED2), diseases and epidemics (ED3), political instability (ED4), and technology changes (ED5) will motivate researchers to develop new contributions in this area. It is well known that recent events such as the Ukraine war in 2022 have led to record levels of energy and fuel prices. This triggered a wave of growing anger among many Spanish truck drivers which led to a nationwide strike causing serious disruption in the food sector (mainly in the dairy industry), fishing industry, construction sector (building materials), healthcare system (nursing homes), and timber industry (West, 2022).

Moreover, the multiplicity of disruptive events and potential impact on business competitiveness and continuity have attracted a great deal of interest from the scientific community in supply chain resilience (SCR) (Jüttner & Maklan, 2011). A supply chain is resilient when the network can withstand, adapt, and recover from unforeseen events to meet customer demand and ensure good performance (Hosseini et al., 2019). A recent study by Schatteman et al. (2020) states that SCR can improve the manufacturing process (15–25%), significantly reduce the lead time (40–60%), and also increase customer satisfaction by 20–30% (Suryawanshi & Dutta, 2022).

According to Dolgui et al. (2018), SCR capacity is made up of two parts: resistance and recovery. Resiliency describes the ability of the network to minimize the disruption impacts by avoiding the adversarial event or starting to recover quickly (Lohmer et al., 2020). The recovery stage, however, can be understood as the network's ability to return to a steady or improved system state once a disruption has been encountered (Melnyk et al., 2014). Other contributions define more specific resilience strategies. Among many of them are backup capacity and inventory, redundant plants, backup suppliers, supply chain integration, postponement and capacity pooling, flexible allocations or flexible rerouting strategies, and information sharing (Azadegan et al., 2020; Behzadi et al., 2020; Lohmer et al., 2020).

In this section, we adopt the general framework on SCR proposed by Ivanov and Dolgui (2019). These authors identify three main groups of resilience strategies that ensure disruption resistance and recovery resource allocation. They cluster some specific strategies (facility fortification, segmentation, decentralization, diversification, etc.) into a key SCR characteristic called structural variety. This is nothing more than a lean network design to reduce the structural complexity of the supply chain under disruptive events. In addition, Ivanov and Dolgui (2019) propose the use of product line-based resilient supply chain segmentation with minimum intersections between the different lines. The above would reduce the propagation of the ripple effect avoiding supplier failure due to the absence of intersections between the supply chains in different product lines. The second group of strategies is related to process flexibility. This is about a set of reactive tactics that may include backup/dual sourcing, product substitution, better coordination (e.g., with the suppliers), postponement, and capacity pooling. Finally, the third group of strategies, termed by Ivanov and Dolgui (2019) as nonexpensive parametric redundancy, target the efficient reservation of capacity, inventory, and lead time. It basically deals with the optimization of network redundancy and can be considered a new research topic in the field of resource/capacity allocation.

Figure 6 depicts our literature review on SCR. We examine those 29 articles (one of the 30 articles, Khalilpourazari and Arshadi Khamseh (2019), does not propose any resilience strategy) in which different types of disruptive events are identified.

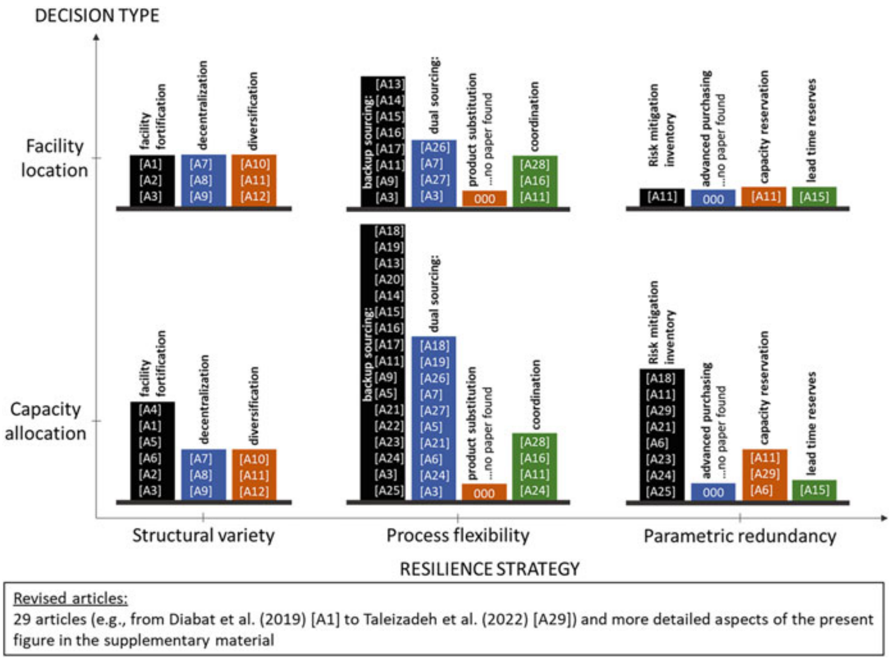


**Fig. 6** Review of resilience strategies applied in disruptive supply chains

We now limit ourselves to analyze how these contributions include facility location and capacity allocation decisions in resilient SCND.

As seen in Fig. 6, there are more contributions addressing capacity allocation (backup sourcing and dual sourcing) compared to those that study facility location decisions in the context of resilience in SCND. It is also clear that resilience strategies related to process flexibility are the most frequently applied, while strategies related to parametric flexibility (e.g., lead time redundancy and capacity reservation) have been very little studied. Finally, we found no contributions where product substitution and advanced purchasing have been used to deal with disruptive supply chains.

## 3.5 Omnichannel Distribution Network Design

E-commerce has changed the way products are sold and delivered to consumers. Today, more and more retailers have readjusted their business processes to engage customers in the online channel (Ishfaq et al., 2016). However, the most significant growth in online retailing comes from omnichannel retailers who sell products both in-store and online (Mahar & Wright, 2017). Numerous articles have highlighted the importance of omnichannel (e.g., Melacini et al. (2018)), but most of them also agree on the fact that omnichannel distribution network design is very difficult to implement when it comes to logistic efficiency and customer utility (Kembro et al., 2022).

The COVID-19 outbreak definitely increased the importance and potential of omnichannel SCND (Verhoef, 2021). It is well-known that customer purchasing habits were forced to change (because of periods of lockdown) to online channels and, therefore, retailers had to react urgently by rethinking their online offers in order to continue their activities despite the crisis (Wang et al., 2020). According to Arora et al. (2020), some customers were first-time online purchasers, which may have significantly increased the percentage of demand purchased through online channels after the pandemic, thereby complicating the order fulfillment and product distribution (Ishfaq et al., 2021).

Moreover, competition in online channels is also forcing decision-makers to design, with practical and efficient orientation, supply chain networks to provide better products and services to customers (Zhang et al., 2016). It is important to ensure flexible delivery to achieve a high level of customer service and economic performance (Millstein et al., 2022). In this regard, there are several contributions that emphasize the most important decisions in so-called omnichannel supply chains. For instance, Bijmolt et al. (2021) and Ishfaq et al. (2021) identify order fulfillment and product distribution as two critical decision areas. However, in Xie et al. (2014), the authors recognize that capacity planning and allocation are the most challenging decisions due to long production lead times and high demand uncertainty. None of these contributions include facility location as one of the crucial supply chain decisions in omnichannel retailing. Nevertheless, the recent contribution by Millstein et al. (2022) studies the effect of location decisions on omnichannel network design. The authors investigate the impact of four channel designs (ship-from-store, ship-from-warehouse, ship-from-store-and-warehouse, and ship-from-warehouse with backhauling from the store inventory to the warehouse) on the overall profitability of the omnichannel distribution process.

In this section, we review key literature (12 research articles) related to the design of omnichannel supply chain networks. We analyze, more comprehensively, the main decisions (warehouse location, inventory in-store/warehouse, demand allocation among fulfillment facilities, and customer behavior) that have been addressed by the authors of the reviewed contributions. In addition, Table 4 shows which types of objective functions (economic, environmental, and social performance) have been included in the revised mathematical formulation. We also identify which modeling approaches (Mixed-Integer Linear Programming – MILP, Two-Stage Mixed-Integer Linear Programming – TS-MILP, Linear Programming – LP, and Non-Linear Programing – NLP) and solution strategies (commercial software, exact methods, and heuristics) were proposed. Table 4 also indicates whether the studied problems deal with a single product or multiple commodities.

Table 4 helps us to understand, to some extent, what research efforts have been conducted in the field of omnichannel network design and, not least important, gives an indication of which research topics require further analysis. In this sense, we observe that decisions related to facility location (the focus of this chapter) and customer behavior are much less studied in the key literature. Only six contributions

**Table 4** Selected features of articles addressing omnichannel network design

| Studied component | Specific aspect | [O1] | [O2] | [O3] | [O4] | [O5] | [O6] | [O7] | [O8] | [O9] | [O10] | [O11] | [O12] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Main decision | Warehouse location | | ✓ | ✓ | | | ✓ | | ✓ | ✓ | | | ✓ |
| | Inventory in store | ✓ | | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | ✓ | |
| | Demand allocation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Customer behavior | | ✓ | ✓ | | ✓ | | | | | ✓ | | |
| Objective function | Economic | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Environmental | | | | | | | | | | | | ✓ |
| | Social | | | | | | | | | | | | |
| Modeling approach | MILP | | | | | | | | ✓ | ✓ | | | ✓ |
| | TS-MILP | ✓ | ✓ | | | | | | | | | | |
| | LP | | | ✓ | | | | | | | | ✓ | |
| | NLP | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | | |
| Solution approach | Commercial software | | | ✓ | | | | ✓ | ✓ | ✓ | | | ✓ |
| | Exact method | ✓ | ✓ | | ✓ | | ✓ | | | | ✓ | ✓ | |
| | Heuristic | | | ✓ | | ✓ | | | | | | | |
| Flow type | Single product | | ✓ | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Multiproduct | ✓ | | ✓ | ✓ | ✓ | | | | | | | |

**REVIEWED ARTICLES ON OMNICHANNEL NETWORK DESIGN:** Arslan et al. (2021) [O1]; Chen et al. (2021) [O2]; Guerrero-Lorente et al. (2020) [O3]; Ishfaq and Bajwa (2019) [O4]; Lee (2017) [O5]; Liu et al. (2010) [O6]; Mahar and Wright (2017) [O7]; Millstein et al. (2022) [O8]; Millstein and Campbell (2018) [O9]; Xie et al. (2014) [O10]; Xu et al. (2017) [O11]; Yadav et al. (2018) [O12] out of the 12 articles include facility location decision variables. It is also noteworthy that all of these contributions address facility location based on a static configuration (no expansion, contraction, or closing of facilities over the planning horizon). Hence, it would be interesting to investigate what kind of effect a dynamic capacity configuration (formulations for capacity expansion and facility closing proposed by Chavez et al. (2021); Correia and Melo (2017, 2021)) of warehouses/stores could have on the level of customer service and economic performance.

Likewise, it is also clear from Table 4 that research incorporating a sustainable approach is practically nonexistent. In particular, no article addresses social aspects in the design of omnichannel supply chains. All contributions focus on the optimization of economic performance (cost minimization or profit maximization). Another interesting point is that the authors repeatedly use nonlinear models to formulate omnichannel network design problems; nevertheless, some MILP formulations have also been developed. It is also noteworthy that very few studies propose the use of heuristic methods (only two articles). One would expect a more frequent application of this type of solution methodology given the complexity (NP-hard) of omnichannel network design problems. Finally, more contributions have studied single product distribution, and only four research articles address the configuration of multichannel distribution networks for multiple products.

We conclude this section by noting that new business models will continue to influence how omnichannel retailers (re)design and operate their distribution networks in the future. For example, on-demand warehousing is emerging as a flexible alternative to typical long-term warehouse agreements, offering retailers temporary access to storage capacity (e.g., on a monthly or even weekly basis) (Parodos et al. 2022). The flexibility provided by this new business model means that facility location decisions are reversible in the medium or even short term, which contrasts with the classical approach where these decisions are strategic and therefore have a lasting effect. Thus, new opportunities to model and solve FLPs will arise under this setting.

## 4 Managerial Implications

The emerging trends discussed in the previous section pose enormous challenges to organizations when it comes to designing and operating their supply chain networks. In the future, these challenges are expected to become even more pressing as environmental, socioeconomic, and technological issues will continue to gain prominence on a global scale. As a result, managers should be aware of the complexity issues that are created by them and the potential benefits of using optimization models to support decision-making. For example, our discussion in Sects. 3.1 and 3.2 regarding the growing importance of environmental and social factors indicates that it has become imperative for managers to consider them in evaluating supply chain performance beyond the classical view of financial achievement. This implies taking all three dimensions of sustainability into account early on at the strategic planning level (i.e., planning the configuration of the supply chain). Likewise, the different types of data uncertainty and disruption risks discussed in Sects. 3.3 and 3.4 also need to be apprehended by management, who should realize the need to proactively design their supply chain networks. To help managers deal with external and internal supply chain uncertainties, different methodologies have been proposed (e.g., stochastic programming, robust optimization, and fuzzy mathematical programming). However, other avenues, such as simulation and system dynamics, could also be explored. The importance of robust and resilient strategies in network design and redesign is timely and significant due to recent events, e.g., the COVID-19 outbreak and its impact on the performance of supply chains worldwide. This last example has changed the purchasing habits of many consumers, compelling retail firms to complement classical distribution channels with online channels as discussed in Sect. 3.5. Again, managers in this sector should be aware of the impact of this trend on their distribution systems, which must be aligned with the expectations and preferences of consumers. New business models have emerged, such as the on-demand warehousing model, which drive the structure of distribution networks to be adjusted periodically in order to sustain the competitiveness of retail firms.

The potential benefits of using mathematical programming models coupled with efficient solution methods to address the challenges previously described are multifold. They bring added value to DMs (especially in senior management), as they help them understand the far-reaching implications of different settings in the configuration of their logistic networks. In addition, valuable insights into the trade-offs associated with facility location decisions along with other decisions related to logistic operations (e.g., procurement, production, and transportation) are also perceived by the DMs. Given the typical substantial capital investment and limited reversibility of strategic decisions, it is essential that stakeholders appreciate the impact of such decisions on the overall performance of their supply chains.

An example of this type of analysis is described in Yildiz et al. (2016). The authors present a roadmap for DMs regarding the structure of the logistic network to be established and the associated cost as a function of different levels of reliability. While it is not surprising that to achieve a network structure with higher reliability a company should make a greater investment in locating more facilities, maintaining more distribution channels, and diversifying the choice of suppliers, this study quantifies the impact of such decisions, thus allowing various solutions to be aligned with management targets. Furthermore, risk mitigation strategies are also proposed, e.g., by engaging backup suppliers even though this measure is more costly.

Another example of an extensive discussion of managerial implications is provided by Cortinhal et al. (2015, 2019) on how the structure of a multitier logistic network is affected by combining in-house manufacturing with product outsourcing. The results reveal that under a very moderate level of outsourcing, a less costly network configuration can be achieved by opening fewer facilities but with higher production capacity. In this case, not only is the production capacity better utilized, but also procurement, production, and transportation costs decrease compared to a network configuration that can meet all customer demand through in-house manufacturing. Other strategies for designing networks with lower total cost and their relationship to the risks an organization is exposed to (e.g., deterioration in customer service level) are also discussed.

Studies such as those mentioned illustrate the importance of the role that research into SCND problems plays in aiding decision-making. Naturally, the benefits will be greater with increased collaboration between academia and industry practice.

## 5 Summary and Conclusion

This chapter examined facility location problems within the context of designing and redesigning supply chain networks. Facility location planning cannot be considered in isolation, but rather intertwined with other decisions related to supply chain operations such as procurement, production, and transportation, among others. This field has attracted considerable attention from the OR/MS community, resulting in a rich class of challenging optimization problems. In particular, there is a growing concern to develop comprehensive mathematical models that integrate more and more features of SCND problems encountered in practice (recall Sect. 2). This is evidenced by the wide range of contributions reported in literature, many of them addressing realistic SCND problems. Nevertheless, there are still many opportunities for expanding this field. In particular, our selection of five emerging areas showed that more effort is needed in developing mathematical models and solution techniques for SCND problems (including facility location decisions) to address the challenges they pose. The latter is related to environmental and social concerns, as well as recent events affecting supply chains on a global scale. Traditionally, SCND problems have been dominated by economic aspects, but sustainable development and promotion of a circular economy can only be achieved if environmental and social factors are considered along with financial performance. We have pointed out several research gaps in this area, mainly related to the lack of integration of the social dimension. Another domain that deserves more attention concerns how to deal with data-scarce environments, most notably in the presence of epistemic uncertainty. Although fuzzy/possibilistic-based modeling approaches are often employed, they are insufficient to cope with situations characterized by deep uncertainty, such as those brought about by pandemics, wars, and natural disasters. Such events cause major disruptions in the supply chain and negatively affect business competitiveness. We have also identified a wide variety of other disruptive events, so far not addressed by SCND models (e.g., political instability, labor strikes, supplier quality problems, and IT-driven disruptions). Accordingly, additional research is needed to help decision-makers design resilient supply chains. Finally, we have discussed how e-commerce is changing the structure of traditional distribution networks so that retailers can better meet customer expectations and compete for market share. Research devoted to the design of multichannel distribution networks is relatively new, and many issues remain unresolved, such as the integration of sustainability concerns.

***The supplementary material to this chapter is available under https://www.htwsaar.de/wiwi/forschung-transfer/schriftenreihe-logistik/dateien/2022_htw-arbeitspapiere-logistik-nr-20.pdf.*

## 6 Cross-References

▶ Resilience in the Supply Chain
▶ Reverse Logistics Within the Supply Chain

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# Outsourcing in Supply Chain Management

Mohammadreza Akbari

## Contents



**Abstract**

With growing global business competition and complexity in supply chains, firms have recognized that it is not possible to maintain competitiveness in a global market on their own. Therefore, involvement of third-party providers is an important strategic tool to allow companies to focus on their core competencies and access global resources. Outsourcing, therefore, plays an important role in global supply chains.

Outsourcing is sure to grow. Today, supply chain firms are facing a wide variety of alternatives, needing to consider several important considerations before making the right decision. It has therefore become important to understand

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the phenomenon of outsourcing to better facilitate effective and successful decision-making. These points are relevant, as recent evidence hints at an increasing number of failures in cost management and issues arising out of related partner engagements.

This chapter focuses on outsourcing in the global supply chain, examining its different classifications and characteristics and providing insights into past, current, and emerging concerns in the management of outsourcing processes. Furthermore, this chapter combines theoretical and practical insights, focusing on the main challenges of implementing outsourcing in the supply chain discipline that practitioners and professionals are confronting.

With continued globalization and unpredictable situations like pandemics, outsourcing is forecasted for continued growth. As such, it is not only timely to explore new sourcing dimensions, such as outsourcing 2.0, crowdsourcing, and Industry 4.0 technologies but also to examine sustainable practices for the future of logistics in supply chains.

**Keywords**

Outsourcing · Contracting · Make-or-buy · Supply chain management · Outsourcing 2.0 · Crowdsourcing

## 1 Introduction

In today's business climate, there is an important question that encapsulates the drive for continuous improvement: "Is there any better way?" This question was what urged people like Thomas Edison and Albert Einstein to challenge the status quo to create a better solution (Vitasek et al., 2013). This question is exactly what drives companies to solve the complexity of globalization to meet the real needs of end customers. For example, the search for a better way has transformed the music industry from cassette tapes to CDs and MP3. Still, only finding a better way is not the answer that inventors and engineers are looking for.

Over the past three decades, supply chain management (SCM) has become important as companies have undergone significant changes. Growth and global expansion have become important to companies that have led to an unprecedented number of mergers and acquisitions across industries, around the world, and on each individual continent. Factors such as sustainability, emerging technologies (i.e., Industry 4.0), and unpredictable pandemics (i.e., SARS, MERS, and COVID-19) have forced companies to expand and/or shift their supply chain networks to significantly increase the level of new products/services to survive in such a turbulent environment (Maleki Far et al., 2017). All these changes greatly affect supply chain firms that have expanded or shifted their network globally and as a result require complex utilization of different modes of transportation such as sea, air, rail, and road (Rushton & Wlaker, 2007). Consequently, supply chains are becoming more complex (Akbari & Do, 2021). All this has had an extreme impact on outsourcing decisions and their processes. While supply chain firms have outsourced part of their activities, these changes in business operations and supply chains have led companies to search for more effective ways to manufacture and deliver their products/services around the world.

The goal of SCM is to ensure continuous improvement in business performance and competitiveness through the implementation of numerous strategies (Lee, 2021). Businesses are increasingly turning to strategies that could enable them to achieve a variety of competitive performances such as flexibility, responsiveness, price, quality, and dependability (Gunasekaran et al., 2015). However, companies do not have to do everything on their own; they can, instead, focus on their core competencies while outsourcing what external players can do *better*, *faster, cheaper, and of higher quality* (Somjai, 2017). Such realization has driven outsourcing into one of the most well-acknowledged strategies in the supply chain (Yang et al., 2021).

Regardless of the increase in practice and research, Lahiri et al. (2022) reiterate that findings in the literature with reference to the performance implications of outsourcing remain unclear. Of note, the studies of Bertrand (2011) and Kroes and Ghosh (2010) found positive correlations between business performance and outsourcing, while Broedner, Kinkel, and Lay (2009) and Weigelt (2009) suggested the opposite. Other works such as Bhalla, Sodhi, and Son (2008) found that outsourcing had no significant impact on business performance, while Rothaermel, Hitt, and Jobe (2006) highlighted moderated impact. The difference in results is that outsourcing can be beneficial and detrimental to supply chain operations depending on many factors presented in focal companies at this time. To understand deeper how outsourcing can influence a business's performance, it is necessary to revisit the fundamentals of outsourcing (Lahiri et al., 2022).

This chapter examines the existing outsourcing background that has attracted the interest of many researchers, students, and practitioners around the world. It provides a comprehensive review of background information and definition of outsourcing and SCM, alongside the major differences between outsourcing and strategic partnerships. The chapter will also examine existing outsourcing models, selection activities, the different considerations around its operationalization, and ultimately approaches toward successful outsourcing processes. It also includes discussions of past, current, and future concerns that exist in the process of outsourcing. The chapter will then conclude with the future directions and managerial implications regarding outsourcing.

## 2 Background

Companies use resources and recruit employees to achieve their goals and objectives (Kantarelis, 2007). In order to continue their operations and their existence, they need to focus on customer satisfaction and implementation of the best strategies, reduce overall costs, and seek reasonable returns for stakeholders (Akbari, 2013). As a result of their operations, it satisfies existing demands and creates new jobs which have a positive impact on the economy.

As stated by Porter (1980), the company's strategy leads it toward success or failure. Therefore, companies focusing on entering new markets should always implement strategies to be able to compete effectively against existing businesses.

## 2.1 Outsourcing in SCM

The SCM concept was first introduced in the early 1980s and was referred to as multi-echelon inventory management. Since then, the importance of SCM among companies has received significant attention owing to globalization. As a result, supply chains are becoming more reliable and at the same time complex and costly (König & Spinler, 2016).

The supply chain defines the entire process of transforming goods and services from raw materials to end-consumers and meeting the demands (Akbari & Hopkins, 2022). Supply chains support end-to-end production of goods and services and offer many opportunities, especially sustainable perspectives (Vargas et al., 2018). This situation includes numerous supply chain performance efforts to achieve competitive advantages (Lambert, 2008). SCM can be described as the planning and control of the entire process for an efficient stream of products/services, information, and finance (Chopra & Meindl, 2015) (see Fig. 1).

In more recent times, competition is increasingly being identified within the individual supply chain as opposed to previously, where it was seen between multiple supply chains (Christopher, 2016). Therefore, supply chain practitioners and senior executives increasingly recognized the importance of efficient supply chains toward developing their global competitiveness (Coyle et al., 2016).

Since 1990, outsourcing has become more important to practitioners and an important focus in international trade and globalization (Akbari, 2013). This importance was due to the successful outsourcing of information system (IS) by Eastman Kodak to IBM, DEC, and Businessland and Xerox (Claver et al., 2002). Over the years, however, outsourcing has developed to the point where the concept is no longer unique to IS but


**Fig. 1:** SCM . (Source: Adopted from Akbari (2018), Wisner, Tan, and Leong (2012))

to all functions of the supply chain such as procurement, logistics and distribution, HR (human resources), finance, and manufacturing, to name a few (Belcourt 2006; Dinu 2015; Sousa & Voss 2007). Indeed, outsourcing has become one of the most important global supply chain strategies (Miah et al., 2014).

An in-depth analysis of the literature revealed numerous different definitions of the concept of outsourcing, depending on the authors' perspectives. Outsourcing refers to the delegation or contracting out of noncore business processes to a third-party organization or specialist (Lysons & Farrington, 2012). Other authors such as Kotabe and Zhao (2002) considered outsourcing as the action of commissioning external parties to take over a particular process or function of the focal firm. Ellram and Billington (2001) defined outsourcing as the action of transferring existing business processes and functions to an external party. The work of Contractor et al. (2010) referred to outsourcing as the organizational restructuring of certain processes of a company in the country of origin or abroad to external parties.

Regardless of the definitions, it is crucial to understand that outsourcing is a strategic decision to omit an internal process or function. Hence, action on the part of procuring goods and services externally by businesses that lack capital and expertise could not be considered outsourcing since internalization was never a viable option in the first place (Akbari et al., 2020).

Outsourcing has become a fashionable business development method where markets are truly globalized (Christopher, 2016). Increasing use of outsourcing enables companies to improve their supply chain performance and lower operational costs. However, assessing the dimension of outsourcing markets and levels of practice can be extremely complex in different industries and countries. This complexity has led some companies to rethink their outsourcing decision to other forms of this strategy such as offshoring, nearshoring, or even moving toward reshoring or backshoring, especially since 2020 with the COVID-19 pandemic:

- ***Offshoring*** refers to the relocation of business functions to an external provider in another country (Oshri et al., 2013). These activities can be information technology (IT), finance, accounting, and HR. When the business function offshored to a center owned by the same company but different country, it is called *captive* (e.g., R&D). On the other hand, if the business function is offshored to a third-party provider in another country, it is called *offshore outsourcing*.
- ***Nearshoring*** refers to a relocation of a business function to an external provider which is in a neighboring low-wage country, and yet the provider is close in terms of distance, time zone differences, and cultural, economic, linguistic, political, and historical linkage (Carmel & Abbott, 2007). For example, American companies offshore their business function to Mexico. On the other hand, *far-shoring* is opposed to nearshoring.
- ***Reshoring*** or ***backshoring*** or ***inshoring*** refers to bringing back the business function or manufacturing. There are many drivers for this, such as logistics costs, product quality (i.e., damages, defects), losing intellectual property (IP), proximity to the consumers, ease of doing business in the main country, faster delivery, and less supply chain problems (Harrison & van Hoek, 2019).

## 2.2 Common Reasons and Benefits of Outsourcing

There are many reasons and benefits from outsourcing decisions in SCM. According to McCarthy (1996) and Beaumont and Sohal (2004), supply chain firms can benefit from the outsourcing strategy to focus on their core business, reduce staffing levels and management problems, and free up resources for other tasks. Its application also provides more flexibility and risk management, supports business process reengineering (BPR), reduces costs for short/long term, provides wider access to experts in the field, and ultimately supports implementation of new technologies.

On the other hand, companies that choose to outsource their business functions are always looking at increasing profits. Therefore, the *reasons for outsourcing* are categorized into six factors: (a) strategic, (b) management, (c) technology, (d) quality, (e) economic, and (f) other reasons (Assaf & Al-Nehmi, 2011; Brown & Wilson, 2005; Koh Ser Mui, 2003; Slack et al., 2015).

***Strategic Reasons***: Outsourcing decisions can drive the company to have *access to wider talent groups, knowledge, and expertise*. This situation occurs when companies cannot find the expertise in-house for the proposed task; therefore, this can be resolved by outsourcing it to an expert or outsourced supplier.

Also, outsourcing helps companies manage the risk efficiently and effectively. *Risk management* is defined as identifying, assessing, and classifying possible unwanted events to reduce, minimize, or eliminate the likelihood of risk with effective resource management (Douglas, 2009).

***Management Reasons***: There are several management reasons associated with outsourcing decisions. For example, it can help strengthen *capacity management.* During various times, companies can face high turnover and time management failure as well as low-quality products/services. This decision can lead the companies to overcome those challenges.

Furthermore, outsourcing decisions may assist the supply chain firms to improve all aspects of their business operations where issues might arise from in-house shortness, such as *shortage of experienced staff* especially dealing with innovative technologies and also *improving time to market*.

***Technology Reasons***: Access to in-house *operational expertise* can be another issue to address. Outsourcing can assist firms in solving this problem. Another important reason for outsourcing is the management of new or emerging technology skills. By working with third-party companies, outsourcing decisions can help achieve competitive advantages as well as avoid getting costly investments in technology and related training.

***Quality Reasons***: Executives of a company might decide to outsource a business function due to its low quality or low performance. This will help the companies *improve quality* and *improve performance* over time, achieving higher service levels. In some cases, companies are using third parties for a major technology transformation which could not be achieved without them. Therefore, *catalyst for change* and *increased flexibility* are another key reason for outsourcing decisions.

Another reason for outsourcing is *commodification* to standardize IT and business processes. This allows business access to services that were previously classified as exclusive domains.

***Economic Reasons***: Supply chain firms might consider outsourcing their business functions to *lower overall costs*. Outsourcing IT and logistics functions are the common decisions in this field to lower the overall cost. This can help with *cost restructuring* where companies shift their fixed cost to variable costs in their income statement considerations, leading toward more predictable variable costs for firms. Likewise, Deloitte (2020) has suggested that cost reduction is the most important factor in outsourcing decisions, where outsourcing has moved away from just cost reduction focus to other key goals. The recent impact of the COVID-19 pandemic has also been a major driver of outsourcing (Deloitte, 2020).

***Other Reasons***: There are many reasons to outsource. For example, accessing or expanding a *time zone* for a business function allows progress toward 24-hour daytime shifts and/or summers and winters for the southern and northern hemispheres. *Customer pressure* is another driver for these changes allowing value-added activities to benefit them and remedying any low-performance areas.

The service of outsourcing the *contract* itself, between the company and third-party provider, is another major change. Contracts are particularly important to both sides, and often companies do not have the expertise in-house to prepare these documents.

When considering the *benefits* of outsourcing, it should be noted that organizations could realize several gains owing to numerous factors and circumstances (Kremic et al., 2006). While it is unfeasible to describe every benefit of outsourcing, Kremic Tukel and Rom (2006) attested that numerous benefits are general enough that they could be observed across different organizations. For instance, some of the most common benefits of outsourcing are cost reduction (Somjai, 2017), allowing firms to focus on their core competencies (Smadi & Al-jawazneh, 2016), and access to new technology/global talent (Iqbal & Dad, 2013):

- *Cost reduction:* Reflecting the economic reasons above, cost reduction is one of the most cited (if not the most) important benefits for small- to medium-sized enterprises (SMEs) and large enterprises that choose to outsource their processes/functions (Lacity et al. cited in Asatiani, Penttinen, & Kumar, 2019). For example, in the cases of large enterprises, U.S. Steel (USS) and Alcoa Inc. both outsourced their production activities to other countries to reduce their operational costs (Smith & Krivacek, 2019). These companies understood the benefits outsourcing could bring to their bottom lines, thus exercising cost reduction through cheaper labor costs (Smith & Krivacek, 2019). Regarding the case of SMEs, Somjai (2017) examined the impact of outsourcing on 20 SMEs and noted that cost reduction was one of the most important benefits.
- *Concentrate on core competencies:* Outsourcing noncore business processes allows firms to allocate and focus their resources on their core competencies

(Akbari et al., 2020). The decision to select which function to outsource is challenging (Iqbal & Dad, 2013). Nonetheless, those that succeeded in this venture such as Dell (R&D as core focus) and Tesco (online shopping as core focus) were able to outsource noncore activities to external parties (Windrum et al., 2008).

- *Access to new technology:* Businesses are increasingly adapting outsourcing to gain access to technology that they do not hold in-house. For instance, Augustana Care Corporation used to manage the payroll process manually in-house, and the company discovered that this manual process was labor-intensive with the possibility of human error (Infinit-O Global, 2017). The firm decided to outsource this process to Minneapolis' Payroll Control Systems to gain access to new technology and streamline the process (Infinit-O Global, 2017).

## 2.3 Levels of Outsourcing

Outsourcing decisions can be considered at three distinct levels of operation: tactical, strategic, and transformational levels. Depending on operational needs, supply chain firms can decide at what level their functions are outsourced:

***Tactical outsourcing***: The first level or basic level of outsourcing is tactical or traditional outsourcing. A supply chain firm may choose tactical outsourcing to overcome a current or specific problem, as a quick approach to tackle problems. Consequently, tactical outsourcing creates competition between in-house business functions and external parties. The success of such a decision depends on the relationship between the company and third-party provider(s).

According to Mazzawi (2003), noncore business functions are at the heart of tactical outsourcing through the sharing of best practices. It is just a change between an internal business function and an external party that can perform the same task more efficiently.

***Strategic outsourcing***: Over time, companies realize the importance of long-term relationships and the superior values that can be gained. One of the main concerns always with outsourcing decisions is losing control; however, strategic outsourcing helps the managers gain more control over the business function rather than losing.

This level of outsourcing is looking for a long-term relationship with the intention of working with fewer third-party providers. Strategic outsourcing is an advanced method of maintaining the overall goal of companies and their core competencies.

**Transformational outsourcing**: The highest level of outsourcing is so called *transformational outsourcing* with the intention of revolutionizing the current business or responding to market shifts. At this level, companies have the potential to benefit from new market opportunities, accelerating the companies toward smarter, flexible, and innovative management. While tactical outsourcing is about quickly solving the existing problem, transformational outsourcing is about creating a competitive advantage.

## 2.4 Types of Outsourcing

In todays' business environment, it is particularly important to understand the distinct types of outsourcing. There are four major types of outsourcing (Oshri et al., 2013):

***Total insourcing***: In this type, supply chain firms maintain the in-house management function and keep a provision of almost 80% of business functions.

***Total outsourcing***: On the other hand, total outsourcing refers to a transfer of more than 80% of the business functions to an outside company, or it can be called *outsourcing in totality*. In this type of outsourcing, the company keeps the customer support and contract management in-house. At the same time, the level of required management, as well as the risks associated, is extremely high (Koh Ser Mui, 2003; Willcocks & Kern, 2001).

***Selective outsourcing***: This type of outsourcing refers to sourcing a preferred business function to an outsider, and usually between 20% and 80% of business functions stay in-house. The supply chain firms can involve one or more third-party companies in this process. Selective outsourcing is a widespread type of outsourcing and can overcome many of the problems associated with total outsourcing.

There are many advantages for selective outsourcing (Jones et al., 1998):

- The level of risks is significantly lower than total outsourcing.
- The possibility of establishing a partnership relationship with a third-party company is high.
- The level of control over the business functions is higher.

***Transitional outsourcing***: The decision to outsource can be a practice of temporary change due to any major transitions (i.e., implementation of new technology). In this case, the company will outsource the old system to a third party until the transition is completed. A good early example of this transitional outsourcing is the 3-year contract between Sun Microsystems and tech consultant CSC (Computer Sciences Corp.) worth US$ 27 million (Willcocks & Lacity, 1998).

## 2.5 Outsourcing Success Factors

The success of such a decision is especially important to supply chain firms to achieve competitive advantages in the current or future markets.

*Coming together is the beginning. Keeping together is progress. Working together is success.*
*– Henry Ford (1863–1947)*

In typical outsourcing cooperation, it is often difficult to work together for mutual success (Vitasek et al., 2013). Therefore, it is necessary for companies to understand the fundamentals of outsourcing. By doing so, it may assist the companies to advance toward success. These successes are classified as follows (Brown & Wilson, 2005; Koh Ser Mui, 2003):

***Prior need analysis***: The first step toward the outsourcing decision is to perform a thorough examination of current needs. The organizational goals, objectives, strategic vision, and business operations need to be assessed, analyzed, and classified accordingly. Any lack of knowledge from its existing situation can lead to a delay or failure of the outsourcing process.

***Choosing the right provider***: According to Kliem and Ludin (2000), one of the crucial steps of successful outsourcing is finding the right provider, where examination of their current status should be undertaken with caution and due diligence. It is particularly important to choose an external provider with a successful previous project history and their ability to respond to changes quickly.

***Enhancement of convention***: Drawing a strong agreement and contract is another success factor for consideration. The contract needs to have a clear and complete description of required services (i.e., service-level agreement), timeline, report arrangement, rates, and related costs. One consideration is to have a flexible agreement in place, in case of technological changes, although a clear roadmap for both business partners is still recommended. Performance evaluation is another crucial factor in any contract. As stated by Gonzalez, Gasco, and Llopis (2005), every company *lives or dies* with a written contract, not a verbal promise.

***Open communication***: This is a very crucial step for the success of outsourcing processes. Everyone in the organization should be aware of having open and transparent communication with the affected individuals or groups. This will, certainly, reduce the employees' fear of losing their jobs. In fact, ongoing and continuous management of relationships and communications is required. Open communication will resolve any foreseeable dilemmas and allow modification to achieve a successful relationship between the company and third-party providers.

***Support from top management***: Developing strategic goals is the top management responsibility; however, getting support from them is also beneficial. Top management is responsible for initiating the goals and objectives, supporting the third-party provider in achieving these, and to allocate resources accordingly. Many studies around the world indicate that top management support is the highest-ranking factor leading toward the success of outsourcing.

***Others***: By looking at the existing literature in the outsourcing area, these five factors were the most influential elements for success. Other factors include transparency, rewards and penalties, capability identification, and distinguishing levels of qualified and skilled in-house employees.

The major outsourcing characteristics are summarized in Table 1:

**Table 1** Outsourcing characteristics

| | |
|---|---|
| ***Reasons for outsourcing*** | Cost saving<br>Cost restructuring<br>Quality improvement<br>Performance improvement<br>Operational expertise<br>Access to wider knowledge, experience, and technology<br>Capacity management<br>Contracts and agreements<br>Catalyst for change<br>Commodification<br>Risk management<br>Time zone<br>Customer pressure |
| ***Levels of outsourcing*** | Tactical Level<br>Strategic Level<br>Transformational Level |
| ***Types of outsourcing*** | Total/full outsourcing<br>Selective outsourcing<br>Transitional outsourcing |
| ***Success factors*** | Prior need analysis to identifying the intended business function to outsource<br>Established strategic vision and plan<br>Establishing financial planning and analysis<br>Top management supports at all levels<br>Establish appropriate selection criteria and attention to the third-party strength (i.e., ISO 9001)<br>Third-party provider understands the company's vision and plan and the requirements from the customer<br>Appropriate resource allocations<br>Ongoing and continuous open communication with employees and third-party providers<br>Drawn up a proper contract and establishing strong relationships<br>Well-defined terms and conditions in contract/agreement<br>Attention to employees' concerns<br>Performance measurement and continuous improvement |

# 3 Current Practice

## 3.1 Logistics Outsourcing

In today's business climate, as competition intensifies, the organization's primary strategic focus is on core competencies (Christopher, 2016). As a result, there is significant worldwide growth in logistics outsourcing or third-party logistics (de Grahl, 2011). Outsourcing logistics functions to other external logistics service providers (LSP) have become a widespread practice in the supply chain (König & Spinler, 2016). In SCM, outsourcing usually refers to sourcing out warehousing and transportation functions or so-called logistics outsourcing or third-party logistics

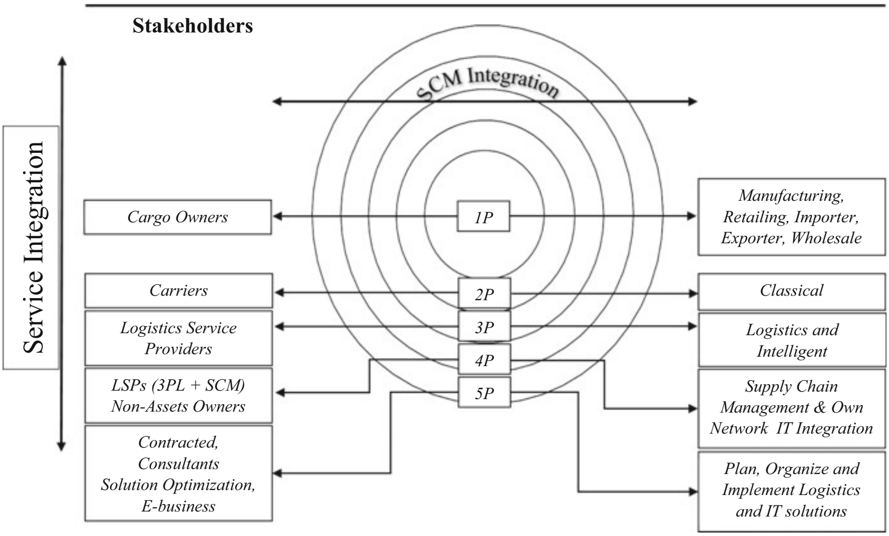


**Fig. 2** Category of service providers. (Source: Adapted from Akbari, Ha, and Majo (2020); Farahani et al. (2011))

(TPL/3PL) (Akbari, 2018). LSP can be categorized into five levels (1PL, 2PL, 3PL, 4PL, and 5PL) (see Fig. 2) (Ciemcioch, 2018):

***First-party logistics (1PL)***: Or sometimes it refers to in-house logistics that utilize their own vehicles, warehouses, and facilities and do not rely on external firms (Odnokonnaya, 2017).

***Second-party logistics (2PL)***: Refers to carriers who specialize in one part of the supply chain, such as transportation, warehousing, etc. (Rodrigue et al., 2016).

***Third-party logistics (3PL)***: The service providers who offer services beyond 2PLs, such as add-value services (i.e., packaging, labeling, bundling/unbundling, reverse logistics, and repair services) (Beamberlin, 2018).

***Fourth-party logistics (4PL)***: Independent firms that do not have any assets and utilize the services by subcontracting to other LSPs (Saglietto, 2013).

***Fifth-party logistics (5PL)***: Also known as *logistics aggregators* by looking into organizing and implementing logistics solutions/technologies for multiple customers (Matlack Leasing, 2019). A new model that utilizes technologies with 3PLs and 4PLs to oversee the entire supply chain (Matlack Leasing, 2019).

Logistics outsourcing is a fairly common form of purchase or manufacturing strategy. A good example is Apple, where they outsource all manufacturing to external companies in East Asia (Scott, Lundgren, & Thompson, 2018). Therefore, Apple acts as integrator of supply chain best practices to its partners (Simchi-Levi, 2013).

Nonetheless, there remain some concerns about outsourcing decisions and their impact on business functions. For example, outsourcing last-mile delivery, which is one of the most common forms of outsourcing (Third-Party Logistics Study, 2022), means losing a direct customer interface. This reduced level of customer contact may impact the relationship.

## 3.2 Risks of Outsourcing

With the rise in competitive pressures across the globe, firms are focusing on their core competencies and letting external players take care of noncore processes/functions. As such, in the last few decades, outsourcing has been a common observation in every industry. The reason is that outsourcing could engender numerous significant benefits to a business (Kalinzi, 2016). Even so, firms should also be aware of the risks that entail with the decisions to outsource their processes/functions to external parties (Yazdani et al., 2021). In that vein, this section is dedicated to examining the risks of outsourcing in general, where later sections will focus on transportation outsourcing in specific.

### Risks of Outsourcing

Some of the most frequently observed risks of outsourcing are the creation of potential competitors (Lim & Tan, 2010), loss of control (Lacity et al., 2010), and poor performance of the vendors (McMillan, 2010):

- *Creation of potential competitors:* When implementing the outsourcing strategy, companies run a risk of their chosen vendors turning into their competitors (Lim & Tan, 2010). This can be observed in the period of the 1980s where several firms such as Goldstar, Samsung, Kia, and Daewoo built up their product leadership in their respective areas through their early OEM-supply contracts with Western companies (Prahalad & Hamel, cited in Lim, & Tan, 2010). Another more recent case that suffered from this potential is Apple; their outsourcing strategy has unintentionally created two major competitors in Samsung and Foxconn (Griffin, 2015).
- *Loss of control:* One of the biggest risks of outsourcing faced by companies is the loss of control over the outsourced functions (Tayauova, 2012). In the case of the Royal Bank of Scotland and their unnamed IT vendor (Peston, 2012), wherein 2012, the bank experienced a crash in their banking software system which rendered both their individual and business customers unable to process their transactions (Krigsman, 2012). As the bank had handed the control of the system over to their vendor through outsourcing, it was at the mercy of the IT vendor. Unfortunately for the bank, the incident lasted for nearly a week, causing irreversible financial and reputational damage (Magenest, 2021).
- *Poor performance of the vendors:* Another risk of outsourcing is the failure to live up to the agreed expectation of the contracted vendors (Best Practice Group, 2019). This risk could be observed in the case of KFC (in the UK) and their logistics vendors (Uddin, 2020). In October 2017, KFC decided to switch from their long-term specialist Bidvest to other 3PLs such as DHL and QSL (Henderson, 2020). Despite the promise of improved performance, these 3PLs failed to

deliver the promised expectation, forcing more than 560 of KFC's 900 UK restaurants to close down due to the lack of supply (Pooley, 2018). This case is a prime example of how a business could be impacted due to the poor performance of the selected vendors.

#### Transportation Outsourcing Risks

Numerous companies have foregone self-sufficiency and, instead, adopted specialization strategies as a measure to ensure higher levels of competitiveness (Baeza et al., 2019). In that vein, outsourcing the transportation function is one of the frequent decisions made by businesses, choosing to leave transportation function to the specialists in order to leverage their expertise and reduce operational costs (Baeza et al., 2019). The work of Moeen et al. (cited in Mills & Opoku-Akyea, 2019) defined transportation outsourcing as an entity engaged by a service provider to perform transport service.

Despite transportation outsourcing providing potential benefits to the firms, this delegation is not without its risks (Mills & Opoku-Akyea, 2019). An interesting observation is that there are numerous papers that focus on the benefits of logistics outsourcing, yet the body of literature concerning the risks of logistics outsourcing remains scarce (Govindan & Chaudhuri, 2016). This gap is even more obvious if we specifically focus on transportation outsourcing risks (Stojanović & Aas, 2015). In light of this, Stojanović and Aas (2015) strived to fill in the gap by composing a list of transportation outsourcing risks and categorizing them into *external* and *internal* dimensions. According to Cakić (cited in Stojanović & Aas, 2015), external risks are the risks that originated from transport demand uncertainty, whereas internal risks are aligned to provider-related uncertainty. To illustrate, the risks of transportation outsourcing are condensed into tabular form with cited references below (see Table 2).

### 3.3 Statistical Tools and Methods

There has been a proliferation of methodologies that incorporate data-driven analysis and decision-making in light of the growing complexity in SCM. These facilitate not only better understanding and informed decision-making across the different channels but essentially reflect the changing dynamics and the move toward technological innovations as part of Industry 4.0. Perçin (2019) proposed a robust multi-criteria decision-making (MCDM) tool to solve the problems in selecting outsourcing providers, where Erdoğan and Kaya (2018) proposed a multi-criteria decision-making methodology based on the hesitant fuzzy enveloped Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to identify the best outsourcing providers. Uygun, Kaçamak, and Kahraman (2015) adopted integrated decision-making trial and evaluation laboratory (DEMATEL) and fuzzy analytic network process (FANP) techniques for selecting outsourcing service providers in telecommunication.

**Table 2** Internal/external transportation outsourcing risks

| External transportation outsourcing risks | Internal transportation outsourcing risks |
|---|---|
| The inability to adapt and configure resources to satisfy changing market needs due to the lack of flexibility (Harland et al., 2003) | Risks related to the complexity of the supply chains such as strategic risks, operational risks, supply risks, customer risks, asset impairment risks, and reputational risks (Harland et al., 2003) |
| The lack of flexibility for shifting business environments and fluctuating demands for products, services, and technologies (Greaver & Greaver II, 1999) | Failure to manage outsourcing relationships with the chosen vendors (Harland et al., 2005) |
| Demand unpredictability and amplification of related risks (Potter & Lalwani, 2008) | Failure to communicate and design appropriate service-level agreements with the outsource partner (Harland et al., 2005) |
| The variability in currency exchange rate and the use of nontariff barriers (Chang et al., 2015) | The lack of own competency in making outsourcing decisions (Solakivi et al., 2013) |
| The stability of government, social, and legal systems as well as the differences in social, cultural, and legalities of different countries (Schniederjans & Zuckweiler, 2004) | Relationship risks such as power asymmetry, vendor opportunism, and the lack of shared goals (Tsai et al., 2012) |
| | The risks of inefficient management, loss of control of the 3PL providers, loss of logistics innovative capability, and increased dependence on the service providers (Tsai et al., 2012) |
| | Poor performance of the chosen 3PL providers (Best Practice Group, 2019) |

In terms of enhancements to the process, Sinkovics, Kuivalainen, and Roath (2018) analyze the value of co-creation between manufacturing and third-party logistics providers to understand the level of customer engagement with companies. Wang et al. (2019) studied the use of the artificial neural network (ANN) and the shuffled frog-leaping algorithm (SFLA) to promote cloud-based production efficiency. Song (2019) adopted the analytic hierarchy process (AHP) to rank several substantial benchmarks for establishing new outsourcing relationships. Razi (2017) used the Kohonen network and slack-based measures for selecting outsourcing activities.

There is also a need to develop new further models in outsourcing focusing on new technologies and emergent sustainability issues. For example, Rezaeisaray, Ebrahimnejad, and Khalili-Damghani (2016) adopted the hybrid MCDM to offer an innovative approach to selecting new outsourcing suppliers. Cai et al. (2020) proposed an emergy-based evaluation of sustainability to improve resource utilization and its efficiency.

Ultimately, these are just some examples of the growing range of statistical approaches to outsourcing in SCM, with increasing innovations and new tools being constantly under development.

## 4 Emergent Concerns and Future Directions

The research on outsourcing decisions has raised worldwide attention among practitioners and researchers. Regarding optimization of outsourcing production, McCarthy and Anagnostou (2004) proposed outsourcing measures to improve economic benefits by reconfiguring the organization and cutting transaction costs (Moosavirad et al., 2014), as well as using input-output analysis for quantifying impacts of the environment, economy, and society, as a guide to managers. Similarly, a risk evaluation framework for outsourcing e-procurement services was proposed by Ramkumar, Schoenherr, and Jenamani (2016) by using strengths, weaknesses, opportunities, and threats (SWOT Analysis). Likewise, Zhang's (2015) study helped develop a dynamic programming-based algorithm to consider many outsourcing dimensions.

Further, there are several directions for future research considering outsourcing decisions in SCM:

**Outsourcing 2.0**: There are several explanations for outsourcing 2.0. Frank Casale (2007) calls outsourcing 2.0 an advanced way to manage relationships with greater collaboration, collective stability, and efficient communication, resulting in better access to supply chain information. Other terms are included: strategic impact, mature relationship, multi-sourcing, multi-language, risk-sharing, short from cost and efficiency toward value and innovation, business process outsourcing (BPO), and eventually shifting toward knowledge process outsourcing. Vitasek, Ledyard, and Manrodt (2013) call this *vested outsourcing* where relationships become the core principle of business creation and suppliers and companies *vested* in each other's successes.

Linden, Schmidt, and Rosenkranz (2017) linked outsourcing 2.0 to IT outsourcing (ITO) by introducing a relationship process model in five phases (see Fig. 3):

- ***First phase*** – initiating and evaluating *outsourcing strategy* to satisfy business requirements

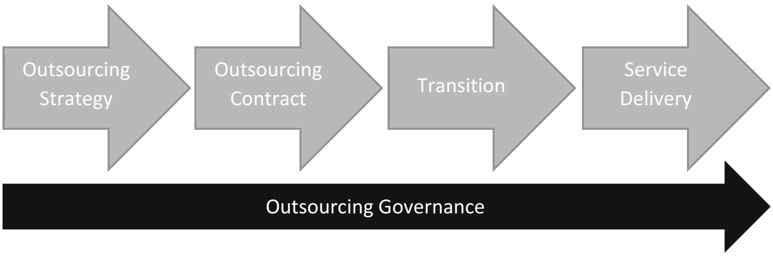


**Fig. 3** ITO relationship process model. (Source: Adapted from Linden, Schmidt, and Rosenkranz (2017))

- ***Second phase*** – the establishment of the necessary outsourcing services and the appropriate selection of suppliers, which leads to the development of *outsourcing contracts*
- ***Third phase*** – the *transition* of selected services to the supplier and the establishment of delivery capabilities
- ***Fourth phase*** – maintaining the value of outsourced *service delivery* between the company and the supplier
- ***Fifth phase*** – considered as the comprehensive phase of the entire process, known as *outsourcing governance* which allows joint leadership to propose effective decisions to any necessary business changes

Furthermore, Kaushik (2009) states the adoption of web 2.0 into offshoring outsourcing 2.0 by (a) offshore as a platform; (b) syndicating global delivery networks; (c) stronger user experience, success as a measure and human relationships and interactions; and co-creation as a way of engagement.

**Crowdsourcing**: Since the significant impact from COVID-19, crowdsourcing has attracted more attention from supply chain firms over traditional work environments. Crowdsourcing is defined as a strategy to allocate task(s) to an outside member (member of crowd) via an open call to harness their expertise, knowledge, and skills (Nguyen et al., 2016). This strategy lifts the boundaries of the traditional working environment to an open call for performing tasks (Howe, 2008). Among the adoption cases around the world, crowdsourcing by the New Zealand government is the most interesting (Nguyen, 2019). In 2015, the government established a $25.7 million project called *Flag Consideration Project*. This project looked at the future flag for New Zealand by offering citizens an opportunity to design their future flag. More than 10,000 designs were received in 3 months, and four were shortlisted. Through two rounds of referendums, more than two million New Zealand citizens voted for the current flag to remain.

Crowdsourcing presents a promising future for supply chain firms to solve their complex problems, with many trends shaping future applications:

- *Decentralization* is a way to effectively set up a business by looking at the future of work after COVID-19. Disseminating the tasks to lower-level and mid-level management can help top management focus more on the important or critical tasks. Many FinTech companies have adopted such a model, and, in fact, Blockchain uses decentralized technology, as well as Uber and Lyft.
- *User-generated content* can be another form of crowdsourcing to boost brand awareness. Supply chain forums can use this option to invite audiences to create branded content for them and share these on social media using hashtags with businesses monitoring them (Kache & Seuring, 2017).
- *Co-creation* allows supply chain companies to use their network's skills, connections, and resources. This is significantly different from traditional R&D and given the ever-changing and dynamic nature of technologies provides significant opportunities. Through providing customers with a voice, co-creation can attract customers to support the development of different business models and products.

**Emerging Technology (Industry 4.0)**: In today's climate, technologies are changing so quickly, and digital revolutions such as Industry 4.0 (I4.0) are changing global business models (Arlbjørn et al., 2011). Emerging I4.0 is the key driver toward such a transformation in supply chains (Akbari et al., 2022). One of the main outsourcing activities in supply chains is logistics and transportation to 3PLs. With the use of emerging I4.0 technologies, such as machine learning (ML) and artificial intelligence (AI), the next trend is focusing on a new generation of 3PL, 4PL, and 5PL.

6PL is a fully integrated and automated supply chain through the use of ML and monitored/controlled by AI. This is still at the theoretical stage, but with the current prospects of how AI can affect the entire SCM, this can have a significant impact on the future of logistics outsourcing (see Fig. 4).

Since sustainability has become a global concern, technology and other sustainable innovations are growing significantly to achieve the 17 Sustainable Development Goals (SDGs) by the United Nations.

**Sustainability**: Supply chains are facing increasing pressure from stakeholders to operate sustainably, taking into account the environment, economy, and society (Kane et al., 2021). However, many firms might not have the capability or expertise to implement these initiatives, so they would outsource sustainability efforts to outside organizations. Outsourcing companies acknowledge the importance of being sustainable to stay competitive in such a dynamic global market because supply chain companies realize that sustainability cannot be achieved solely.

There are many examples of such practices around the world. For example, in the case of Apple, stakeholders using social media and other news outlets in 2012 called Apple to action on improving working conditions in their suppliers' plants, such as Foxconn (Mendoza & Clemen, 2013). In the same year, Apple partnered with the Fair Labor Association (FLA) for a volunteer audit. This case shows how important sustainability is for the stakeholders of companies. Walmart, Nike, and Adidas are other examples of manufacturing companies working to improve their sustainability performances (Plambeck et al., 2012).

Another example is the incorporation of environmental measures which adds more complexity to the global supply chain (Yang et al., 2021). Dissimilar regulatory environmental policies such as carbon tax are one source of this

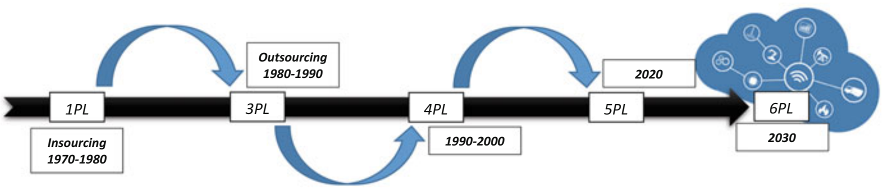


**Fig. 4** Advancement of party logistics. (Source: Adapted from Gruchmann, Melkonyan, and Krumme (2018))

complexity. Governments impose carbon taxes on companies to compensate for every ton of greenhouse gas they release. Finland was the first country to ratify carbon tax in 1990. Therefore, when manufacturers face higher local carbon tax, they choose to reduce their own production and outsource the function. As a result, the carbon tax will reduce the home countries' emissions. In general, customer awareness of sustainable practices has a better positive impact on the reduction of emissions (Yang et al., 2021). Governments should therefore take strategic steps to introduce solid measures such as low-carbon propaganda to raise customer awareness.

## 5 Managerial Implications

Practitioners and managers who want to improve the performance of their supply chain companies should always look for more viable strategies such as outsourcing. Well-integrated planning and efficient implementation of outsourcing initiatives have a positive impact on the financial and nonfinancial performance of companies. To achieve this result, companies must weigh the trade-offs between outsourcing rather than insourcing and the related direct and indirect costs in having these functions performed by third-party providers.

The first step in outsourcing is for managers to identify noncore activities and start outsourcing these activities to third-party providers, being careful to retain core activities internally. Clear knowledge of this will ensure a strong focus on the core competencies while outsourcing noncore activities to potentially specialist organizations.

The second step is to understand the differences between manufacturing and service activities, allowing greater success in the outsourcing strategy. Finally, given the globalized nature of logistics, contracting international or multinational providers has an associated advantage over domestic providers. Signing contracts and maintaining a long-term relationship with international service providers can be less complex and provide more consistency than domestic providers. However, due to the impact of the COVID-19 situation, it is particularly important that managers thoroughly exercise due diligence on the resourcing of their suppliers and continuously monitor them during the life of their contracts.

It is vital for supply chain firms to recognize an effective sourcing decision to lead them toward achieving their optimum performance level (Cohen & Russel, 2013). In order to gain the maximum achievement, the outsourcing process can be categorized into seven steps (see Fig. 5) (Schniederjans, et al., 2005).

Once the decision to outsource is made and agreement and goals are developed, the next step is to select the supplier. The decision to outsource noncritical functions is likely to be straightforward; however, this process for critical functions is complex and can impact the supply chain firms' competitive advantage. There should be multiple criteria in consideration for selecting suppliers. According to Wisner, Tan, and Leong (2012), there are factors to consider selecting suppliers:

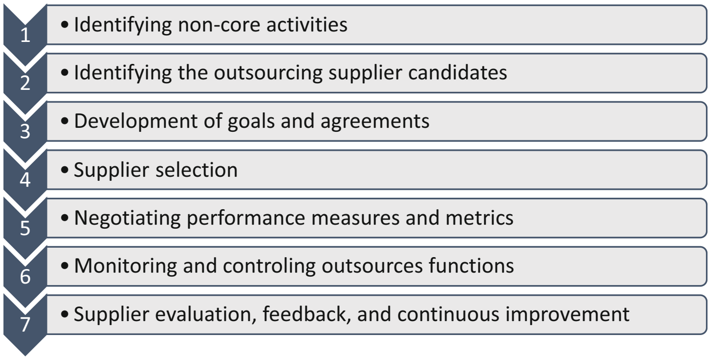


**Fig. 5** Outsourcing process overview. (Source: Adopted from Schniederjans et al. (2005))

– Selected suppliers should be able to *use technologies* to produce goods or perform services at a reasonable cost to improve the competitive advantage of the company.
– With the current changes in business operations and rapidly evolving technologies, it is especially important that suppliers are *willing to share the technologies and information*.
– The *quality* of the product or service should be consistent and at the highest level, as it has a direct impact on the final goods or service for the customer.
– Although the unit price is not the only criterion for selecting suppliers, *total cost of ownership (TCO)* is crucial (i.e., inventory costs, quality costs, technology costs, logistical costs, and maintenance costs).
– Supplier *reliability* is another key factor, such as their financial stability, lead time, etc.
– An easy *ordering system* and its effectiveness can affect companies by reducing cycle times and/or inventory costs.
– There should be considerations regarding supplier *capacity* to fulfill the orders. It is also important to recognize the ability of a third-party provider to fulfill large orders if necessary.
– Capability to *facilitate communication* between the parties is another key factor for supplier selection.
– *Geographic location* can have a significant impact on lead time or transportation costs.

Lastly, managers who are concentrating on such decisions should be aware that outsourcing efficiency and effectiveness requires appropriate time to be phased in successfully. Other crucial factors that managers should consider are the location of the providers and their infrastructure, along with potential cultural and financial differences (Lahiri et al., 2022). In sum, successful outsourcing depends on different business cases, where supply chain firms should only consider outsourcing their business functions once they are completely aware of the potential and ramifications of its undertaking.

## 6 Summary and Conclusion

In recent years, competition between supply chains has gradually attracted more attention to uncover new ways to find resources and strengthen their global competitive advantages (Lee, 2021). This means that companies will pay more attention to outsourcing strategies that can strengthen their core competencies. In other words, such efforts are needed to improve supply chain efficiency and find new opportunities by exploring different outsourcing methods.

This chapter summarizes the role of outsourcing in SCM by looking into various aspects and signposts the many dimensions for consideration: reasons to outsource, types and levels of outsourcing, success factors, benefits and risks, and supplier selection steps.

Further, particular attention was given to emerging concerns and future directions, such as outsourcing 2.0, crowdsourcing, emerging I4.0 technologies, and their impact on 3PLs, as well as the implementation of sustainable practices. Moreover, there are certain aspects supply chain firms should consider when selecting suppliers, namely, its crucial and time-consuming nature, understanding of partners' capabilities, and the legal implications that remain a persistent necessity if things do not go as planned.

Finally, as we approach a new normal and post-COVID-19 recovery period, it is critical for supply chain firms to comprehend the various outsourcing avenues and required management methods to navigate its risks and hurdles toward achieving its inherent benefits.

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# Reconfiguring the Global Supply Chain: Reshoring

Li Wan, Guido Orzes, and Guido Nassimbeni

## Contents



**Abstract**

Reshoring – the relocation of insourced or outsourced manufacturing activities back to the home-country – has become a topical issue in the scholarly, management, and policy debate. The political and economic changes in the global

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chessboard, the decrease in cost advantages of some countries, the growing awareness of the "total cost" of offshoring, and the supply shortages experienced during the covid-19 pandemic have caused many companies to rethink their global supply chain configuration choices. The aim of this chapter is to shed light on the reshoring phenomenon by identifying the main trends, presenting some exemplary cases, discussing motivations and determinants, and explaining the decision-making and implementation processes. This chapter can support managers in global supply chain reconfiguration decisions and policy makers in designing suitable interventions at this respect.

**Keywords**

Reshoring · Backshoring · Back-reshoring · Global supply chain · Relocation of second degree

## 1 Introduction

The political and economic changes in the global chessboard, the thinning of location advantages in some low-cost countries, the growing awareness of the *total cost* of offshoring, and recent supply chain disruptions caused by the covid-19 pandemics have led many companies to reconfigure their (global) supply chains. In some cases, they are relocating offshored operations back to their home country (reshoring) or to countries closer to their headquarters (nearshoring).

This shift is evident in the case of General Electric (GE) who relocated a portion of its appliance manufacturing, including water refrigerators, washing machines, and dryers, from China to Louisville, Kentucky (US) (McIntyre, 2017). Other well-known companies, such as Bosch and Philips, also applied relocation strategies in the early 2010s (The Economist, 2012). This phenomenon is referred to as *reshoring*.

**What Is Reshoring?** Reshoring has recently become a buzzword. In broad terms, reshoring is understood as "moving manufacturing back to the country of [the firm's] parent company" (Ellram, 2013). It is important to note that other labels have also been used for this phenomenon – such as back-shoring, back-reshoring. For instance, Kinkel and Maloca (2009) pointed out that moving manufacturing capacities from foreign locations back to the domestic location is quite a common event; they term it as "backshoring."

The reshoring phenomenon has generated a variety of terms and definitions, which consider different dimensions. The first academic definition of back-shoring – "*the geographic relocation of a functional, value creating operation from a location abroad back to the domestic country of the company*" – was proposed by Holz (2009). Later on, Gray et al. (2013) defined reshoring as a location decision and recognized that four possible types of reshoring exist (based on the ownership mode adopted abroad and in the home country): (a) in-house reshoring, (b) reshoring for outsourcing, (c) reshoring for insourcing, and (d) outsourced reshoring. Similarly, Fratocchi et al. (2014) defined reshoring as "*a voluntary corporate strategy regarding the home country's partial or total relocation of (in-sourced or out-sourced) production*" (Fratocchi et al., 2014, p. 56), clarifying "what" production relocation to the home country is and "which forms" it can take.

The reshoring conceptualization is still evolving; our hope is that the aforementioned definitions advance the understanding of reshoring and reduce ambiguities. While we acknowledge the existence of these alternative labels, for the sake of clarity we use only the term *reshoring* in this chapter and adopt the definition provided by Fratocchi et al. (2014).

**How Important Is Reshoring?** The economic, social, and policy relevance of reshoring has been recognized by policymakers, managers, and scholars. From a global supply chain perspective, reshoring requires a firm to develop the organizational capabilities to geographically relocate specific tasks and coordinate dispersed production networks (Hernández & Pedersen, 2017). The emergence of reshoring and its growth are changing the outlook of the global value chains (GVCs) (Gereffi et al., 2005) and global production networks (GPNs) (Coe et al., 2017), which in turn affects both country and company development (Gereffi, 2019).

It has been widely recognized that the relocation of manufacturing activities plays a fundamental role for country employment and economic prosperity (Vanchan et al., 2018). Increasing employment in developed countries is a striking example. According to the *Reshoring Initiative Report* (2020), for the first time, reshoring created more US jobs in manufacturing than foreign direct investment (FDI) did (i.e., 69,000 reshored jobs, +45% with respect to 2019). After experiencing the supply shortages of personal protective equipment (PPE) in the initial phases of the Covid-19 pandemic – as well as scarcity of many other components in the subsequent phases, such as chips and metals – the role of reshoring in building a smart and resilient supply chain has gained prominence.

From the individual firm's point of view, reshoring strategy empowers the orchestration of the value chain or supply chain on a global scale to gain competitive advantage and to achieve strategic objectives including cost reduction, quality improvement, and performance optimization (e.g., Brandon-Jones et al., 2017; Johansson & Olhager, 2018). For example, reshoring can drastically reduce outbound delivery and shipping costs, resulting in significant savings. Reshoring can help companies to reposition their products and to obtain a premium price – because of the product origin such as the "made-in" effect.

Reshoring holds a considerable potential to create value as an international configuration choice. Companies constantly reshape their global value chains, such as with cooperation and supply chain integration, and reconsider their location choices to maintain global competitiveness. During these reconfiguration processes, reshoring companies could further explore and exploit their location advantage to strategically adapt to the local and global business environment.

An increasing number of studies have investigated the reshoring phenomenon; we now provide a comprehensive overview of reshoring. Prominent and intriguing questions on reshoring include the following: What are the reasons behind the reshoring decision? How will reshoring trend evolve? What is the process followed by companies to take reshoring decisions and implement them? The aim of this chapter is therefore to offer insights into an emerging debate on reshoring and to provide empirical evidence on the phenomenon. Addressing these questions can help support managers in taking (global) supply chain reconfiguration decisions and policy makers in developing suitable interventions.

The remainder of this chapter is structured as follows. We first present the reshoring trends and provide some exemplary cases. We then analyze the reshoring motivations in detail. We illustrate the decision-making and implementation process. We discuss key aspects of reshoring decisions (i.e., reshoring propensity, timing, and entry mode). Finally, we provide some concluding remarks.

## 2 Reshoring Trends and Exemplary Cases

Data on reshoring, in particular primary data, are still quite limited. The reasons for this scarcity are manifold. For instance, Hennart et al. (2002) note that the revision of location decisions is generally perceived as a negative experience, making practitioners reluctant to discuss the topic. Despite the fact that identifying the whole population of reshoring projects at the global-level (or country-) level is difficult, existing studies, reports, and publications have shed some light on the reshoring trend, particularly in the USA and Europe.

Some companies and organizations have created their own metrics and collected evidence from secondary economic data or surveys. This can be seen in the case of the Inbound Logistics (2021) publication, which reported that "*ThomasNet has been tracking supply chain shifts since the pandemic began, and their data shows that the increased interest in reshoring is accelerating. In February 2020, 54% of survey respondents said they wanted to bring production back to North America, but as of July, 69% were actively looking to do so.*"

Reshoring is a global phenomenon; however, based on the published data, it is evident that it affects mainly US and European companies. We now illustrate reshoring trends of US and European companies and present some exemplary cases.

### 2.1 Reshoring Trends of US Companies

There are two relevant databases which collected large-scale data on reshoring cases and their implications, providing prominent source of data and analyses: the Reshoring Initiative (https://www.reshorenow.org/) and the European Reshoring Monitor (ERM – https://reshoring.eurofound.europa.eu/). The former is focused on the USA, while the latter on Europe.

The Reshoring Initiative database was founded in early 2010, to help manufacturers realize that North America is an advantageous location to produce goods and the local production in some cases reducing the total cost of ownership (Reshoring Initiative website). The Reshoring Initiative tracks data on reshoring announcements by US headquartered companies and FDI by foreign companies that have moved production or sourcing activities to the USA. The database is drawn primarily from published media articles and includes three categories of relocation choices: reshoring, new FDI, and kept from offshoring (KFO).

According to the Reshoring Initiative 2020 Data Report, reshoring will continue to be key to US manufacturing and economic recovery in 2022 and beyond. It is interesting to see that cumulated reshored jobs (including FDI) rose in 2020 more than in 2019 (Fig. 1), suggesting that companies acknowledge the need to shorten supply chains and produce goods at home, despite the covid-19 pandemic.

Reshoring and FDI job announcements for 2020 were 160,649, bringing the total jobs announced since 2010 to over 1 million (1,057,054). Notably, reshoring surged to a record high in 2020, with 109,000 new jobs announced; furthermore, reshoring exceeded FDI by nearly 100% (Fig. 2). Additionally, 1484 companies reporting new reshoring and FDI have been noted, which is also the highest in the period 2010–2020. Although there are numerous negative business consequences from the covid-19 pandemics, the Reshoring Initiative shows that companies have been more inclined to reshore. Accordingly, US reshoring outpaced FDI for the first time since 2013.

The Reshoring Initiative also provides a thorough analysis of reshoring and FDI trends by taking industry and host country into consideration. The report states that the most affected industries include transportation equipment, medical equipment and supplies, chemicals, computer and electronic products, and electrical equipment and appliances. US companies reshoring from China are in first position, with 46% of reshoring cases from 2010 to 2020. The rate of reshoring from China did drop in

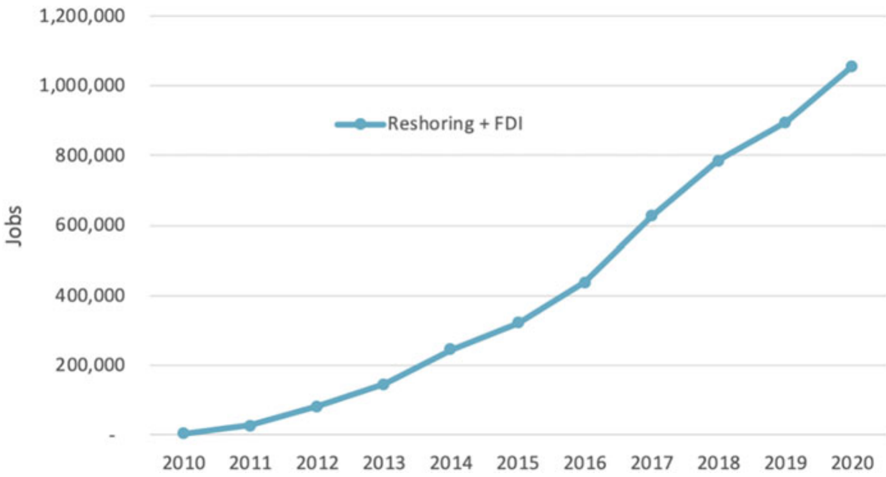


**Fig. 1** Jobs announced, reshoring + FDI, Cumulative 2010–2020. (Source: Reshoring Initiative 2020 Data Report. © Reshoring Initiative 2020, reproduced with permission)

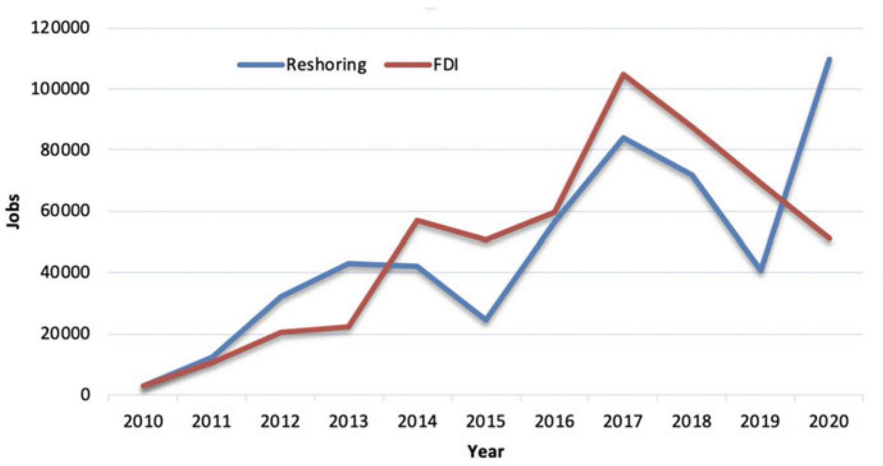


**Fig. 2** Job announcements by year, reshoring, and FDI, 2010–2020. (Source: Reshoring Initiative 2020 Data Report. © Reshoring Initiative 2020, reproduced with permission)

2019 and 2020. Other countries include Mexico, Canada, India, and Japan – accounting for 21%, 10%, 6%, and 5%, respectively.[1]

## 2.2 Reshoring Trends of European Reshoring

The European Reshoring Monitor (ERM) database was founded in 2015. ERM is a collaborative project between the EU agency Eurofound and a consortium of Italian universities (Bologna, Catania, L'Aquila, and Udine). As part of a multiannual research project on the "Future of manufacturing in Europe," ERM aims to identify, analyze, and summarize evidence on the reshoring of manufacturing and other value-chain activities to the EU (European Reshoring Monitor website) from 2014 onward. ERM monitors three main areas: media monitoring of reshoring cases, relevant research articles and reports, and policy initiatives. A research report entitled "Reshoring in Europe Overview 2015–2018" uses ERM – hereinafter called ERM 2018 report. This report presents and analyses evidence concerning the reshoring of manufacturing and other value chain activities in the EU and European Free Trade Association (EFTA) countries.

By analyzing the 253 reshoring cases collected by ERM up to the end of December 2018, the ERM report identifies reshoring trends, country of reshoring – home country versus other EU country – firm size, industry, reshoring motivations, off-shoring countries, and employment impact.

Accordingly, three distinctive reshoring strategies are included in ERM: *back-reshoring*, *near-reshoring*, and *other reshoring strategies*. As shown in Fig. 3,

[1] The information about the country from which the activities are reshored from is available only for about one-third of reshoring cases in the Reshoring Initiative database.

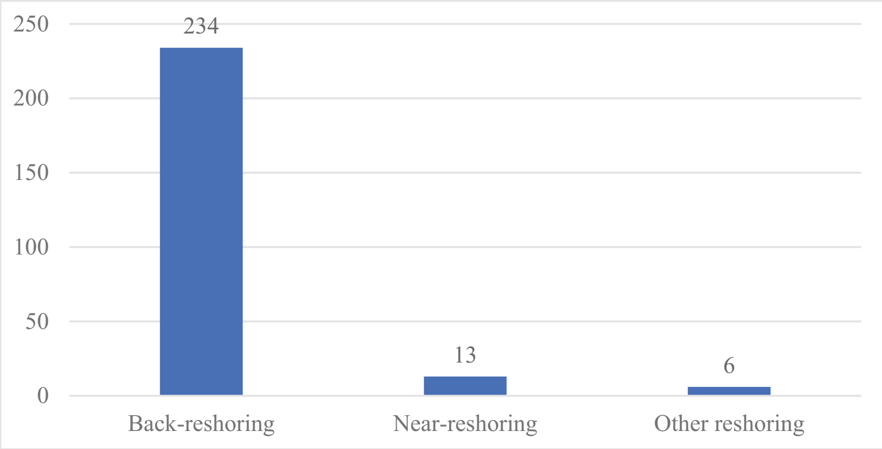


**Fig. 3** Reshoring strategies. (Source: ERM 2018 Report. © European Foundation for the Improvement of Living and Working Conditions (Eurofound), 2019. Reproduction is authorized provided the source is acknowledged)

among 253 cases, back-shoring represents the dominant strategy for companies (92.4%), illustrating that companies prefer to move back to their home country rather than to a nearby country.

The ERM 2018 Report shows that the number of reshoring cases varies significantly across countries. The UK, Italy, and France are the countries with the highest number of cases (Fig. 4). Surprisingly, Germany ranks only seventh among the EU reshoring countries despite its strong manufacturing tradition. Over the past 12 years, a decreasing number of German companies have also reduced their domestic production capacities in favor of foreign locations, that is, offshoring (De Propris & David Bailey, 2020). From 2013 to mid-2015, about 3% of German manufacturing companies engaged in the reshoring of foreign production back to Germany (Kinkel & Jäger, 2017).

Many companies have also realized that reshoring can enable them to be more competitive when global supply chains are suddenly interrupted. Producing at home allows them to react more quickly to market developments. It is easier to come up with new prototypes, which is of particular importance during pandemic times. It was recently reported that the covid-19 crisis seems to have accelerated France's efforts to bring back industrial production capacities to the country (Louis, 2021).

The total number of reshoring cases has not increased sharply over the last years; however, data derived from different databases (e.g., Reshoring Initiatives and ERM) clearly show that reshoring is becoming a more widespread phenomenon. Nearly half of identified reshoring cases (both in Europe and in the USA) took place from China, and this share remains quite stable over time. There is however evidence of increased reshoring from India, Poland, and Germany by European companies (Fig. 5).

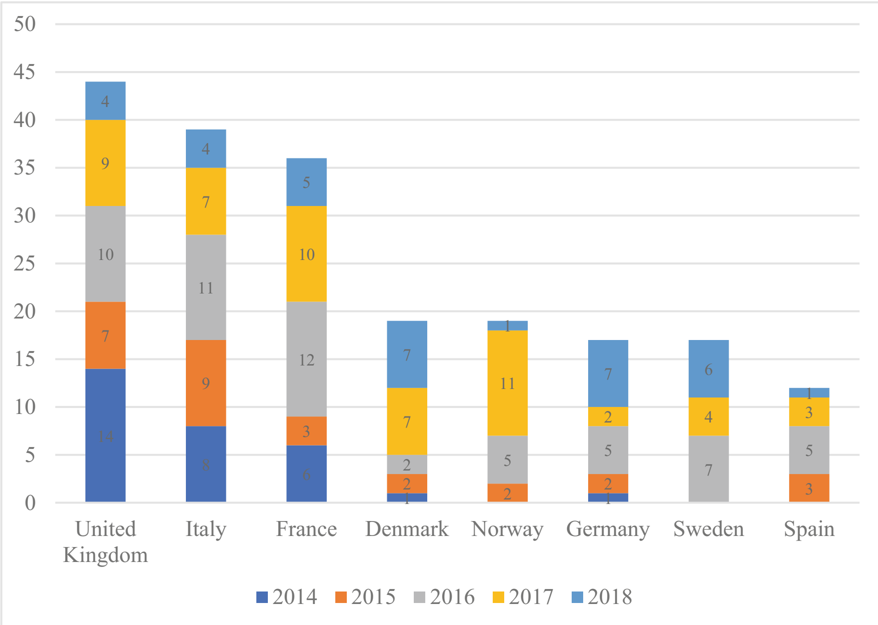


**Fig. 4** Number of reshoring cases per home country (only decisions >10). (Source: ERM 2018 Report. © European Foundation for the Improvement of Living and Working Conditions (Eurofound), 2019. Reproduction is authorized provided the source is acknowledged)

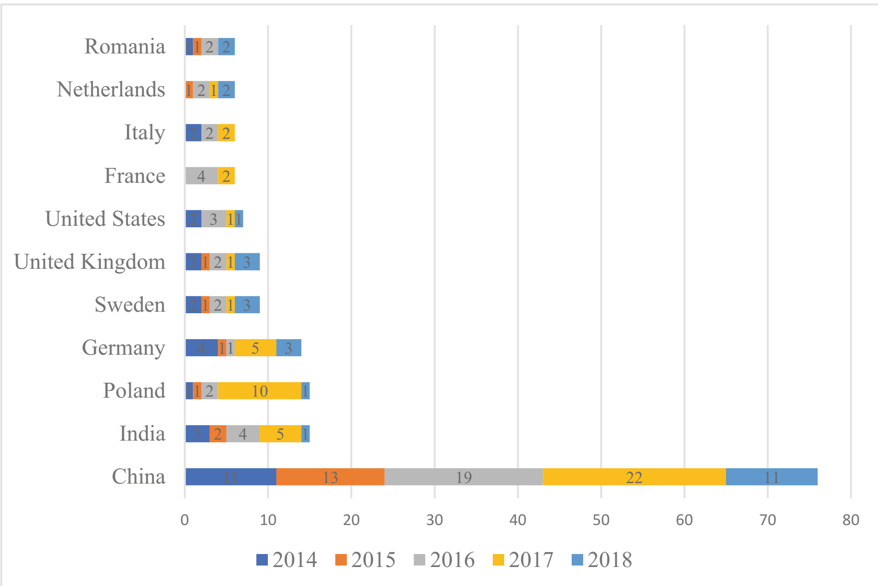


**Fig. 5** Number of reshoring decisions by host country and year (>5 decisions). (Source: ERM 2018 Report. © European Foundation for the Improvement of Living and Working Conditions (Eurofound), 2019. Reproduction is authorized provided the source is acknowledged)

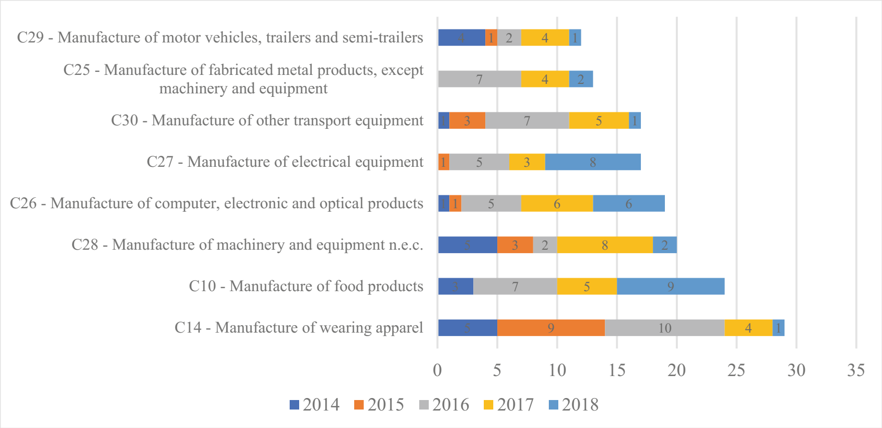


**Fig. 6** Number of reshoring cases per industry (only decisions >10). (Source: ERM 2018 Report. © European Foundation for the Improvement of Living and Working Conditions (Eurofound), 2019. Reproduction is authorized provided the source is acknowledged)

As far as the industry is concerned, reshoring occurred mainly in the manufacturing sector, which represents around 85% of total reshoring cases identified. A decreasing number of cases have occurred over time in clothing and apparel – despite this industry representing the highest total number of cases with 29 in total. Alternatively, an increasing trend in food, electronics and optical products, and electrical equipment can be observed – see Fig. 6.

## 2.3 Exemplary Reshoring Cases

Although reshoring trends are more significant in the USA and Europe, Asian firms have also reshored their production activities. Below we present six reshoring exemplary cases within American, European, and Asian companies, highlighting the underlying motivations.

### La Brava: Proximity to Customer

La Brava Beer is a Spanish brewing company which decided to offshore its production activities in Czech Republic, given the expansion possibility due to the presence there of a century-old brewery. The company defines itself as "nomad" and "gypsy," in the same fashion as some of the most famous brewers in the history. However, it always used ingredients totally produced in the Girona area – near Barcelona – and has always adopted the traditional recipe. It plans to move its production activities from the Czech Republic to Spain and invest in a new plant by 2023. The decision was made because the company mainly sells in the Girona and Barcelona markets, although it also exports to France and Australia.

### Fitwell: *Made-in* Effect

Fitwell is a small Italian firm producing outdoor and mountain shoes. It is headquartered in the shoe district of Montebelluna. The firm was created in 1979 and initially focused on the production of highly technical mountain shoes. Given the small volumes, the company also worked as a contract manufacturer. In 1999, Fitwell began outsourcing its production to Romania, as the main commercial customer demanded lower costs/prices. However, in 2009 Fitwell partially reshored the Romanian production, deciding to manufacture in Italy not only top end shoes but also two out of the three main production stages for medium end shoes (with its own brand).

Mr. Grotto, the company founder, commented on his reshoring decisions as follows: "*We came back because we are rooted in the territory [the Montebelluna district], because we are able to manufacture a product but in order to make it a quality product we must produce it in Italy [. . .]. With the concept of made in Italy we have gained as far as quality is concerned, but we have also regained the pride to produce here at home.*"

### Diadora*: Made-in* Italy Effect

Diadora is an Italian company mainly producing shoes, t-shirts, and other products for sport activities. During 2017, the company announced it will reshore to Italy 10% of its high-end production activities. The remaining products are to be produced in China, Thailand, and Vietnam. The decision has been taken to support the product innovation process bringing production and R&D department closer. In addition, the company leveraged the "made in Italy" label and reduced the environmental impact of its production network.

### Deutsche Bank: Business Reorganization

Deutsche Bank is a leading German bank operating at a global level. The bank announced to move a large part of its securities trading business from London (UK) to Frankfurt (Germany) in response to Brexit. Moreover, the bank will concentrate its business for European corporate clients there. This relocation project started in 2017 and is still underway. The relocation impacts hundreds of employees.

### General Electric: Delivery Optimization

General Electric (GE) is a well-known American company, which has reshored a portion of its appliance manufacturing to Louisville (Kentucky, USA) in 2012. The $1-billion-dollar investment done by the company encompassed a full renovation of the facility at Appliance Park. GE's decision to reshore its appliance product lines from China was based on multiple factors. Their organization was struggling with inventory and delivery problems that completely offset labor cost differentials between the USA and China.

### YJS: Complete Industrial Chain

YJS is a small Chinese clothing company. The main business is the production of garments for the USA and European markets. Before 2016, this company produced clothes in Dongguan, a city in China's manufacturing heartland of Guangdong province (China). In 2018, rising labor and land costs in Dongguan drove YJS to move its production to Vietnam. After 2 years, the company decided to reshore the previously offshored production activities back to Dongguan.

The owner of YJS declared: "*although Vietnam's factory buildings and labor were much cheaper than Dongguan, the total cost of production is not necessarily low, importantly, you feel it's inconvenient to buy various raw materials and components. In Dongguan, it is very fast to find the suppliers and buy the things you want in one or two days, the industrial chain in Dongguan is complete. By contrast, we have to import some raw materials from China to Vietnam, it is really slow. Additionally, the gap in worker efficiency between China and Vietnam is also another significant problem.*"

## 3 Reshoring Country Peculiarities

In the previous sections, we have presented both descriptive data and exemplary cases of reshoring from different countries. A question might therefore be raised: **Do reshoring projects differ across countries?** We state that the answer is affirmative. By analyzing a sample of 529 cross-industry reshoring projects by companies headquartered in five countries – the USA, Italy, Germany, UK, and France – Wan et al. (2019b) show that reshoring projects in these countries significantly differ in terms of industry, entry mode, firm size, and motivations. They argue that the home country effects may manifest themselves in reshoring processes through multiple dimensions involving institutions, culture, size, and profile of the manufacturing industries.

**Italian reshoring projects** are characterized in terms of sector – with a significant and positive prevalence of the clothing and electronics subsectors – and drivers with a strong "made-in effect" but a lower relevance of the cost and delivery reliability factor. **German reshoring projects** can be distinguished in terms of industry (mechanical machinery, equipment, and metal products), firm size (large), entry mode (insourcing prevails), and some motivations ("quality issues," "made-in effect"). **UK reshoring projects** are characterized by the dominance of time motivation, where "delay in deliveries" and "total costs" are found to be significant and positive.

## 4 Motivations for Reshoring

**Why Do Companies Reshore?** Extant literature has put much emphasis on the motivations of reshoring and identified an array of factors. In this section, we discuss this topic in detail.

Using a survey of 1450 companies in the German manufacturing industry, Kinkel et al. (2007) illustrate that *cost* is the most important reshoring driver. Fratocchi et al. (2016) identify 26 motivations based on the secondary data of reshoring projects and point out the top three motivations: “the pursuit of lower logistics costs,” “made-in effect in the home country,” and “poor quality of offshored product.”

Other scholars argue that reshoring could also be driven by factors such as higher control and coordination costs of globally extended supply chains (Kinkel & Maloca, 2009; Martínez-Mora & Merino, 2014); the firm’s inability to develop distinctive resources abroad; the exploitation of the host country’s resources in order to establish competitive advantage (Canham & Hamilton, 2013); consumer demand (Arlbjörn & Mikkelsen, 2014; Harrington, 2011; Tate et al., 2014); the correction of mistakes occurred in offshoring choices (e.g., Gray et al., 2013); global competitive dynamics such as changes in the global economy, political risk, and tax rate (Wiesmann et al., 2017); and infrastructure (Benstead et al., 2017).

Scholars classified reshoring motivations and drivers based on different dimensions – see Table 1 – indicating that reshoring is a very heterogeneous phenomenon.

Among these classifications, the theory-driven framework introduced by Fratocchi et al. (2016) is particularly explanatory. This framework distinguishes reshoring motivations based on two main dimensions: the contextual factors affecting the decision (external to the firm vs. internal), and the strategic goal (customer-perceived value vs. cost efficiency).

For illustration, external contextual factors include the home or host country legislation, culture, labor markets, availability of suppliers, and intellectual property protection. Internal contextual factors refer instead to production processes, integration of company’s functions, and process and product innovation. Crossing the two dimensions – goals and main contextual factors – reshoring motivations can be mapped in a 2 × 2 matrix. The matrix also includes four hybrid areas in which alternatively one of the strategic goals or one of the factors becomes the dominating characteristic. This framework was adopted in Di Mauro et al. (2018) and the ERM research report. By conducting a systematic literature review, Di Mauro et al. (2018) identified 42 motivations covering all the quadrants of the framework – see Fig. 7.

While offshoring choices are often driven by cost-related factors (Ferreira & Prokopets, 2009; Johansson et al., 2019; Lewin & Peeters, 2006), reshoring decisions cannot be uniquely explained by changes in cost differentials between the offshore country and the home country. Rather, strategic intent behind reshoring decisions has been highlighted as another key driver (Bals et al., 2016; Benstead et al., 2017; Di Mauro et al., 2018).

The theoretical frameworks and specific motivations in existing literature indicate a multifaceted nature of reshoring, pointing out the main reasons behind this decision. To complement this analysis, we also considered the reshoring motivations mentioned in the ERM cases (56 motivations in total) and classified them based on the aforementioned framework in Fig. 7 – now populated in Fig. 8.

Figure 8 shows that the two upper quadrants (value-driven motivations) account for around 33% of the total reported motivations. Among them, the most frequent are the “made in” effect and “poor quality of offshored production” (40 and 48 instances, respectively) located in the upper-right quadrant – the external environment- and customer-perceived value quadrant. These two motivations are likely linked with high-end luxury products, for which offshoring could be risky, since it might

**Table 1** Overview of the existing framework of reshoring drivers

| Authors | Dimensions | Data source |
|---|---|---|
| Ancarani et al. (2015) | Efficiency seeking | Secondary data |
| | Market seeking | |
| | Resource seeking | |
| | Strategic asset seeking | |
| Foerstl et al. (2016) | Human and behavioral factors | Literature review |
| | Transactional factors | |
| Fratocchi et al. (2016) | Value-driven internal | Secondary data |
| | Value-driven external | |
| | Efficiency-driven internal | |
| | Efficiency-driven external | |
| Srai and Ané (2016) | Quality and brand image | Literature review |
| | Country factor costs | |
| | Reconfiguration and restructured cost | |
| | Enhanced innovation | |
| | Responsiveness and resource efficiency | |
| | Risk management and dependability | |
| | Institution | |
| Stentoft et al. (2017) | Cost | Literature review |
| | Quality | |
| | Time and flexibility | |
| | Access to skills and knowledge | |
| | Risk | |
| | Market | |
| | Other (e.g., government incentives) | |
| Benstead et al. (2017) | Cost-related | Literature review |
| | Competitive priorities | |
| | Infrastructure-related | |
| | Risk, uncertainty, and ease of doing business | |
| Wiesmann et al. (2017) | Global competitive dynamics | Literature review |
| | Host country | |
| | Home country | |
| | Supply chain | |
| | Firm specific | |
| Barbieri et al. (2018) | Managerial mistake | Literature review |
| | External environment (six subcategories) | |
| | Internal environment (six subcategories) | |
| Heikkilä et al. (2018) | Changing costs of operations | Literature review |
| | Quality | |
| | Time and flexibility | |
| | Access to skills and knowledge | |
| | Other | |
| Ancarani et al. (2019) | Flexibility priority | Secondary data |
| | Cost priority | |
| | Quality priority | |

(continued)

**Table 1** (continued)

| Authors | Dimensions | Data source |
|---|---|---|
| Johansson et al. (2019) | Cost | Survey |
| | Development | |
| | Quality | |
| | Market proximity | |
| | External influence | |
| | Trade policy | |

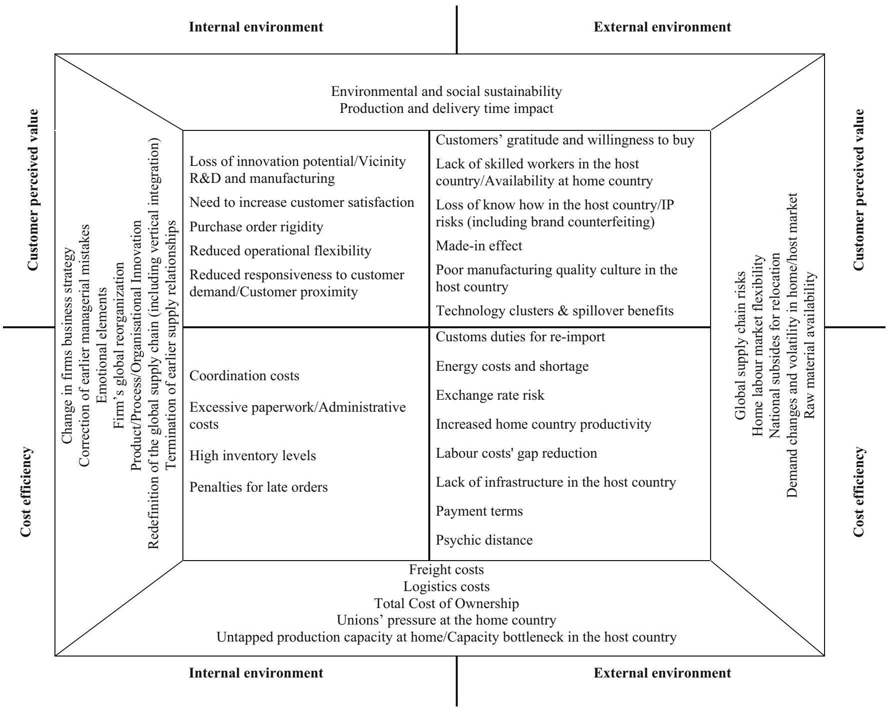


**Fig. 7** Reshoring motivations highlighted in the extant literature. (Source: Di Mauro et al. (2018). © 2018 The Authors. Published by Elsevier Ltd. – reproduced with permission)

cause problems related to the satisfaction of high-quality standards. Section 2.3, (43 instances) and "Implementation of strategies based on product/process innovation" (28) are the most frequent motivations in the upper-left quadrant – the internal and customer-perceived value quadrant.

Figure 9 presents the 16 most cited motivations – by number of identified cases. Firm global reorganization, delivery time, and automation of production process are the three most important motivations. In this chapter Sect. 2.3 we presented one reshoring case which was motivated by global reorganizing and delivery optimization.

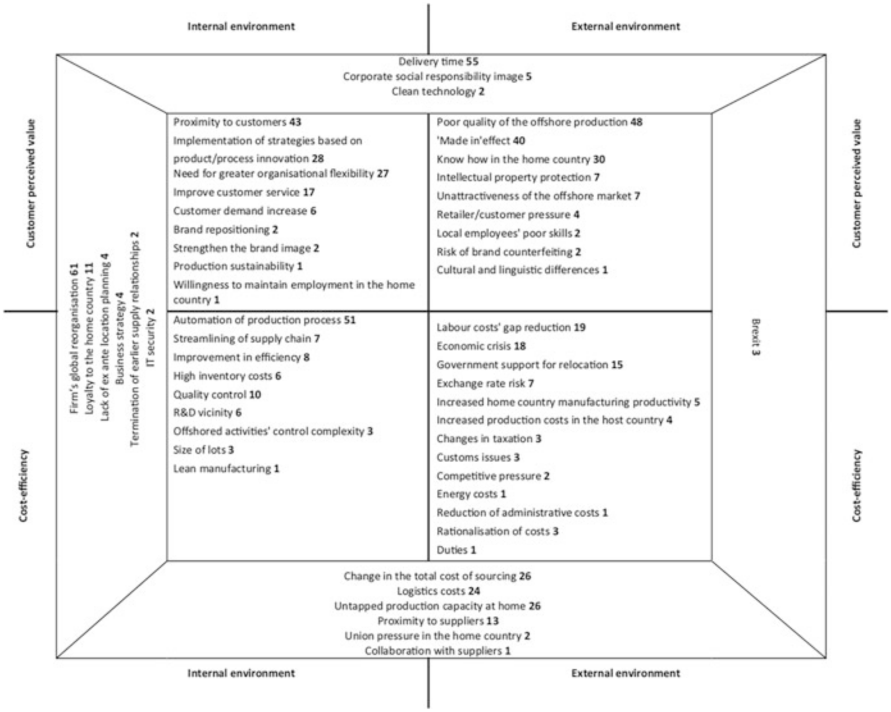


**Fig. 8** Reshoring motivations' classification (Source: ERM 2018 Report. © European Foundation for the Improvement of Living and Working Conditions (Eurofound), 2019. Reproduction is authorized provided the source is acknowledged)

Automation is also a great equalizer that makes European and US factories more economically attractive. For instance, the Danish company Welltec brought its production activities earlier offshored to Poland (mostly for cost reasons) back to Denmark because of better automation production capability within their home country. The company invested heavily in robotics and automated production systems in its Danish plant, reducing the demand for labor and improving the level of efficiency. It should however be acknowledged that automation is also significantly raising in offshore locations – in particular in China.

## 5 Decision-Making and Implementation Process

Bals et al. (2016) propose a decision-making and implementation framework for reshoring, drawn from previous literature on outsourcing and offshoring. The framework encompasses a linear process consisting of eight sequential phases: (1) determine the current boundary of the firm; (2) capability and performance analysis of the current state; (3) information-gathering on alternatives – including own capabilities; (4) data analysis and solution development; (5) shoring sourcing decision; (6) disintegration at former source/location; (7) relocation to new source/location; and

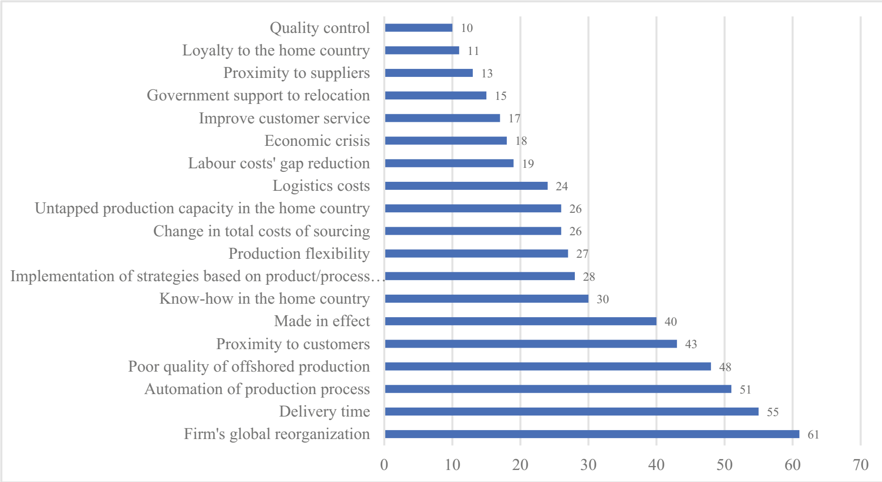


**Fig. 9** Reshoring motivations (only the ones declared at least 10 times)*. (Source: ERM 2018 Report. © European Foundation for the Improvement of Living and Working Conditions (Eurofound), 2019. Reproduction is authorized provided the source is acknowledged. Note: multiple motivations can be indicated for a single reshoring case)

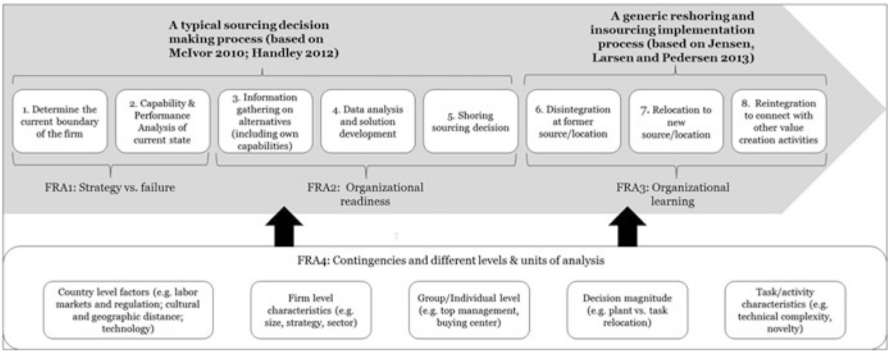


**Fig. 10** Reshoring decision-making and implementation framework. (Source: Bals et al. (2016). ©Springer Science+Business Media New York 2016 – reproduced with permission)

(8) reintegration to connect with other value creation activities (see Fig. 10). While the main objective of the authors was to identify future research avenues, their work also provides practical guidelines for managers making and implementing reshoring decisions.

The information-gathering stage (stage 3) might also be supported by various tools available online for estimating the total costs of ownership (TCO), such as the one developed by the Reshoring Initiative: https://reshorenow.org/tco-estimator/.

Gray et al. (2017) acknowledge however that the reshoring decision-making process – as in case of many other firm's decisions – is characterized by high intrinsic complexity and normally does not follow a well-defined set of phases. Based on this assumption, the authors develop a system dynamics model of offshoring and reshoring decisions that allows for simulation of complex and dynamic behaviors, capturing loops in the process and time delays. As an example, the authors suggest that a complete or too detailed analysis of all costs and benefits of reshoring versus offshoring often just slows down the decision-making process. This situation is especially true given the uncertainty characterizing location decisions and the difficulty in developing accurate forecasts. The authors refer to the *ecological rationality* concept (Gigerenzer, 2008) and advise managers to use tools with analysis levels that consider the complexity and uncertainty of the decisions.

Boffelli et al. (2020) analyze the reshoring decision-making and implementation processes of four companies and observe that they are cyclical processes, made of loops, trials, and errors. Sometimes there is not even a "clear" separation between decision-making and implementation.

In Fig. 11, we summarize the process followed by one of the case studies analyzed by Bofelli and colleagues – a company who in 2010 moved part of its manufacturing activities carried out in China back to Italy to extend the core business to high-end products (such as zippers and other accessories for clothing and leather items) aimed at luxury brands. The decision was triggered by the opportunity to enter into a more profitable market.

In this documented process, the entrepreneurs quickly collected general information about costs, financing opportunities, and investment analysis, with the support of an external business consultant and a technical expert (supporting in the machinery selection). After the decision was made, the implementation took approximately 6 months – the time needed to produce and import the machinery from China. Some critical issues arose however during this process. It was more difficult than expected to penetrate the new market, thus leading to lower revenues and longer time to

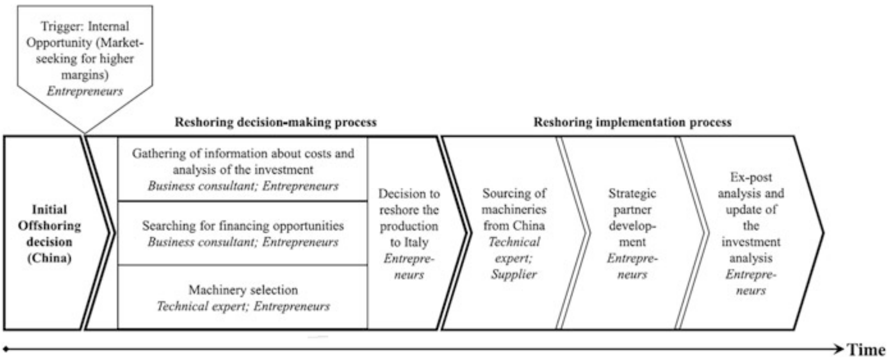


**Fig. 11** Reshoring decision-making and implementation process of a company. (Source: Boffelli et al. (2020). © 2020 Elsevier Ltd. – reproduced with permission)

payback the investment. Also, the company did not evaluate the availability of suitable suppliers during the decision-making process, and this revealed critical in the implementation phase. To solve the issue, the company had to make some additional investments to help key strategic partners to develop the needed competencies.

## 6 Key Aspects of Reshoring Decisions

As mentioned above, reshoring is characterized by high complexity, volatility, and instability – especially given that new circumstances are not fully known. It is a process that involves decisions as well as changes not only in the network structures of the host country but also in those of the home country (Baraldi et al. 2018). In order to explore and exploit reshoring opportunities, companies should make a set of strategic decisions including: (1) whether to reshore or not, (2) when to reshore, and (3) how to reshore. In this section, we shed therefore light on the determinants of reshoring propensity (e.g., Canham & Hamilton, 2013; Dachs et al., 2019), reshoring timing (e.g., Ancarani et al., 2015), and reshoring entry modes (Wan et al., 2019a).

### 6.1 Reshoring Propensity

Reshoring is a relocation of second degree – a possible step following offshoring. When companies reconsider their global manufacturing footprint, they usually have three options: maintaining their current offshoring strategy, further offshoring, or reshoring. These options are not mutually exclusive; a combination of them, for instance, based on different product lines, production phases, or markets served, is indeed frequently pursued. However, how do companies choose among these options? In order to answer to this question, scholars adopt two main approaches. Some studies compare companies which have already implemented a reshoring strategy to those that did not (e.g., Canham & Hamilton, 2013; Dachs et al., 2019; Delis et al., 2019; Kinkel, 2012; Uluskan et al., 2017). Other studies instead compare reshoring companies with companies that have implemented other shoring strategies such as further offshoring or maintaining at home (Albertoni et al., 2017; Barbieri et al., 2019; Ellram et al., 2013; Heikkilä et al., 2018; Tate et al., 2014).

Reshoring propensity is associated with multidimensional factors involving firm characteristics such as products of the firm, past experiences, and offshoring motivations (Albertoni et al., 2017; Dachs et al., 2019); industry such as HIGH-TECH firms (Canham & Hamilton, 2013; Dachs et al., 2019; Heikkilä et al., 2018); and country given such events as the global financial crisis (Delis et al., 2019; Kinkel, 2012).

Among the risk propensity dimensions, **firm-level factors** have been studied in more detail. Surprisingly, previous studies have shown that the firm size does not affect company reshoring propensity (Canham and Hamilton, 2013; Kinkel, 2012).

The past experiences of the firm, either reshoring or offshoring, play a critical role in affecting reshoring propensity (Albertoni et al., 2017; Delis et al., 2019; Kinkel, 2012). For example, scholars have demonstrated that past reshoring experiences positively influence reshoring propensity (e.g., Delis et al., 2019; Kinkel, 2012), highlighting learning effects in reshoring.

For offshoring experience, the results are mixed. Albertoni et al. (2017) observe that companies are likely to relocate when their offshoring had been motivated by access to new markets, whereas the unsatisfactory performance of activities offshored for efficiency reasons or search of talents does not necessarily lead companies to relocate elsewhere. More recently, using data from the ERM, Barbieri et al. (2019) find that, when a previous offshoring investment is driven by market-seeking location advantage, companies are more likely to opt for a "*relocation to the home country (RHC) [i.e., reshoring], except during the economic crisis where market-seeking European companies seem to prefer relocation to a third country (RTC) [i.e., further offshoring].*"

For **industry-level factors**, existing studies provide mixed results. For example, based on a survey of 229 Finnish manufacturing firms, Heikkilä et al. (2018) show that companies that had transferred their production back to Finland belong to higher technology-intensive industries. By contrast, based on the data of 151 New Zealand manufacturers, Canham and Hamilton (2013) demonstrate that there is a higher occurrence of reshoring among consumer goods producers.

For **country-level factors**, one notable element is the economic crisis. Based on a large data set of 1484 German manufacturing companies as part of the European Manufacturing Survey (EMS), Kinkel (2012) finds that companies which are engaged in customer-specific product development have been less active in production backshoring before the emergence of the global economic downturn (1999–2006). Similarly, based on 3683 MNCs from 14 developed countries investing in 66 host countries over the period 2006–2013, Delis et al. (2019) find a strong relationship between the onset of the financial crisis and the firm-level propensity to reshore.

## 6.2 Timing

The dynamics of reshoring processes are not only reflected by the reshoring drivers but also by its timing.

In international business considerations, the *duration* of specific foreign ventures – such as joint ventures, licensing agreements, plants, and subsidiaries – is an important issue (Habib & Mella-Barral, 2007; Mata & Portugal, 2000; Wren & Jones, 2009).

Ancarani et al. (2015) highlight – using survival analysis of 249 offshoring experiences terminated with a reshoring decision – that industry-, firm-, and country-specific characteristics are relevant to explain offshoring. Specifically, the authors find that electronics and automotive companies return earlier than companies competing in other industries – such as clothing, furniture, and mechanical industries. This result is aligned with McCloughan and Stone's (1998) findings, which show that electronics presents a shorter survival of plants abroad. For host country, the duration of offshore experiences in China and other Asian countries is significantly lower when compared to other geographical areas.

In addition, EU companies exhibit a shorter offshore duration than US companies; this result may be explained by the different organizational archetypes adopted by US and EU companies to manage their (offshore) subsidiaries. Moreover, Ancarani et al. (2015) also show that there is a significant linkage between duration and reshoring motivations, in particular regarding strategic assets seeking motivations (i.e., quality and "made-in" effect). The "quality" issues emerge as the key factor giving rise to shorter offshore stays. Based on their empirical findings, the authors conclude that the likelihood of termination of offshore manufacturing and the return to the home country may be accelerated by factors such as technology-based industries, small firm sizes, shrinking cost differentials and the psychic distance between home and host country, the organizational archetypes, and quality-related motivations.

## 6.3 Entry Modes

While reshoring is a location decision, companies may also rethink their governance mode or entry mode (EM). Firms need indeed to reevaluate and adapt their location and EM decisions simultaneously to create value (Mudambi & Venzin, 2010). There are several possible reshoring scenarios, depending on the combinations and interaction of location and EM choices (e.g., Foerstl et al., 2016; Gray et al., 2013).

EM is a governance form that companies adopt to gain access – entry or reentry – into a market, ranging from the wholly owned subsidiary (WOS) to contractual agreements with independent suppliers. EM are generally clustered in two major types – equity (in-sourcing or captive) and nonequity (outsourcing) modes (Pan & Tse, 2000).

By combining location decisions (off- vs. reshoring) and make-buy decisions (in- vs. out-sourcing), Gray et al. (2013) and Wan et al. (2019a) trace back reshoring paths to four strategies (see Fig. 12):

**Fig. 12** Reshoring strategies. (Source: Wan et al. (2019a). © 2018 The Authors. Published by Elsevier Ltd. – reproduced with permission)

| From: Offshore | To: Reshore – In-House | To: Reshore – Outsourced |
|---|---|---|
| In-House | In-House Reshoring (IN-IN) | Reshoring for Outsourcing (IN-OUT) |
| Outsourced | Reshoring for Insourcing (OUT-IN) | Outsourced Reshoring (OUT-OUT) |

(a) In-house reshoring, when companies relocate manufacturing activities from offshore wholly owned facilities back to wholly owned facilities in the home country
(b) Reshoring for outsourcing, when companies relocate manufacturing activities from offshore wholly owned facilities back to home-based suppliers
(c) Reshoring for insourcing, when companies relocate manufacturing outsourced to offshore suppliers back to wholly owned facilities in the home country
(d) Outsourced reshoring, when companies relocate manufacturing activities performed by offshore suppliers back to home-based suppliers

The strategic relevance of the EM choice is evident when considering its implications for firm resources, degree of control and risks, switching costs, and performance (Hill et al., 1990; Lu, 2002; Perks et al., 2013; Zhao et al., 2017).

Wan et al. (2019a) shed light on the EM choice in reshoring decision based on the analysis of 747 reshoring cases. The authors find that reshoring EMs are influenced by: industry – the industry in which the company operates; firm (firm size); country (home and host country, cultural distance), and project-specific factors (e.g., reshoring motivation). They are also influenced by the EM adopted in the offshore location.

Their study result confirms the multilevel nature of EM determinants (industry, firm, country, and project-specific levels) already highlighted by previous research. Moreover, a significant path dependence effect is identified, given that about three-quarters of reshoring firms retain the same mode they had offshore, and only one-quarter switch the mode. In other words, results of Wan et al. (2019a) provide support for the reshoring EM's dependence on previous EM choices (Shaver, 2013). However, rather than a generalized stability of EMs, their results also suggest that there is a "selective path dependence," i.e., captive EMs are very seldom changed, whereas offshore outsourcing is equally likely to be followed by reshoring outsourcing or insourcing.

## 7 Conclusion

Reshoring, as an emerging topic, not only brings together scholars and practitioners from a variety of disciplinary fields, but also promotes research and knowledge on a wide array of aspects. Existing studies have primarily analyzed the main drivers behind reshoring, demonstrating that reshoring is driven not only by external environment conditions (e.g., labor cost, economic crisis) but also by internal strategic purpose (e.g., supply chain renewal, quality improvement). Clearly, the dialogue has gradually shifted from the motivations of reshoring toward a broader set of topics, including how companies reshore and what the outcomes are. Reshoring, as a nonlinear internationalization process, is complex, dynamic, and evolutionary, resulting in a myriad of relevant topics for scholars, managers, and policy makers.

Today, the manufacturing industry is at a crossroads. Manufacturers are challenged by supply shortages on many key components (chips and metals as notable examples), but at the same time they are also facing emerging opportunities for growth and innovation. In the postpandemic age, how to increase connectivity, resiliency, and competitiveness to mitigate disruptions by reconfiguring global supply chains has been one of the key questions. Right shoring strategies – i.e., a holistic and balanced combination of global and local supply chains (Tate & Bals, 2017; Hilletofth et al., 2019) – may serve to mitigate risk, to face uncertainty, and to seize new opportunities.

The role of reshoring for countries' employment and economic prosperity has also been acknowledged (Vanchan et al., 2018). The question of what reshoring can bring has indeed been increasingly debated. Therefore, to get a stronger grasp on reshoring, continuous research and policy debate on its dynamics, evolutionary paths, and impacts in the context of global operations is needed.

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# Retail Supply Chains and Sustainability: True Possibilities or Insolvable Paradox?

David B. Grant

## Contents



**Abstract**

This chapter discusses the effects of sustainability on retail supply chains in the context of the triple bottom line of the economy, environment, and society and the UN's sustainable development goals. The chapter's objective is to look at current issues in retailing and how they are affected by sustainability requirements or indeed affect sustainability themselves. Major areas of concern include the current state of the global economy, the demographic shift in market segments toward generations Y and Z, the growth of ecommerce and online retailing, the influence of information and communications technology on retail supply chain

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processes and management, and concerns about human resources across the entire retail supply chain. Sustainability is considered from a holistic perspective and various frameworks and performance measurement and environmental management systems are presented that could assist retailers in improving their sustainability initiatives. The chapter concludes by noting that true possibilities for sustainable retail supply chains exist but current practices and understanding provide an appearance of it being an insolvable paradox.

**Keywords**

Retailing · Supply chain management · In-store · Online · Sustainability

## 1 Introduction

This chapter discusses the effects of sustainability on retail supply chains as it pertains to current issues facing this sector and whether there are true opportunities to develop sustainability or whether it remains an unsolvable paradox. The triple bottom line (TBL) elements of the economy, environment, and society (Elkington, 1994) and the UN's (2022) Sustainable Development Goals (SDGs) comprise the theoretical underpinnings of sustainability. For the purposes of this chapter, key retailing operational activities with sustainability implications include the following:

1. Understanding consumer demand and subsequent behavior for retail products and services (P&S)
2. Sourcing and procuring P&S across the globe and acquiring (or transporting) and distributing the P&S to market, either by the retailer itself or in conjunction with business partners such as third-party logistics (3PL) service providers
3. Managing stock levels and allocations across the retailer's entire platform
4. Disposing waste, obsolete, and excess stock
5. Costs related thereto that lead to the consumer's price to purchase

Retailing is the last link in the supply chain and the main interface between retail companies and consumers. Consumers visit retail locations, either physical stores or online retail websites, to examine goods and make purchase decisions according to their needs and wants. In this way, retailing provides time and place utility for consumers. Retailing is also an interface between logistics, supply chain management, and marketing – the output of an efficient and effective logistics and supply chain system is a satisfied customer, which is the same output as the marketing concept (Grant, 2012).

Retail logistics and supply chains have been transformed since the 1980s. Retailers, once passive recipients of products allocated to stores by manufacturers for anticipated demand, are nowadays active designers and controllers of product supply in reaction to known customer demand (Fernie & Sparks, 2019). As a result, instead of being *order takers* retailers are now *market makers* who control, organize, and manage the retail supply chain from production to consumption (Grant, 2011, 2021).

However, retailers cannot exercise direct influence over their own internal operations, but can only indirectly influence over raw material producers, suppliers, and manufacturers further upstream in their supply chain. Retail supply chains and networks can be vast, especially for large, international retailers who engage with large, international suppliers such as in the food retail and fast-moving consumer goods (FMCG) subsector (Fernie & Grant, 2019).

A thorough discussion of retail supply chains and all issues affecting them is beyond a manageable scope of this chapter. Hence, the emphasis here is delimited to retailers themselves and their relationships with consumers and first tier suppliers or logistics service providers, within the primary context of sustainability but with commentary on some other important issues.

## 2 Background and Current Retail Concerns

### 2.1 Retail Processes

Figure 1 provides a simple diagram of upstream to downstream product processes for both in-store and online retailing. Essentially, retailers receive goods from suppliers at a distribution center (DC). Suppliers can be national or international, and modes of transport used can include road freight, rail, ocean shipping, or air cargo.

A large retailer may have more than one DC in a hierarchy. On the top will be a national distribution center (NDC) supplying several regional distribution centers (RDC) depending on the retailer's geographic reach. Each DC will serve several

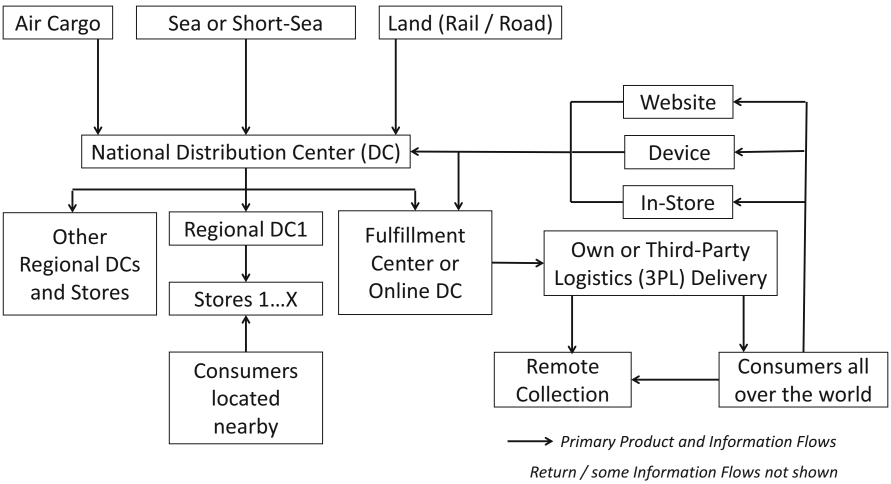


**Fig. 1** In-store and online retail processes

retail store locations, and the choreography of assigning stock, in terms of product types of stock keeping units (SKUs) and volumes to each store along with transportation distribution, forms part of a retailer's distribution network strategy. Consumers, who are primarily local to a particular store, will travel to the retailer to browse, purchase, and take away goods.

The process for online retailing is different and somewhat less complex. Goods from suppliers will be received at a distribution center and then sent to a specific online DC for online purchases known as an online fulfillment center (OFC). Consumers will make their online purchases through various purchases such as smartphone devices, in-store kiosks, or generally through a website on their home computer. Purchase request information is received by the retailer at the NDC or fulfillment center depending on its operational setup, and orders are processed for delivery either to consumers or to a remote collection pick up location where consumers can collect their purchases. Retailers may use their own delivery services or outsource delivery to third-party logistics (3PL) service providers (Fernie & Grant, 2019).

Reverse product and information flow processes are not shown in Fig. 1 for clarity but are nonetheless important in retailing activities, especially online. Retailers may provide a remote drop off location for consumers to return online purchases, possibly at the same remote collection location, allow consumers to return them to a store, or may pick up goods for return from a consumer's house or other designated location.

McArthur et al. (2016) conducted a metareview of retailing literature to delineate the disparate, interdisciplinary strands of knowledge and developed a typology of six factors that may explain change in retailing: economic efficiencies, cyclical patterns, power inequities, innovative behavior, environmental influences, and interdependent parts of the system in coevolution. While not abstract, these factors are at a high level and do not provide sufficient granularity for retail firms to improve operations, especially in their supply chains. From these factors, Grant et al. (2021a) derived and discussed four important issues facing retailers in the 2020s with operational and supply chain impacts: the economy, changes in consumer expectations behavior, online or e-commerce retailing, and the environment or sustainability. Two additional issues to these four are the rapid change in, and use of, technology in retail operations and human resources at the retailer or within its business partners and suppliers.

## 2.2 Economic Concerns

The TBL suggests firms should focus on maximizing shareholder wealth or economic value they create, i.e., economic sustainability in the long term, while ensuring that they add environmental and societal value to achieve long-term natural environment security and proper working and living standards for all human beings. However, the economic outlook for retail sales and consumption is always a concern in retail supply chains.

Neoclassical economic thinking encouraged libertarian, efficient, or *free market* economic models that became embedded in global production and consumption

(Olsen, 2017). Retailers responded to this by outsourcing manufacturing internationally thereby lengthening their supply chains to produce and deliver at the lowest cost for their markets. However, this model has been increasingly criticized for being not only environmentally unsustainable but also the progenitor of inappropriate human behavior, and more recently as a contributor to poor resilience of supply chains and greater potential supply disruptions, that has led to notions of *deglobalization* (Grant et al., 2021b).

Further, economic growth has been slow for the past 40 years and has been exacerbated by the 2008–2010 financial crisis, the 2020 COVID-19 pandemic, and the 2022 Russia-Ukraine conflict. World output was 4.4% in 2020 due primarily to the pandemic, was estimated to recover to 5.9% in 2021, and is forecast to moderate back to 4.4% in 2022. The recovery however was led by emerging economies at 6.0% as opposed to advanced economies at 3.9%. This performance has been exacerbated by a rise in inflation across all global economies from 1–1.5% in early 2021 to 6–7% at the beginning of 2022 (IMF, 2022).

This has seen retail sales fall leading to massive numbers of store and shopping mall closures across the advanced economies in the 2020–2022 period, decreased retailer market values, and many brand names disappearing altogether (Grant et al., 2021a). Finally, real incomes have fallen some US $47 trillion over the last 40 years for the bottom 90% of population in advanced economies and reducing their spending power while global purchasing power has shifted to emerging economies (Price & Edwards, 2020).

Stephens (2020) considers the COVID-19 pandemic is the commercial equivalent of a *meteor impact* on Earth that will eradicate many *retail "species,"* which, for example, might include restaurants and lunchtime coffee shops as people *work from home* (WFH) and stay home, but provide rapid growth and evolution by a few, for example, home delivery of meals using online *"courier"* services. He argues a new class of *apex predator* retailers have emerged that face few threats from economic factors, for example, Amazon, Alibaba, Walmart, and JD.com.

Several major UK retailers including the department store Debenhams and the Arcadia group, whose fashion store brands include Topshop, Topman, Dorothy Perkins, Burton, Wallis, and Miss Selfridge, all went into liquidation in the late 2010s. However, some Internet retailers came to the rescue for Arcadia as ASOS is acquiring the Topshop, Topman, and Miss Selfridge brands while Boohoo is acquiring the other three; however, neither retailer is retaining the physical stores (Grant et al., 2021a).

Hence, the retail landscape is dramatically changing, not only economically but also as regards its major consumer segments and their expectations.

## 2.3 Changing Consumer Expectation Concerns

As previously noted, meeting consumer needs through retailing is one of its key outputs (Grant, 2012); however, the sector may have lost its way regarding consumers and supply chain management (SCM) (Esper et al., 2020) and as a result retailers may have missed a significant demographic shift. Each consumer generation exhibits specific characteristics, attitudes, preferences, and behavior depending on events marking its existence, for example, conflicts, social upheavals, and need to work from an early age (Dabija et al., 2018). Values shared by a generation determine its behavior, which is a key element that sets one generation apart from the others. Thus, it is imperative to know, understand, and develop strategies suited for each consumer generation to enable product and service satisfaction.

There are six consumer generations: the *Silent* (born before 1945), *Baby Boomers* (1946–1964), *Generation X* (1965–1979), *Generation Y* or *Millennials* (1980–1994), *Generation Z* (1995–2012), and *Generation Alpha* born after 2012 (Grant et al., 2021a). Generations Y and Z segments have outgrown the three previous generations while Generation Alpha is not yet mature enough to be counted (Fry, 2020). Hence, Generations Y and Z will be the significant retail segments going forward for retailers, but their needs and ways of shopping are different to the previous generations who are in less consumptive life stages, and hence retail growth for them is limited, save for lifestyle services such as travel and healthcare (Popa et al., 2019).

Generations Y and Z are interested in quality products, services, and experiences and will pay a fair price relative to quality – respecting a price-value relationship – but are nevertheless cost-conscious (Deloitte, 2021). The UK Office of National Statistics noted that consumer confidence in 2020 was down 20% from a 2016 baseline of 100, and that consumers have adopted habits and behaviors to enhance well-being across three dimensions: physical (health), emotional, and financial – i.e., they are pursuing money-saving measures and only spending for necessity and not discretionary products (Danziger, 2020). Generations Y and Z also embrace this notion of demanding retail P&S for their well-being (Deloitte, 2021).

Generations Y and Z have also grown up in a context of innovation and rapid change; as *digital natives*, they are living with different forms of personal technology – such as computers, tablets, and smartphones – for their information needs. Generations Y and Z have witnessed the development of these and social networking technologies in a global and massively connected world. They are also highly educated, mostly being e-learners, very environmentally and sustainability conscious, and active (Popa et al., 2019; Deloitte, 2021).

## 2.4 Online Retailing Concerns

There has been debate since the turn of the millennium on whether physical retail stores, often referred to as *bricks-and-mortar*, will cease to exist in coming years, and all retailing activity will take place online (Grant et al., 2021a). Many cities in North America and Europe have seen a decline in city centers, and as a result *brick-and-mortar* stores no longer simply represent a channel for the distribution of products nor act as the final point in a purchase funnel (Caro et al., 2019).

Online retailing or e-commerce has grown significantly since the mid-1990s, and the primary reason for this growth is increased access and connectivity to the Internet – the primary vehicle for such activity. Europe was the world leader with an estimated 85% of households having Internet connectivity and access in 2018, followed by Russia and Eastern Europe at 76%, the Americas at 71%, and all of Asia at 53% (Johnson, 2022).

Total worldwide retail sales were estimated to US $23.7 trillion in 2020 and projected to be $31.7 trillion in 2025 (Sabanoglu, 2022). Total retail e-commerce in 2021 amounted to US $4.9 trillion, or about one-fifth of all retail sales, and is projected to be $7.4 trillion in 2025, or about 31% of all retail sales (Chevalier, 2022). Top countries in online retail sales in 2018 (Fernie & Grant, 2019) were estimated to be China at $1.6 trillion, the USA ($482 billion), the UK ($132 billion), Japan ($123 billion), Germany ($83 billion), France ($53 billion), Republic of Korea ($51 billion), and Canada ($40 billion).

Morgan (2018) suggested larger retailers will migrate online and smaller, niche stores will dominate traditional physical retail spaces while surviving retail stores will move toward a more experiential approach – with more like showrooms allowing consumers to touch and feel the products and then have them delivered to their homes straight from a warehouse. It may be that retail evolves into a blend of these two ideas in the long run – that is, with more integration between the physical retail and e-commerce spaces. This evolution will have an impact on the design and implementation of retail logistical systems.

The term omnichannel – sometimes spelled omni-channel – has come into use since the mid-2000s for the online or e-commerce retail phenomenon. This situation which means that a consumer's entire online shopping experience – both buying and receiving their goods – is seamlessly and consistently integrated across all channels of interaction, including in-store, digital media including computers, mobiles and tablets, social media, catalogs, and call centers (Fernie & Grant, 2019).

There are two primary methods for online fulfillment: picking in an existing retail store or using OFCs. Fulfillment operations under both scenarios are expensive to carry out (Grant et al., 2006), entail operational difficulties (Fernie et al., 2019), and are more environmentally unfriendly (McKinnon, 2019). Retailers will have to select the optimum distribution channel to succeed financially with online fulfillment, whether it is by consumers ordering in-store and the retailer delivering to home, or consumers ordering online and the retailer or 3PL service provider fulfilling from any store or OFC location. Each option has a different cost structure that retailers need to understand.

For example, a study in the USA of 177 retail executives regarding their omnichannel fulfillment activities found a wide gap in cost-accounting capabilities of OFCs versus stores (Banker & Cooke, 2013). While most respondents could pinpoint the costs associated with various activities at the OFC, few had a clear picture of the corresponding costs for store fulfillment. For example, 78% said they knew the cost of picking individual items by stock-keeping unit (SKU) or product class in their OFC. However, only 38% could identify corresponding costs for a store's back room and only 29% said they understood expenses associated with picking individual items in the front-of-store. Additionally, 70% said they could calculate transportation costs by SKU or product class for deliveries from an OFC, but only 57% had that same level of understanding for shipments from store.

Consumers today – especially the Generation Y and Z segments – are equipped with technology to make shopping via desktop, tablet, and mobile a seamless and content-rich process from start to finish. Consumers also want to obtain their purchases quickly – products in-stock and delivered promptly in good condition, at a time convenient to them. But, if the purchase fails for any of these reasons, consumers also want prompt and convenient satisfaction (Xing & Grant, 2006). However, product discovery and purchase are only one part of the online path. Retailers and their 3PL fulfillment partners must ensure they go the *extra mile* in the *last mile* to provide consumers the best fulfillment experience possible.

A study of Generations Y and Z online behavior and preferences (Grant et al., 2017a) found they look for information and carry out their online shopping relying on a variety of sources, are motivated by the opportunity to be able to shop online anytime, day or night, have retail P&S delivered at home, and avoid dealing with salespeople. When it comes to online fulfillment, these generations have a clear preference for convenience, and the ability to return products, timeliness, and cost. They prefer home deliveries via courier or arranged by retailers with their own van or truck).

Generations Y and Z do not return products very frequently but will return products if they are different from what was ordered, if they receive a wrong product, if it is defective, or if the quality is poor. Finally, they prefer having a courier pick up the products at their address free of charge and do not like to pay for a return service. Alternatively, they will drop the product at the retailer's physical store of (59%) or to a collection and drop-off point if free of charge.

## 2.5 Information and Communications Technology Concerns

The expansion of retailing and DCs as well as the increase in online retailing or e-commerce is driven by advances in information communications technology (ICT). However, data only becomes information when it is timely and relevant. The notion of time and place utility for consumers requires that timely information for both consumers and retailers is of the utmost importance. The use of ICT application in retail supply chains over the past half century – which for some large retailers may include over 20,000 different products or SKUs – has delivered significant benefits that enable retail managers to make better decisions which impact on financial performance (Grant, 2012). Successful supply chain applications of ICT include the following:

- Creating consumer orders or making payments through electronic data interchange (EDI) which automate repetitive transactions for retail P&S inputs and outputs. ICT include radio frequency identification (RFID) or near field communications used in chip-and-pin cards to enable instantaneous payment and electronic point-of-sale (EPOS) scanning at physical stores. These ICT can track sales and generate inventory and replenishment records.

- Automating warehouse operations and monitoring performance through warehouse management systems (WMS) including the current use of autonomous robots to pick products.
- Enabling transport management systems (TMS) to use computerized routing and vehicle scheduling (CRVS) for the choreography of P&S movements through the retail supply chain from suppliers, DCs, RDCs, and stores and performing load and item tracking and tracing for both physical store and online P&S.
- Cloud computing is used for storage, and integrated data used by firms in the retail supply chain.
- Invoking *blockchain* solutions, where a data ledger is fixed at the point of data entry, for secure tracking and tracing throughout the supply chain.
- Using artificial intelligence (AI) and predictive data analytics to increase forecasting accuracy (Fernie & Grant, 2019).

Such technologies – especially those using Internet-based platforms and referred to as the Internet of things (IoT) – support strategic decision-making as well as operational activities. For an e-commerce retailing example, the UK grocery retailer Tesco integrated its online consumer order-processing systems using EDI. An order received from the website is sent to the computer server at the store nearest to the consumer's home and assigned to a specific van that will deliver the products. It is then sent to a *picking trolley*, a shopping cart with a screen, and *shelf identifier* software that takes a picker to where each item is found. Pickers scan the items they select, and the system compares bar code details with the item ordered on the customer's shopping list, sounding an alert if the wrong item is selected. Pickers also inspect expiry dates and check for damage on every item. Once the trolley is loaded, it is sent straight to the van for delivery. Average picking time is 30 s per item, and a typical order of 64 items could be filled in about 30 min. Tesco's strategic decision to *pick out-of-store* enabled the rollout of this online service that meets the needs of *cash rich* and *time poor* consumers (Grant et al., 2006).

In the physical store arena, Amazon introduced *Just Walk Out* technology in early 2022 at its Whole Foods Market store in Washington, D.C. The store features *cashierless technology* where consumers enter the store, select their products, and walk out through large panel scanners without stopping and have the option to use Amazon One. There is also a contactless way for shoppers to enter, identify themselves, and pay using the palm of their hand. After they leave the store, consumers will receive a digital receipt.

The benefits to Amazon from this AI-driven technology include dramatically reduced labor costs, improved inventory management, and better in-store operations overall. It also allows Amazon to showcase the capabilities of *Just Walk Out* technology for purchase consideration by other retailers. Already, Amazon Go collaborated with Starbucks to open a new store concept involving *Just Walk Out* technology. Amazon is working with retailers such as the UK grocery retailer Sainsbury's and the US airport retail operator Hudson Group to enable select stores with *Just Walk Out* technology (Acosta, 2022).

The application of ICT and IoT in retail supply chains depends on the technology objectives and types of technology being deployed; however, there are barriers which may inhibit adoption and use. Kamble et al. (2019) identified twelve of them: lack of standardization, high energy consumption, security and privacy, high operating and adoption costs, long payback periods, issues of seamless integration and compatibility, issues of scalability, lack of validation and identification, systems architecture, lack of government regulations, lack of sufficient Internet infrastructure, and lack of human skill availability. They found that the latter three barriers were the most important and should be the focus of retail managers.

The sheer volumes, velocity, and different varieties of *big data* available from ICT and IoT are also problematic for retailers. Data analytics is the scientific process of transforming data into insights for users and enhancements such as machine learning provides opportunities for multilevel and atheoretical approaches to finding patterns in data. However, this situation has led some to observe that there may be *big data hubris* which implicitly assumes *big data* is a substitute for, rather than a supplement to, traditional data collection analysis whereby firms may still be in a reactive analytic stage (Lazer et al., 2014).

Vidgen et al. (2017) found three interrelated elements for a firm's business analytics ecosystem. One is that data resources require an evaluation of data availability and access to data sources, managing that data's quality, and dealing with restrictions of extant IT platforms. A second relates to organizational resources that are driven by people and culture to build data and analytics skills in the organization to deal with any skills shortages. The third element is an output for firms to establish a case for their overall business strategy by using analytics as a tool for improved decision-making and measuring its impact on value creation. The intersection of these three elements is the creation of a big data and analytics strategy to transform data resources into desired outputs. However, firms need to not only develop business, ICT, human resources, and analytics strategies, but also ensure these strategies need to be aligned.

## 2.6 Human Resource Concerns

Discussions above about human resource highlighted several issues in retail supply chains affecting employees and staff across the supply chain – including suppliers, 3PL service providers, and other business partners – and within the retailers themselves in their DCs, stores, and head offices. Consideration in this section excludes consumers, who were considered under changing consumer expectations.

Human resources are part of the societal element in the TBL, and the globalization of retail supply chains has had profound impacts on social relations and work. Various calls have been made for SCM research to extend beyond into more holistic contexts. While sustainable SCM has been growing as a research theme over the past decade, this work has largely been focused on economic and environmental sustainability, as opposed to social sustainability (Tuomala & Grant, 2021).

While the impacts on social sustainability in retail employment have created new opportunities for millions of workers in emerging economies and changed the nature of work, they have also exacerbated exploitative conditions through downward pressure on employment practices such as training, prevention of discrimination, and trade union representation (Reinecke et al., 2018).

The use of *cost-effective* practices such as downsizing, outsourcing, and contingent labor has incurred social costs and increased levels of precarious work and affected worker identities. Concerns have been raised regarding the role of migrant labor to pick seasonal fruit and vegetables, the use of domestic versus foreign labor, the balance between permanent and temporary work, and the impact of outsourcing and offshoring on terms and conditions which may have led to *modern day slavery* (Gold et al., 2015). These issues appear across various tiers of retail supply chains: workers in production and manufacturing domestically and internationally, operators and drivers in retail distribution and transport, independent retail store staff, and *independent contractor* e-commerce delivery drivers (Fernie & Grant, 2019).

By viewing global supply chains as embedded in social relationships rather than purely as chains of economic transactions, attention is drawn to the role of institutional norms and expectations beyond the narrow commercial sphere. For instance, multinational corporations at the retail end may originate from multiple jurisdictions that bring with them different institutional and cultural expectations into a single supplier site (Reinecke et al., 2018).

Retail staff in-store provide important consumer services including shelf replenishment of products and minimizing *shelf gaps* when products are out-of-stock and attending to packing and payment activities for consumers. While the Amazon *Just Walk Out* technology discussed above is innovative, it is not yet widespread across retail nor beyond the USA and parts of Europe. Retail store performance still depends to a huge extent on the way store employees are managed throughout in-store execution processes.

Research in the mid-2000s by the European Logistics Association identified the importance of human resources for the performance of DCs, which are equally applicable to supply chain activities within a retail store. Not only do human resources represent a large share of costs in retailing, but they also have a direct impact on the service delivery (Trautrims et al., 2012). Service delivery includes providing sufficient on-shelf availability and preventing out-of-stock situations which have a direct economic impact on profit and consumer satisfaction (Trautrims et al., 2009).

Supply chain managers need to be proficient in three skill categories – in order of importance – management skills, business skills, and supply chain skills (Mangan & Christopher, 2005). However, these skills cannot exist in isolation as functional silos need to be overcome and ideally result in integrated supply chains. This integration of skills principle applies to retail stores where the activities of many business functions, including replenishment, pricing, and sales, coexist in a more-or-less integrated way (Trautrims et al., 2012).

There is a need for a greater cross-training across functional boundaries such that human resources will have a *T-shaped skills profile* (Mangan & Christopher, 2005).

Although in-store staff may operate in their functional area, such as sales, they need to understand other functions such as pricing and distribution and that their own function outside the store can affect other steps in the supply chain and vice versa. The concept here is that as well as bringing in-depth and specific skills to the job – the vertical bar of the "T" – human resources will also need a wider understanding of related functional areas of the firm's supply chain. These other functional areas include marketing, real estate, and activity-based costing – the horizontal bar of the "T."

## 3 Sustainability and Retailing

### 3.1 Sustainability in General

Sustainability has become increasingly important and needs to form part of firm logistics and supply chain leadership and strategies, including retailers (Grant et al., 2022). The term sustainability entered the popular lexicon with the World Commission on Environment and Development, known as the Brundtland Commission, *meeting the needs of the present without compromising the ability of future generations to meet their own needs*. The Brundtland Commission delineated five key areas related to sustainability: species and ecosystems, energy, industry, food, and population and urban growth; however, Grant et al. (2017b) added fresh water to form a holistic view of sustainability.

This holistic view is manifested through the United Nation's (UN's) sustainability development goals (SDGs) (UN, 2022) which are a *"blueprint to achieve a better and more sustainable future for all . . . address global challenges . . . including those related to poverty, inequality, climate, environmental degradation, prosperity, and peace and justice . . . interconnect . . . and in order to leave no one behind . . . important to achieve each Goal and target by 2030."*

Essentially, the SDGs are a call to action for countries and organizations to promote prosperity while protecting the planet. Actions include tackling climate change and environmental protection, and which recognizes that ending poverty goes together with strategies that build economic growth and address a range of social needs including education, health, social protection, and job opportunities. There are seventeen SDGs, and each contains specific targets to achieve the overall sustainability goal. They are listed below along with their applicability to retail supply chains.

- SDG1: No Poverty. Applicable for retailers to provide good-quality P&Ss at affordable but fair prices
- SDG2: Zero Hunger. Applicable for food retailers to provide secure access to safe and sources of food P&S
- SDG3: Good Health and Wellbeing. Applicable for retailers to provide P&S to promote and engender good health and well-being

- SDG4: Quality Education. Not particularly applicable to most retailers, but likely to retailers specializing in educational P&S
- SDG5: Gender Equality. Applicable for retailers to ensure equal employment opportunities for all retail workers, and provide P&S for all retail consumers, regardless of gender, race, and creed
- SDG6: Clean Water and Sanitization. Applicable for food retailers to ensure access to safe, clean water
- SDG7: Affordable and Clean Energy. Not particularly applicable to most retailers, but likely to retailers specializing in energy P&S
- SDG8: Decent Work and Economic Growth. As in SDG5, applicable for retailers to ensure fulfilling employment with prospects for advancement
- SDG9: Industry, Innovation, and Infrastructure. Applicable for retailers to work with their supply chain partners to provide continuous improvement of P&S to ensure more sustainable and desired P&S are available in the marketplace
- SDG10: Reduced Inequalities. As in SDG5, applicable for retailers to ensure equal employment opportunities for all retail workers, and provide P&S for all retail consumers, regardless of gender, race, and creed
- SDG11: Sustainable Cities and Communities. Applicable for retailers to provide equal access to all potential consumers of retail P&S at fair and affordable prices
- SDG12: Responsible Consumption and Production. As in SDG9, applicable for retailers to work with their supply chain partners to ensure more sustainable and required amounts of P&S are available in the marketplace and encourage responsible consumption and behavior by consumers
- SDG13: Climate Action. Applicable for retailers to review and improve their supply chain and other practices to ensure they are sustainable and contributing to climate action initiatives
- SDG14: Life Below Water. As in SDGs 2 and 6, applicable for food retailers to provide access to safe and responsibly sourced seafood P&S and not detrimentally impact life below water
- SDG15: Life on Land. As in SDG13, applicable for retailers to ensure their retail supply chain and other activities to not detrimentally impact life on land
- SDG16: Peace, Justice and Strong Institutions. Not particularly applicable to retailers except to ensure cooperation and adoption of SDG16 principles and initiatives
- SDG17: Partnerships for the Goals. As in SDG16, not particularly applicable to retailers except to ensure cooperation and adoption of SDG17 principles and initiatives

Grant et al. (2017b) identified six key exogenous trends affecting logistics and supply chain sustainability in firms: globalization, relationships and outsourcing, technology, time compressions or the lean versus agile debate, the rise of e-commerce, and the one-way flow of logistics. They also noted that firms should address issues of reverse logistics – which forms part of the circular economy debate; assessment of greenhouse gas (GHG) emissions – particularly cardon dioxide or $CO_2$ emissions; and the *greening* of four functional activities – transportation and networks, buildings, sourcing, product and packaging, and administration. These activities can each improve logistical and supply chain sustainability.

These trends and issues also affect the retail sector where sustainable retail supply chains encompass many issues. These issues include the following:

- Consumer expectations and their own sustainable behavior
- Reverse logistics of packaging
- Distribution devices such as roll cages from manufacturer to distribution center to stores
- Transport considerations regarding modes, fuel choice, consumption, and greenhouse gas (GHG) emissions
- Location and number of storage facilities and distribution centers as they affect land use, inventory levels, and waste reduction
- Disposal of various products from lithium batteries used in electronic devices to out-of-date perishable food
- Responsible sourcing of environmental and societal friendly products in the global supply chain

All these issues are imbedded in one or more areas of the SDGs (Grant et al., 2017b).

## 3.2 Sustainability Performance Measurement

An issue for all firms, including retailers, is how to delineate, measure, manage, and report sustainability initiatives. That is, there is importance in sustainable or environmental performance measurement. Interest in supply chain environmental performance measurement and management has increased since the early 2000s due to climate change, diminishing raw materials, excess waste production, and increasing levels of pollution and has garnered attention in the academic literature (Sarkis et al., 2011).

One method that has been suggested is the World Business Council for Sustainable Development, or WBCSD, and the World Resources Institute, or WRI (GHG) framework first introduced in 2004 (World Business Council for Sustainable Development (WBCSD), 2004) & (World Resources Institute (WRI), 2004. This framework considers three scopes for emissions: Scopes 1, 2, and 3. Scope 1 are emissions which are calculable by the firm, Scope 2 includes indirect emissions from electricity use, while Scope 3 emissions are from sources not owned or controlled by the firm.

Integrated environmental management requires combining many aspects into a holistic system (Grant & Elliott, 2018). In the natural environment, problems caused by materials or infrastructure added to, or removed from, a system require a risk assessment framework, which is subsequently managed using actions through vertical integration of governance and the horizontal integration of stakeholder action. Those actions are required to ensure the structure and functioning of the system is protected and maintained while at the same time the goods and benefits required by society are delivered. Consideration of these interactive environmental relationships gives rise to assessing whether the strategy or strategic option fulfills various criteria related to environmental management.

Elliott (2013) presented the *10-tenets* of sustainable or environmental management which were designed to ensure that the management of, and solutions for, a natural environmental problem will be sustainable, successful, and acceptable to society. As such, these *10-tenets* should fall within what is realistically possible by encompassing the socioeconomic and governance aspects – a pragmatic approach. Using the *10-tenets* also suggests that environmental management would be seen by wider society as achieving sustainability and in turn would more likely be accepted, encouraged, and successful. While devised for natural environment problems, the underlying principles for each of the *10-tenets* are also applicable for business management and supply chain activities, including retail (Grant & Elliott, 2018). The *10-tenets* are listed below and are self-explanatory.

- Socially desirable/tolerable: Environmental management measures are required or at least are understood and tolerated by society as being required; that society regards the protection as necessary.
- Ecologically sustainable: Measures will ensure that the ecosystem features and functioning and the fundamental and final ecosystem services are safeguarded.
- Economically viable: A cost-benefit assessment of the environmental management indicates (economic/financial) viability and sustainability.
- Technologically feasible: The methods, techniques, and equipment for ecosystem and society/infrastructure protection are available.
- Legally permissible: There are regional, national, or international agreements and/or statutes which will enable and/or force the management measures to be performed.
- Administratively achievable: The statutory bodies such as governmental departments, environmental protection, and conservation bodies are in place and functioning to enable successful and sustainable management.
- Politically expedient: The management approaches and philosophies are consistent with the prevailing political climate and have the support of political leaders.
- Ethically defensible: How costs of acting are determined and calculated for current and future generations.
- Culturally inclusive: Notwithstanding actions are desired and tolerated by society, there may be some cultural considerations taking precedence.
- Effectively communicable: Communication is required among all the stakeholders to achieve the vertical and horizontal integration encompassed in the foregoing nine tenets.

However, Sullivan and Gouldson (2013) noted that there may be inconsistencies in information provided by firms for emission sources and the factors influencing performance. For example, if a firm reports a reduction in GHG emissions from energy use, was this change due to an actual reduction in energy use by shifting toward lower carbon intensity fuels or changes in calculation methodologies such as new emission factors? This dilemma requires more granular and standardized measures and management systems.

Traditionally, supply chain performance measures have been quantitative and orientated around measuring cost, time, and accuracy. In one study in the mid-2000s, the most widely used measures identified were financial (38%), but 60% of all measures were functionally based. The proliferation of supply chain measures is a symptom of how supply chains are managed – they are complex structures, and practitioners have consequently created numerous measures to manage them, often duplicating them within and across supply chain nodes or sites (Grant et al., 2017b).

Sustainable supply chain performance measures have focused on long-lived GHG emissions due to the importance attached to them in the fight against climate change. For example, the Glasgow Climate Pact in 2021 (UN COP26, 2022) secured near-global net zero emissions target – known as Nationally Determined Contribution or NDCs – from 153 countries. The pact kept in place a limit to temperature rises to below 1.5 degrees Celsius or below by 2030.

Shaw et al. (2021) investigated the use of sustainable performance measures by members of the UK's chartered Institute of Logistics and Transport (CILT), which included retailers, and found that the three key enablers and inhibitors, in order of importance, were, respectively, a desire to reduce cost, improve operational efficiency, government regulations and legislation, and cost, supply chain complexity, and obtaining data.

## 3.3 Environmental Management Systems

Some confusion exists on the operationalization and management of measures and what form of framework to use. For assistance in doing so, firms can adopt an environmental management system (EMS), which includes the International Organization for Standardization's ISO 14001 series or the European Union's eco-management and audit scheme or EMAS to provide guidance. ISO also developed ISO 14031:1999, an environmental performance evaluation tool that provides firms with specific guidance on the design and use of environmental performance evaluation and on the identification and selection of environmental performance indicators. This allows any firm regardless of size, complexity, location, and type to measure their environmental performance on an ongoing basis. ISO 14031 divides environmental performance indicators into three classifications (Shaw et al., 2010):

- Management Performance Indicators (MPI) of an organization's efforts in influencing its environmental performance, e.g., environmental costs or budget (dollars per year), percentage of environmental targets achieved, and time spent responding to environmental incidents (person-hours per year)
- Operational Performance Indicators (OPI) of an organization's operational environmental performance, e.g., raw materials used per unit of product (kilograms per unit), hours of preventive maintenance (hours per year), and average fuel consumption of vehicle fleet (liters per 100 km)

- Environmental Condition Indicators (ECI) of local, regional, national, or global conditions of the environment and which are useful for measuring the impact of an organization on the local environment, e.g., frequency of photochemical smog events (number per year), contaminant concentration in ground or surface water (milligrams per liter), and area of contaminated land rehabilitated (hectares per year)

A study of EMS use in three countries by Grant et al. (2021c) found ISO 14001 was the most common EMS adopted. Key benefits for EMS adoption were financially linked to customer requirements, reducing waste, and operating more efficiently. Key barriers to effective implementation included a lack of standard reporting and measurement tools and government direction, and supply chain complexity. Firm size and motivation are also issues regarding adoption. Grant et al. (2021c) also found SMEs did little reporting at all, and while larger firms internally report their environmental supply chain performance measures, they may not do so externally unless required by government or legislation.

This supported extant research that reporting, and benchmarking, of environmental supply chain performance measures and EMS adoption remain very much underdeveloped and indicated that many firms do not feel under any pressure to report but in any event are also struggling with an initial concept of *what to measure* and *how to measure it*. Further, they found many respondents in UK have developed their *own company-designed* reporting framework and concluded practitioners are leading academia. In a retail supply chain context, Shaw's (2013) study, which informed Grant et al. (2021c), found that the most important environmental performance measures for retailers were in order of importance cost, electricity use, waste recycling, and warehouse efficiency. These measures are intuitively sensible as they reflect a retailer's role in providing goods for sale in fixed store locations where emissions and costs related to electricity and/or heating, dealing with packaging waste for goods delivered to store, and efficient and thus sustainable warehouse throughput.

Missing from these measures are those related to upstream transportation and downstream delivery to consumers purchasing online, which may not be provided by the retailer. The most important environmental performance measures for the transport and warehousing sector in Shaw's (2013) study were electricity, fuel consumption, and mileage as they relate to cost. Hence, the latter two measures could be added to a retailer's "environmental performance measurement mix" so they can determine their overall environmental impact. However, consideration of the entire retail supply chain is still lacking here if retail, transport, and third-party logistics providers operate in their own domains.

### 3.4 Sustainability in Retail Supply Chains

Supply chain activities are responsible for much of the environmental impact of modern retailing. Notwithstanding this is a nascent topic in retailing, progress has been made – between 2005 and 2015, 22 of the UK's largest retailers reduced the carbon intensity of store deliveries by 40% and the amount of waste sent to landfill from 40% to 4% (McKinnon, 2019).

Specific environmental effects of retail supply chains and related SDGs include the following (Rogers & Tibben-Lembke, 1998; Piecyk & McKinnon, 2007; McKinnon, 2019; Gold et al., 2015; Manninen et al., 2018):

- Not only GHG emissions including carbon dioxide ($CO_2$), the most important of them due to it being emitted from transport and warehouse activities, including refrigeration, but also pollutants such as nitrogen oxide (NO), sulfur dioxide ($SO_2$), and other particulate matter or PM10 (SDGs 7, 9, and 13)
- Aural intrusion from noise emanating from heavy goods vehicles (HGVs) and DCs, and increasingly vans used for e-commerce or online deliveries (SDGs 9 and 11)
- Accidents due to the large volumes of HGV traffic that lead to personal injury or death, property damage, and use of emergency services (SDG9)
- Waste in the form of packaging materials and food that is no longer saleable or edible (SDGs 12 and 13)
- Visual intrusion from large DCs dominating some landscapes and large HGVs in urban or rural environments where they may be out-of-place in terms of scope and scale (SDGs 9 and 11)
- Procurement practices that encourage overbuying by both retailers and consumers (SDGs 2 and 9)
- Human resource practices where retailers do not treat workers fairly and equitably and may be guilty of indirectly supporting modern-day slavery in their upstream supply chain (SDGs 5, 8, 9, and 10)
- Reverse logistics and recycling that form part of the circular economy concept (SDGs 9, 11, 12, and 13)

Additionally, while not direct environmental effects, retailer influence over consumers is still limited and more needs to be done to ensure consumers are also cognizant of sustainability issues and practice what they believe (Blechingberg-Kilpi & Grant, 2020). Retailers also face reputational risk if they practice in *greenwashing*, defined by Delmas and Burbano as the "art of misleading consumer regarding the environmental practices of a company," i.e., at the firm level, or the "environmental benefits of a product or service," i.e., at the product level (Delmas & Burbano, 2011, p. 65). More than 10 years after Delmas and Burbano's article, 58% of 1,491 chief executive officers (CEOs) around the globe admitted their companies were guilty of greenwashing; that figure jumped to 68% among US CEOs. Almost two-thirds of CEOs globally questioned whether their firm's sustainability efforts were genuine (Peters, 2022).

## 4 Future Directions for Retail Research and Practice

There are major issues regarding sustainability and retail supply chains that require further research and action by firms. First, generations Y and Z have become the predominant market segments for the foreseeable future in a difficult economic environment. They will still purchase but are discerning consumers regarding product quality and value for money and prefer e-commerce or online solutions that are provided free of charge. While there is extant research about these two generations across many disciplines, researchers need to better understand their needs and behaviors for retailing and order fulfilment either in-store or online through in-depth, mixed methods studies. Retail practitioners need to recognize the changes in their market segments and purchasing behavior brought about by current economic circumstances and focus on their needs and preferences for quality, convenience, and sustainability, particularly in making them aware of the trade-offs and real costs of sustainable actions.

Second, technology appears to be misunderstood regarding its true potential as technology has become the end as opposed to being the means – an enabler. Research should follow the lead of Vidgen et al. (2017) and Kamble et al. (2019) to better understand ICT and IoT's role in modern supply chains. Retail practitioners should revisit all their technological processes and activities to ensure the outputs they receive represent true information about their supply chain and retail activities for better decision-making in meeting consumer demand through their sourcing and procurement, stock management and waste disposal through better forecasting to achieve tangible and long-lasting cost savings.

Third, the e-commerce-online-omnichannel phenomena is here to stay, especially for generations Y and Z, but has various operational and cost challenges. The e-commerce business environment truly represents individualized solutions for a market segment of one. Research should look at these issues more on a granular level before suggesting aggregate, one-size-fits-all solutions. Retail partitioners should deconstruct their e-commerce offerings and practices to develop more innovative operations that achieve true efficiencies.

Fourth, sustainable or environmental performance measurement and management continue to represent underdeveloped areas in retail supply chains. Research should investigate the lack of adoption of sustainable performance measurement and environmental management systems among organizations to crystallize barriers and inhibitors to provide better guidance for retail firms to know what they might measure, why they do so, and how they should do it. Retail practitioners should embrace sustainable performance measurement and management and incorporate measures into their ongoing supply chain practices. They will also need to determine the appropriate measures for their firm and its supply chain either through their own initiatives or from guidance provided from research.

Fifth, the social element of the TBL needs to be better addressed to ensure consumers, employees, and suppliers are treated fairly, equally, and with dignity. Researchers need to better investigate the nature or relationships and the "social contract" among these stakeholders. Much has been written over the past 40 years about the nature of relationships and collaboration in the supply chain, and many findings argue more and better collaboration and integration are needed in SCM. However, collaboration and integration do not appear to move beyond transactional relationships (Grant, 2005) and researchers need to get to the true root causes to effect real firm-behavioral change. Retail practitioners should review their internal human resources practices and those of their key partners, including suppliers and 3PL service providers, to ensure the proper treatment of all.

Finally, while it might seem intuitive, the specific environmental effects of retail supply chains discussed above need to be put into practice in more retail supply chains. Research and practitioner initiatives should follow the fourth point above regarding measurement and management, but holistic solutions could include adopting techniques such as the WRI GHG Scope framework, the *10-tenets*, or even life cycle analysis (Grant et al., 2017b) to achieve holistic sustainability in retail supply chains.

## 5 Summary and Conclusion

This chapter has discussed issues of concern in retail supply chains focusing on a triple bottom line view of sustainability as an underlying theme related to them. The seventeen SDGs form part of that focus and enable a better appreciation of discrete aspects within the TBL.

Not every issue concerning retail supply chains and their implications on sustainability could be addressed in this limited space. However, the essence of whether sustainability is well understood and practiced by retailers or whether it represents a paradox that cannot be solved was presented in insufficient detail to allow reflection by readers. The chapter has demonstrated there are opportunities for retail supply chains to embrace sustainability such that the paradox should not exist. However, some elements of sustainability are underdeveloped and nascent, and not well understood, and thus provide an appearance of paradoxical behavior.

SCM is recognized as one of the most important business functions in firms, particularly in the retail sector where consumer demand is independent from retailer activities and highly variable. This importance has been well-lit in the early part of the 2020s due to externalities such as the COVID-19 pandemic, the state of the world economy, and various conflicts around the globe. Some say that "supply chain management" has become one of the key phrases in daily conversation during this time. Hence, supply chain managers have greater opportunities to actively participate in setting a firm's strategy to meet challenges and contribute to the firm's success.

A strategic imperative increasing in importance is sustainability and the three elements of the economy, environment, and society in the TBL. All firms with active supply chains, including retailers, need to address these three mandates do provide sustainable maintenance of the natural environment, long-term economic growth and development, and a regard for societal and human concerns on this fragile planet. The rewards for recognizing and accepting these challenges in a creative and proactive manner should prove substantial.

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# Reverse Logistics Within the Supply Chain

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## Contents



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**Abstract**

While much emphasis is on the procurement of raw materials, manufacturing of products, storage, and delivery to the end user in the forward supply chain, the backward or reverse logistics process of the supply chain is of growing strategic and environmental importance. Examples of reverse logistics are included in this chapter along with examples of reusing products and remanufacturing wastes, recycling, reclamation, refurbishing, restocking, and even repurposing and upcycling products. All processes reduce landfill waste and can decrease manufacturing needs, conserving scarce resources, and reduce emissions and organizations' carbon footprints. Partners in the reverse logistic process include collection and consolidation centers and recover facilities. Managing reverse logistics are critical functions of modern supply chain management. With an increasing interest in the environmental impact of organizational activities, this chapter presents the need to integrate reverse logistics supply chain activities into organizations and the circular economy for social sustainability.

**Keywords**

Reverse logistics · Green supply chain · Social sustainability · Environmental impact · Recycling · Reclamation · Scarce resources · Emissions · Carbon footprint · Circular economy · Green logistics · Supply chain

## 1 Chapter Overview

This chapter begins with a review of the various definitions of reverse logistics in the academic and business literature before presenting examples of reverse logistics in practice in circular supply chains – which include both the forward and reverse logistics flows. Next the reader is introduced to the goals and benefits of reverse logistics in practice followed by a brief introduction to recent reverse logistics research and industry examples from practice to clarify and illustrate reverse logistics. Our examples include the tufted carpet production, the electrical equipment industry, medical and pharmaceuticals, and construction.

The chapter then presents the linkages between reverse logistics and social sustainability as well as internal human resources and social sustainability, particularly the positive impact of the creation of low-skilled jobs from reverse logistics. A presentation of the all-encompassing concept of the circular economy is then presented. The circular economy relies on the use of reverse logistics to complete the birth-to-death-to-rebirth cycle.

Technology, particularly the use of blockchain to support reverse logistics, follows in the presentation along with a coverage of green reverse logistics and green supply chain management – all derivations of the circular economy definition and its components with a green or environmental focus.

The chapter ends with emerging concerns including how to measure reverse logistics performance and the managerial implications of revising accounting standards to value waste and aftermarket reclamation as assets for an organization as well as the call to automate reverse logistics processes.

## 2 Introduction

So, what encompasses reverse logistics? In its simplest presentation, reverse logistics refers to the process of collecting used goods for reuse, repair, remanufacturing, recycling, or disposal to produce new products (Chen et al., 2021). It is the process of moving a typical product in an inverse or reverse path from mainstream logistics to retrieve value or ensure proper disposal (Hansen et al., 2018). Reverse logistics is the proper reuse of returned products. Reverse logistics is also a tool to recover and recycle or implement green (environmentally sensitive or compliant) disposal of goods to reduce pollution (Zarbakhshnia et al., 2019). For example, when you return used Amazon shipping boxes to your town's recycling center to be remanufactured into new cardboard boxes, you are recycling, but the overall process from the manufacturing viewpoint is termed reverse logistics.

Typically, companies pursue three main activities in reverse logistics (1) gathering, where consumers discard their used products; (2) reconstructing, where examination, separation, classification, rehabilitation, or recycling/disposal is done; and (3) managing demand centers, where restored products are redistributed and sold. Reverse logistics is of interest to practitioners, students, and researchers alike because companies gain a competitive advantage (Sharma et al., 2021) and create economic value by returning used products back into the production cycle, to be transformed into new products for the same market or even for new markets (Ribeiro et al., 2021). The core objectives of reverse logistics are cost minimization, profit maximization, and environmental benefits.

End products as well as materials used in packaging, including plastic, metal, and glass, can be collected, fixed, and transformed into new products. There is a rapidly increasing interest in product recovery, closed-loop supply chains, circular economy, and reverse logistics for mitigating environmental impairment. Reverse logistics has attracted many manufacturers, and the reverse logistics restructuring actions offer both direct and indirect benefits to manufacturers as will be discussed.

### 2.1 Defining Reverse Logistics

To better understand reverse logistics, it is first necessary to review several somewhat similar definitions. While reverse logistics definitions are quite similar, the field lacks and need a a standardized definition. Reverse logistics is the efficient control of raw materials, finished goods, and in-process inventory from production to consumption to regain value from the disposed goods. Reverse logistics is important as a profitable and sustainable business strategy (González-Sánchez et al., 2020). Reverse logistics can result in cost savings, and quality and customer service improvements, and be used by organizations to highlight an environmental focus. Definitions of reverse logistics vary. The overall supply chain management concept is seen as "greener" with the development of reverse logistics programs. Both external pressures and internal factors, including reducing costs and increasing operational performance, are motivating companies to pay more attention to these reverse product flows. Reverse logistics, causing both the flow of goods and information to move in the opposite direction from forward logistics activities that support a product and return goods for recycling, remanufacturing, reuse, and disposal (Fan et al., 2020), includes ecological treatment during a product's life (Chen et al., 2019).

Reverse logistics is often defined as the management (planning, organizing, leading, directing, and controlling) of the reverse flow of logistics from the end user to disposal or preferably recapture or repurposing. Long et al. (2019) define reverse logistics as product return, source reduction, regeneration, material substitution, object reuse, waste cleaning, retreatment, maintenance, and reproduction in logistics.

In the concept of sustainability, reverse logistics is defined as a business strategy that acts as a driving force in carrying out recovery activities effectively to improve sustainability. Recovery options include remanufacturing, repairing, refurbishing, cannibalizing, and recycling (Yue et al., 2020). Reverse logistics network implementation is an important strategic decision (Xu et al., 2020) and supports the ecological behavior of industries. Reverse logistics improves competitiveness, reduces waste, provides greater profitability, and improves customer relationships. The flow of returned goods and packaging, including customer service and final disposition of returned items, has found success in highly customized returns-management programs (Melan, 2021).

Modern SCM has become more complex by the necessity to include reverse logistics operations. Literature on green supply chain management (GSCM) that relates SCM with sustainability is growing as well (Lambrechts, 2021). In fact, the latest trends place GSCM within the field of the circular economy (Krikke, 2020).

Strategic factors to consider in implementing reverse logistics programs include costs, overall quality, customer service, environmental concerns, and legislative concerns. On the operational side, factors to consider are cost-benefit analysis, transportation, warehousing, supply management, remanufacturing and recycling, packaging, and the overall desires of the customers or end users. To make reverse logistics operate effectively, all supply channel members must be committed to the process, and it needs to be financially attractive to each participant. For example, do customers feel a responsibility to recycle and return used products and do they demand recycled content in their new products? Often incentive systems or no-cost, easy return systems exist to make reverse logistics work without external governmental regulation. Because the quality of inputs for reuse is important in many situations, clean, safe return methods must exist.

Life cycle analysis can be used to provide a framework for the development, manufacturing, use, and disposal stages of products and can be used for measurement and assessment. Overall manufacturing costs can be reduced if the firms alter their operations through pollution prevention activities including material substitution, process redesign, and reclamation or reuse design, or reverse logistics.

## 2.2 Examples of the Circular Supply Chain

As we have reviewed in our coverage of reverse logistics definitions, reverse logistics is just one director or flow of the entire circular supply chain. Because products and supply chains are unique, their circular flows are unique as well. Success stories of reverse logistics include a global manufacturer of specialty chemicals who manages the return of their reusable stainless containers and a consumer electronics company who recovers products and sorts them for repair, refurbishing, repackaging, or reselling through discount channels. The consumer electronic firm's greatest challenge was collecting items that were obsolete, unrepairable, or of such low value that the costs to transport them outweighed the benefits of repair. Successful companies have developed highly customized returns-management programs to avoid such issues. Reverse logistics programs can recover assets that would otherwise be lost, so firms are urged to place a greater emphasis on managing all returned products.

## 2.3 Goals and Benefits of Reverse Logistics

While briefly mentioned early with the definition of reverse logistics, this section presents a broader coverage of both the goals and benefits or reverse logistics to organizations. There are several reasons why reverse logistics has received attention, from a pure environmental concern to both competition and marketing motives as well as ways to reduce costs and increase revenues. In addition, by implementing reverse logistics a firm gains intangible benefits associated with an improved corporate image, corporate social legitimacy, enhanced goodwill, and competitive advantages. Continuous improvement and satisfaction of the consumer is also a key goal of a reverse logistics system.

Companies gain trust from customers by eliminating defective products from the supply chain. In this regard, the design of the logistics network, as a part of the supply chain planning, is important. Therefore, optimization of this network can have a positive effect on supply chain objectives, especially cost reduction, accountability, and efficiency (Guo et al., 2022). The key stimuli of reverse logistics are often environmental laws, economic benefits, consumer awareness, and environmental responsibility. Table 1 reviews recent academic research on the many benefits of reverse logistics.

**Table 1** The benefits of reverse logistics

| Benefits of RL | Authors |
|---|---|
| Reverse logistics performance increases customer satisfaction | Pham and Ahammad (2017)<br>Nisar and Prabhakar (2017)<br>Mahindroo et al. (2018)<br>Panigrahi et al. (2018) |
| Reverse logistics results in improved economic performance *and* higher customer satisfaction | Euchi et al. (2019) |
| When implemented correctly, reverse logistics performance decreases costs and increases profits | Agarwal et al. (2016a, b and c)<br>Han and Trimi (2018)<br>Tosarkani and Amin (2018)<br>Li et al. (2018) |
| Reverse logistics performance enhances the efficiency of resources' utilization | Sirisawat and Kiatcharoenpol (2018)<br>Chileshe et al. (2018) |
| Organizations approach environmental concerns through reverse logistics contributions | Martinez-Martinez et al. (2019) |
| The main concern of reverse logistics activities should be not only decreasing costs but also be directed to environmental protection and go green concept as well | Tan and Guo (2019) |
| Reverse logistics monitoring and decision-making must be explored to enhance organizations sustainability efficiencies | Farooq et al. (2019)<br>Pundhir et al. (2020) |
| The value of the supply chain should be reinforced with reverse logistics, and reverse logistics significantly contributes to sustainability objectives | De Clercq et al. (2018) |
| Reverse logistics performance maximizing the value of returned products | Han and Trimi (2018) |
| Reverse logistics is considered as a tactical instrument for (Business-to-Consumer) e-commerce since it allows firms to have a potent competitive advantage manifested along with a good corporate image, consumers' loyalty, and a better competing position | Al Majzoub and Davidavičienė (2019) |

## 3 Current Research in Reverse Logistics

The growing emphasis on reverse logistics has led to a corresponding growth in the number of academic studies and professional literature on the topics beyond the research benefits previously mentioned. Organizations participating in reverse logistics are motivated by reasons including economic benefits, pressures from consumers, and even environmental law. Recent studies have analyzed the reverse logistics implementation and methodology, such as cost- minimization (Zhang et al., 2022), valuing return materials (Sonego et al., 2022; Liu et al., 2019), and designing reverse logistics networks for optimal waste collection (transportation routes) (Joshi, 2022). Many forwarding and transport companies are devoting time and energy to the management and understanding of reverse logistics which is often from online purchase returns.

Zhang et al. (2020) agrees that reusing used products will reduce waste and improve industrial environmental performance. In addition, construction of a reverse logistics model is an important part of the research on determining optimal reverse logistics locations. Kashveenjit (2021) study explored the empirical analysis of green product design, which makes reverse logistics and recycling easier, and institutional pressures on firm's performances by employing from ISO14001 certified electrical and electronic manufacturing firms in Malaysia. Richnák and Gubová's (2021) study found that the dominant position in green and reverse logistics was achieved by large production enterprises from the automotive industry.

In e-commerce, reverse logistics the e-commerce vendor is in the middle of the reverse flow of goods from the point of consumption to the point of production (Morgan et al., 2018). In fact, online purchases have led to a closer scrutiny of e-commerces' returning, reducing resources' utilization through effective management of recycling, waste discarding, restoring, and remanufacturing (Mahindroo et al., 2018). Refurbishing is a profitable practice for firms engaged in managing e-waste like cellphones (Santana et al., 2021). Therefore, the success of the e-logistics business highly depends on the effective implementation of reverse logistics activities (Al Majzoub et al., 2019; Majzoub et al., 2020).

Many freight forwarding and transport companies are devoting time and energy to the understanding of the reverse logistics. These companies have tested reverse operations with the best specialists in the field (Kubasakova & Kubanova, 2021). It is possible to determine ways to increase the environmentally friendliness of spare parts delivery, as the use of green vehicles increase along with shift to intermodal freight and terminal transportations and the development of routes that focus on the environmental situation and minimizing empty return truck runs. Suppliers in the automotive industry for manufacturers including Ford of Europe have successfully developed reverse logistic approach by designing returnable, robust, reusable storage trays for the delivery of components, rather than create endless packaging waste (Makarova et al., 2021). Systematic implementation of green logistics methods and tools ensures the achievement of sustainable development aims (Rakhmangulov et al., 2018), and research is ongoing.

## 4 Industry Examples of Reverse Logistics in Practice

The following section discusses several practical examples of reverse logistics in select industries including carpet recycling, electrical and electronic equipment, medical healthcare, pharmaceutical sectors, and the construction sector. By presenting the implementation of reverse logistics within these industry contexts, it is possible to better understand the growth and potential of reverse logistics.

### 4.1 Tufted Carpet Production

Tufted carpet yields much waste when the flooring is changed in offices, schools, and institutional facilities. The amount and visibility of the used carpeting has served to place much attention to recycling. The Carpet America Recovers Effort (CARE – see www.carpetrecovery.org) works to find advance market-based solutions to increase landfill diversion and promote recycling of postconsumer carpet. CARE encourages design for recycling.

The carpet industry, while moving to a circular economic model, is currently focusing on one key facet of reverse logistics, recycling. Recycling is facilitated when governmental regulations mandate industries include recycling in a product's design. Most of the European Community has had environmental regulations for some time. However, in the USA, these federal mandates do not exist for all products and industries. Without mandates, recycling must have a positive financial impact for firms and at the same time provide a competitive edge in the marketplace.

For example, carpet recycling initiatives are growing and are creating new products from recycled carpet content. Carpet recycling is a challenging goal – because it is often very difficult to recycle carpet. Products that have been designed for ease of dismantling and recycling are managed more efficiently and thus have greater value at the end of life, allowing the effective recovery of materials or high-value components that can be used again.

Industry manufacturers have found uses and applications for their internal post-industrial wastes from carpet manufacturing and are using these production wastes to make carpet and padding products, some with more than 25% recycled postindustrial waste component. The remainder of the carpet waste is pelletized for use in plastic products or incinerated for fuel/energy. Most major carpet manufacturers buy yarn with recycled content and manufacture specialty lines of carpet that are marketed as more environmentally friendly, although few consumers question brands, content, or are motivated to make purchases of products with recycled content in this industry today (Hervani & Helms, 2006).

Used carpet can become carpet cushions, carpet backing, new caprolactam, as a raw material input, refurbished carpet, latex binding, new carpet, carpet tiles, carpet yarns and fibers, Nylon 6 pellets, padding, and nylon fiber. Used carpet can become construction products including parking lot vehicle bumpers or stops, road underlay material, plastic wedges, and concrete reinforcement filler. If turned into energy alternatives, used carpeting can be processed into energy conversions, fuel alternatives, and petrochemical feedstock, or used carpet can be processed into plastic pellets or resins that find new uses in automotive parts. Recycled carpets can become filler in waterproof board materials or bags for storm and water control or for archery targets and other landscaping or geotextile applications.

Examples of product creation from postconsumer waste include automotive plastics used in vehicles or storm bags used to hold back rising water in island communities and in areas experiencing rainy weather and flooding. The manufacturers of these products keep postconsumer and industrial carpet waste out of the landfills and fabricate engineering resins from the nylon raw materials. Uther uses of their engineering resins are in lawn and garden, consumer, and electrical products. GeoHay (see www.geohay.com), for example, is a direct substitute for hay bales used in road construction to deter erosion during product completion and uses recycled carpet in the product, and their reuse component makes them more economical than hay.

### 4.2 Waste Electrical and Electronic Equipment

A closed-loop supply chain is critical, and the return and remanufacturing of waste electrical and electronic equipment is key for recycling. In reverse logistics, it is very important to precisely predict the return of waste electrical and electronic equipment to make reasonable recycling plans (Yu and Solvang, 2016; Kilic et al., 2015), and remanufacturing production plans (Bottani et al., 2019).

The frequent and often required perpetual updating of electronic products – such as cell phones and computers – leads to increasing varieties and amounts of waste, which poses a threat to environmental protection and social development. The problem of reverse logistics of waste electronic products has gradually become the focus of increased attention. Waste electrical and electronic equipment importance is even greater with Industry 4.0 initiatives (Li et al., 2019). Not only is the amount of waste electrical and electronic equipment huge, but also the types of waste electrical and electronic equipment are continuously increasing and changing (Wang et al., 2019). However, it is difficult for both academia and industry to predict waste electrical and electronic equipment returns due to the uncertainty of the return quantities.

### 4.3 Medical Health Care and Pharmaceutical Sectors

Expired medicines have no recovery value in reverse logistics, unlike other products. This makes medical revenue logistics somewhat unique and interesting to consider in our discussion of reverse logistics. However, some medicines recovered from the internal supply chain, before the end of life, can be returned to stock and reimplanted for use before their expiration.

The issue of waste disposal in hospitals is a very important problem, and much research has been done in this area (Eren & Tuzkaya, 2019). Due to the global outbreak of COVID-19, the volume of medical waste and its risks have increased dramatically (Kargar et al., 2020; Yu et al., 2020) and there is a need for an inverse logistics system to manage waste. Shadkam (2021) proposed reverse logistics models in the field of COVID-19 waste management and especially vaccine waste and offers a network consisting of three parts – factory, consumers, and recycling centers – each with different subparts.

The increased volume of medical waste can be a great threat to the environment and human health if not recycled and disposed of properly, especially in developing countries. In the pharmaceutical sector, reverse logistics is relevant, contributing to reduced medication exposure to other people and the environment. Drug disposal is a problem for health security, since many drugs are still discharged as contaminants in the receiving waters. From an environmental perspective, studies show pharmaceutical compounds in the aqueous environment of sewage treatment plants, in water distribution systems, and even in rivers and lakes.

Paula et al. (2019) highlighted the environmental impacts of the pharmaceutical supply chains as solid waste and wastewater generation (caused by incorrect discharges), human well-being (increased aging and demographic change leading to an escalating dependency on medicines), and social equality (contrasting with lack of access, high prices, and losses in supply chains). Pharmaceutical supply chain management is a new but growing area of reserve logistic research, particularly in the areas of improved resource management.

### 4.4 The Construction Industry

Construction generates significant waste. Hammes et al. (2020) reviewed performance from suppliers, internal logistics, and waste management using data calculation from each specified indicator, while Vargas et al. (2021) reviewed studies on the application of reverse logistics in solid waste from the construction industry and concluded that reverse logistics is a viable alternative when it is well planned and executed. Vargas et al. (2021) reviewed studies on the application of reverse logistics in solid waste from the construction industry, providing a summary of current knowledge and specific areas for future research.

## 5 Reverse Logistics for Achieving Social Sustainability

Hopefully the industry examples have helped better present the issues across a myriad of production and consumption cycles. Now we turn our attention to the linkages between reverse logistics and the environmental goal of social sustainability. Social sustainability focuses on both identifying and managing business impacts on people, both positive and negative, according to the United National Global Compact (2022). Xue et al. (2021) stated that, in addition to legal regulations and economic operation, an enterprise should consider the effect of corporate image on social impact when making decisions with moral and ethical factors, and an enterprise is obligated to make prosocial decisions and assist in solving social problems.

Research on reverse logistics show that the concept of reverse logistics must be integrated into the supply chain and involve various stakeholders (Hammes et al. 2020). Businesses are under increasing pressure from multiple stakeholders to incorporate the principles of sustainability into their operations and activities. With the current disruptions in supply chain activities caused by the COVID-19 crisis, organizations are considering the social aspects of sustainability more seriously. Organizations should consider environmental and social sustainability criteria and indicators over the life cycle of a product or service. The following subsections will provide a brief description of these dimensions that need to be considered within the benefits of implementing reverse logistics.

### 5.1 Internal Human Resources and Social Sustainability

What does reverse logistics mean for jobs and human resources in general when considered within our larger social sustainability framework? For the internal human resources social sustainability dimension, reverse logistics provides organizations an effective tool to address supply chain interruptions. As an example, reverse logistics processes can generate lower skilled jobs. An organization can also address ongoing health and safety practices within their reverse logistics operations and demonstrate how costs to consumers can be lowered by improving worker health.

Within reverse logistics, however, risks and health and safety aspects could be negative. For example, reverse logistics requires disassembly of returned products, and sometimes these products contain hazardous substances that may not be visible. Organizations can make investments to minimize this exposure to hazardous substances in reverse logistics operations. Reverse logistics activities may add additional work requirements, but these may add to choices and multitasking that can improve employee morale in repetitive recycling jobs which often involve sorting by product type. The introduction and improvement of reverse logistics activities, through research and development efforts, may result in greater productivity and value-added from returned and collected end-of-life materials.

### 5.2 External Populations and Social Sustainability

What is the value of reverse logistics to society and external populations and groups, especially when considered in the larger social sustainability framework? Reverse logistics supports community projects as donations improve community security and safety, saving outlays to reduce such risks. For example, reverse logistics operations may reduce flows of waste disposal and divert waste from landfills, reducing contaminated run-offs, which lower individual and community risk of exposure to toxins.

The involved organizations or agencies can assess the monetary value individuals place on this community improvement activity resulting from reverse logistics. Organizations might also poll customers and community members to assess how they are affected by the improved resources and systems resulting from reverse logistics and recycled content in the organization's products.

Reverse logistics facilities can be based in distressed regions due to labor needs and available employees. An organization can provide ongoing human capital improvements from its reverse logistics operation by improving education and health of employees and community.

If an organization addresses ongoing regulatory and public services within its reverse logistics operations, the activities that help prevent spillages or leakages in the reclamation process that could cause health problems and possible damage to ecosystem can also be valued. An organization may provide ongoing improved resources from reverse logistics, including the value of reverse logistics jobs and generation of new jobs. For example, the economic values for ecosystem products or services contribute to the production of commercially marketed goods from reverse logistics systems, and the socioeconomic benefits they provide (Ellsworth-Krebs et al., 2022). The value of safer water resulting from reduced landfill disposals made possible from reverse logistics operations is another example of a measurable benefit.

### 5.3 Stakeholder Participation and Social Sustainability

Organizations have a number of interested external parties or stakeholders. These stakeholders can include internal employees and managers, owners and shareholders, the local and regional community, interested area citizens, consumers, supply chain partners, and a host of other external players. What is the role of stakeholders in reverse logistics, especially considered within the realm of the larger social sustainability of which reverse logistics is a key component? The presence of reverse logistics activities provides an ongoing collective audience or awareness to a community of an organization's product stewardship and environmentally focused image. This value could lead to greater competitiveness and profitability. Organizations can assess how stakeholder empowerment activities lead to greater awareness and participation among constituents supporting reverse logistics operations, especially for ecosystem preservation and health hazard reductions.

The measures of reverse logistics activities to maintain the benefits of the ecosystem and avoid additional costs to society, should the environment no longer exist, can be estimated. The information provided by stakeholders can aid in reverse logistics valuation. The risk reduction or averted cost from reverse logistics practices that aid communities in reducing wastes are useful computations.

### 5.4 Macrosocial Issues Measures and Social Sustainability

Moving beyond stakeholders to larger macrosocial issues, how is reverse logistics and the larger social sustainability concept viewed with this macrolens? To assess macrosocial issues, organizations must determine the importance of reverse logistics operations for ongoing economic welfare improvement activities. Because an organization may be introducing reverse logistics to comply with regulations, it may be supporting sustainable growth while preserving the natural ecosystem, which can attract travel and tourism to benefit the larger community. These are social benefits to the broader society to be measured.

If reverse logistics compliance promotes broader tourism or even jobs for a region, organizations can measure how far employees will travel for jobs. Reverse logistics programs thus can be justified at an organizational level but can also be applicable for regional policy makers. Reverse logistics can bring about benefits by the change in spending on goods that are substitutes for a cleaner environment and the benefit it generates from having products collected through a reverse logistics reclamation system versus paying landfill tipping fees or incurring the cost of returns.

There are other benefits generated from reverse logistics when the larger community is satisfied with waste reductions. Organizations can determine the values attributed to dimensions of a social benefit, including the contribution to the overall social welfare of reverse logistics. Social incentives from remanufacturing and reclamation may fall within this category, and their measurement can be a strategic advantage for organizations and enhance their macrolevel standing in the region.

An organizations' reverse logistics activities may reduce damage to the environment, and also reduce societal damage (e.g., reducing poverty or loss of jobs) when reverse logistics is adopted in a community by both private and public entities. Reverse logistics activities can lead to productivity improvements from recycling collection. If an organization provides ongoing enforcement of all reverse logistics operations, these activities lessen the burden of enforcement expenses by regulatory entities. The tax burden to the community is therefore reduced.

## 6 Reverse Logistics Linkages to Emerging Concepts

What does the current research tell us about the linkage between reverse logistics, the emerging concept of the circular economy, and social sustainability? The following section provides a discussion of how circular economy and blockchain technology help reverse logistics to achieve sustainability in supply chain. The circular economy is in opposition to a linear economy or the take-make-dispose model.

### 6.1 The Circular Economy and Sustainability

The circular economy works to keep products and materials in use, hence the strong direct relationship to reverse logistics. In addition, the circular economy work asks manufacturing to design waste and pollution out of the system and also asks organizations to help sustain and regenerate natural systems. Like reverse logistics, the circular economy requires products to produce as little waste as possible in the production and consumption process, so resources can be recycled. The advantage of the circular economy is that it can optimize the disposal of waste resources and achieve the goal of recycling and sustainable development of social resources. The circular economy aims to keep the value of a product in use (Wijekoon et al., 2022) and to retain material, labor, and energy. The current efforts toward the circular economy are improved waste management.

Firms should select the best reverse logistics provider for remanufacturing. In, closing the loop of product lifecycles, reverse logistics plays an important role to transitioning to a circular economy. While attention is placed on the environment in the topic of the circular economy, when selecting evaluation criteria, greater importance is placed on the product being environmentally friendly in design for reuse. Disposition is among the critical factors that can strongly relate to reverse logistics in the light of sustainable practices. It improves the overall operative productivity of reverse logistics.

Studies have investigated the topic of sustainability, and the circular economy, which is a subset of sustainability (Schöggl et al., 2020). While sustainable development research is focused on the integration of economic and environmental aspects, the cores of circular economy are “reduction, reuse and recycling,” which have more demands on the circularity and resource efficiency of the manufacturing industry (Pieroni et al., 2021).

The necessary conditions for the realization of circular economy in reverse logistics are complementary to each other (He et al., 2016; He, 2021). The main aim of green, sustainable logistics is to eliminate environmental damage caused by logistics activities and to strike a sustainable balance between economic, social, and environmental aims (Jiang et al., 2019).

Demand for goods and services coupled with increasing resource scarcity and price volatility is causing companies to move from a traditional “take-make-dispose” model to the circular strategy (Pakhomova et al., 2017), or circular economy, and is based on minimizing the consumption of raw materials and reducing waste disposal. It is easy to see how reverse logistics fits in a circular economy. Bringing products back for their next use or life is a central focus of the reverse logistics profession. Makarova et al. (2021) concludes that by closing-the-loop of product lifecycles, reverse logistics plays an important role to transitioning to a circular economy.

Returning to more detail on the circular economy, the circular economy appears to have emerged consisting of different theoretic concepts, for instance, cradle-to-cradle (Kopnina, 2018), and performance economy, reformative design, industrial ecosystem, and biomimicry (Meherishi et al., 2019). The circular economy attempts to significantly reduce raw material input and minimize waste and energy spillage through a circular model, which encompasses an open-ended mechanism supporting the sustainability notion (Sousa-Zomer et al., 2018). The circular economy certainly seems to optimize economic profits by lowering inputs and protecting the environment by reducing waste, but the focus remains implicit on the social aspect of sustainability (do Prado et al., 2020).

Recent studies in the field of sustainability focus on the three pillars of sustainability, namely, society, economy, and environment, to determine the evaluation criteria. In articles related to GSCM, more attention is paid to the reduction of the negative environmental impact in the transportation and manufacturing process when establishing evaluation criteria.

## 6.2 Blockchain Digitization to Support Reverse Logistics

Blockchain is a technology for storing and transmitting information transparently, securely, and operating without a central control body (Lu, 2019). Blockchains are databases that contain a history of all exchanges between its users since its creation. The database is secure and distributed; it is known as distributed ledger technology. It is shared by its users without an intermediary, allowing anyone with permission, if it is private, to evaluate the validity of the chain. As its name suggests, it is presented as a series of "blocks" containing data. The blocks are linked together by identifiers; a block contains its own identifier and that of the block before, yielding the "chain" aspect of the blockchain (Pilkington, 2016). Blockchain technology goals in supply chain management include ensuring transparency, accuracy, and traceability of data across multiple entities; it can serve as an incentive tool that can develop new markets and provide efficiencies. Its potential applications due to its information and process management abilities are extensive.

Blockchain technology with its many elements offers opportunities of visibility, through transparency and traceability capabilities, across the supply chain (Li et al. 2018) and particularly helps digitalizing the end-of-life supply chain loop closing activities that further support circular economy principles of which reverse logistics is critical (Wang et al., 2020). Tracking of materials as they flow through various supply chain and reverse logistics channels becomes important to identify location and to inform transporters of the necessary resources at various stages. Smart contracts can facilitate, improve, or even automate relationships between partners in RL as well as streamline flows. They can objectify legal issues, improve the efficiency of business processes and speed up transactions among other things. Organizationally, transportation, reverse logistics, and blockchain are all very inclined toward multiple partners, stakeholders, and organizations.

How can technology and information support reverse logistics in the future? The circular economy, of which reverse logistics is an integral part, is gaining in importance globally and locally. The COVID-19 crisis, as an exceptional event, showed the limits and the fragility of supply chains, with circular economy practices as a potential solution during and post-COVID-19. Reverse logistics is an important dimension of the circular economy which allows management of economic, social, and environmental challenges. Transportation is needed for reverse logistics to effectively operate, but research study on this topic has been relatively limited. New digitalization opportunities can enhance transportation and revenue logistics, and therefore further enhance the circular economy.

Bekrar et al. (2021) provide practical research, examining the nexus of transportation, revenue logistics, and blockchain as a digitalizing technology and further using a popular revenue logistics framework of activities – collection, separation and inspection, storage, disassembly, shredding and grinding, and outbound logistics; the authors identify a series of blockchain–transportation digitalization concerns across various activities and their overall relationship.

The transportation concerns include technological, organizational, and economic issues. Current business and industry landscapes are changing rapidly, requiring flexible, responsive, and efficient closed-loop supply chains to meet recent challenges such as sustainability and resilience. A symbiosis between the supply chain and technologies is part of the solution, in particular the integration of blockchain and revenue logistics.

Organizationally, transportation, reverse logistics, and blockchain (Lu, 2019) are all very inclined toward multiple partners, stakeholders, and organizations. The expansion and implementation of IT created opportunities in the global market, such as the development of e-commerce and e-logistics (Davidavičienė & Al Majzoub, 2021). The success of the e-logistics business highly depends on the effective implementation of reverse logistics activities (Al Majzoub & Davidavičienė, 2019).

## 6.3 The Role of Green Reverse Logistics and Green Supply Chain Management

With the environmental protection focus of reverse logistics, often implied in the term, the literature has begun to add the word "green" to both reverse logistics and supply chain management. The confusion among the terms remains until definitions catch up with practice, but often the terms are used simultaneously. For example, reverse logistic is an approach that supports the purpose of Green Supply Chain Management to reduce costs and environmental impacts, so it must be integrated along the supply chain (Tan and Guo, 2019; Mehmood et al., 2021) and involve all stakeholders. Due to severe environmental impacts, manufacturers have been encouraged to change their reverse logistics networks into green concepts and reduce harmful ecological impacts. Green supply chain management considers the environmental effects of all activities related to the supply chain, from obtaining raw materials to the final delivery of finished goods. Selecting the right supplier is a critical decision in green supply chain management.

Sustainable logistics can be analyzed and supported with procurement, transport, packaging, distribution, reverse logistics, and design and control of sustainable supply chain activities (Wang et al., 2018). Trivellas et al. (2020) believe that logistics functions are interdependent, and compromises are required in all areas of sustainability. Sustainability has become a global issue, and firms therefore must be careful about environmental issues in order to maintain a good image in today's competitive environment (Khan et al., 2020). Reverse logistics has become a more important topic in the field of environmental performance and sustainability among businesses (Centobelli et al., 2020a). The adoption of green initiatives can play a key role in implementing environmental sustainability strategies that affect all links in the chain complementary (Centobelli et al., 2020a; He et al., 2016; He, 2021).

In green logistics, Cooperation can reduce logistics costs and the negative impact of the bullwhip effect and increase service levels. Assessing the degree of synergy is key to analyzing cooperation, identifying weaknesses, and supporting development and is a key step in building a green logistics system. Seroka-Stolka and Ociepa-Kubicka (2019) agree green logistics is a development trend of modern logistics. The logistics community is turning to green logistics as a crucial concept for a sustainable logistics operation. Freight transport currently faces several challenges, especially in the environmental and social field, by leading to various forms of air, water, and soil pollution and noise, and contributing to global warming.

Parameterizing performance is the key to success in achieving an improvement and reducing waste (Jiang et al., 2019). Performance measurement is the first step to determine the right strategy to make improvements. Many researchers in their previous studies suggest that for the environment and the positive performance of the firm, green supply chain management has played a significant role in it. For addressing the issues of the environment, many firms adopt this to improve their supply chain operations. Mehmood's (2021) study is to test the three major concerns of green supply chain management practices and their implementation effect on the performance of the organization. Several studies have examined the green supply chain management assessment indicators at various phases (Hammes et al., 2020).

The role of reverse logistics in facilitating green supply chain management is being recognized by organizations, and there is a movement in organizations to integrate reverse logistics into their supply chain management activities. Recent studies have shown a significant linkage among reverse logistics, circular economy, blockchain technology, green initiatives, and sustainable green supply chain management.

Green material management is a phase of the project life cycle that has a significant effect on green supply chain management performance and consists of green procurement, green transportation, green warehousing, and reverse logistics. The green supply chain management concept with the project life cycle approach considers that each phase of the project life cycle produces different waste and requires attention through the supply chain to reduce the waste and improve the performance. Green supply chain management activities can affect the interaction of the supply chain with the environment and have a significant financial influence on the environment as well as the efficiency and performance of the organization (Eketu, 2018).

Several studies have suggested that for the environment and the positive performance of the firm, Green Supply Chain Management has played a significant role in it. For addressing the issues of the environment, many firms adopt this to improve their supply chain operations. Thus, it has become more challenging for firms to deal with several internal and external changes at the same time. GSCM is referred to as an incorporation of environment-friendly initiatives into every aspect of the supply chain encompassing sourcing, product design and development, manufacturing, transportation, packaging, storage, retrieval, disposal, and postsales services including end-of-product life management (Choi & Mai, 2018).

Recent studies in supply chain management conclude that there is a need to include reverse logistics operations in green supply chain management initiatives. The most recent literature on GSCM, the number of works that have structured the different concepts that relate supply chain management with sustainability, is growing (González-Sánchez et al., 2020; Lambrechts, 2021). On the other hand, as well as all advantages of green supply chain management, the literature recognizes positive results on the environment and the economic performance of reverse logistics processes. Reverse logistics programs can cause significant savings, considering the environmental and cost benefits. In recent years, there has been an increasing number of studies dealing with the environmental sustainability issue (Centobelli et al., 2020a), especially in supply chain management, mainly because the adoption of green initiatives can play a key role in implementing environmental sustainability strategies that affect all links in the chain (Centobelli et al., 2020a).

## 7 Summary and Discussions

In this section, we summarize the state of reverse logistics and many of the current concerns we have presented in this chapter. We have reviewed the definitions of reverse logistics and compared its use in several industries and have tried to both link it and separate it definitionally from the circular economy, social sustainability, and other "green" or environmental practices. Regardless of the term we use, reverse logistics remains a growing concern to most organizations for business or environmental reasons to "close-the-loop." While reverse logistics *can* be evaluated from a social sustainability perspective, it has rarely been evaluated using this perspective (Sarkis et al., 2010). Yet, the reverse logistics processes of handling, reclaiming, and disassembling products for reuse at the end of their life cycle as well as managing the disposition of returned products for value recovery (repackaging) or disposal are a growing area of profit and concern to manufacturers. As in the forward manufacturing process from creating goods and delivering them to the end user, similar operations are included in reverse logistics and often include warehousing, inventory control, storage, retrieval, transportation, and distribution.

Organizations tend to focus on upstream and downstream processes for social sustainability and have seldom considered reverse logistics from a social sustainability perspective, and performance measurements for green supply chain management as a whole are only in development (Hervani & Helms, 2006). Thus, there is a need to raise awareness and improve focus on managing the social sustainability and incorporating social sustainability into reverse logistics. Whether organizations implement reverse logistics alone or outsource reverse logistics, academic and practitioner literature is emerging, and this research will further knowledge in this area.

Practitioners note several differences between forward and reverse logistics. For example, forecasting in reverse logistics is more difficult due to returns uncertainties. Returned product quality is not uniform, and product packaging may be damaged making repackaging and refurbishment necessary. With damaged returns, there is a difference in the book value of the items. The disposition is unclear, and so is the destination and routing of returned items. Pricing is dependent on many issues, but, unlike forward logistics, speed is often not a priority in reverse logistics. Reverse costs are less directly visible, and the management of inventory is not consistent. Innovation in reverse logistics is emerging and futurists predict technology-embedded products will alert their users how best to dispose of them at the end of their useful life.

Within reverse logistics, products may be returned at several stages of their life cycle. These stages include commercial or viable for resale with minimal repackaging and shipment (i.e., returns from online merchants), repairable for resale as a refurbished product or returned to the original purchaser or a new user (i.e., a remanufactured computer with a new motherboard), end-of-use (for the product itself but not for the components, e.g., recycled car tires to be made into park benches), or end-of-life returns (where there may be reuse from reclamation of critical components or materials along with other disposal of nonviable components or materials such as recycled batteries for their components).

Each type of return requires a separate reverse logistics chain and may be determined by legislation or mandated recycling, obsolescence risk, environmental control, cost, efficiency, or responsiveness as product life cycles shorten and new designs and products quickly replace others in the marketplace; the volume of products suitable for reverse logistics reclamation has increased. Reverse logistics programs have been used to recover assets that would otherwise be lost, and the area is an important dimension of green logistics. Value is reclaimed through returns from end users, and with the growth of online retailing, reverse logistics can save organizations significant costs. Reverse logistics initiatives helps companies reduce waste and improve profitability. (But sometimes economic dimensions may not be as easily identified, and relying on broader, indirect benefits is necessary, particularly with issues such as social sustainability benefits and costs.)

While literature on reverse logistics is growing, there is a dearth of literature applying the social sustainability perspective to reverse logistics practices. Empirical studies have focused on ways to make these reverse logistics paths more efficient or effective for recycling (Rubio et al., 2008). Other research has explored ways to create new reverse logistics paths to reclaim and return the recycled content for reuse or reprocessing by manufacturers. Issues from an ethical and socially responsible indirect viewpoint, however, are important to consider and can provide a more accurate picture of the overall costs and benefits of reverse logistics especially with organizations adopting triple-bottom-line program evaluations. Reverse logistics can provide a means to address supply chain interruptions in the presence of crises brought about by unexpected events such as the COVID-19 crisis. Reverse logistics can address the organization’s concerns with maintaining supply chain capabilities that have embedded necessary sustainable elements such as agility, resilience, and flexibility.

## 8 Emergent Concerns: Measuring Reverse Logistics Performance

Evaluating reverse logistics costs and benefits is necessary to make a case for organizations to adopt the practices. Therefore, the area of measuring reverse logistics performance has begun to grow in importance (Ka et al., 2019). The costs of reverse logistics include designing systems and infrastructures to collect and store recycled goods as well as building facilities for sorting and separating materials for reprocessing. Other costs include the transportation and logistics for reclaiming and reprocessing returned products. Benefits include recovering assets that would be lost as well as saving money on warehousing, reclamation, and finding new life for recycled materials and perhaps extending the life cycle for goods. Determination of third-party reverse logistics providers requires a significant business case and justification analysis as well. Part of this justification would mean considering how reverse logistics costs or benefits social sustainability. It is possible to determine ways to increase the environmentally friendliness of spare parts delivery, such as the use of "green" vehicles, the shift to intermodal and terminal transportations, the development of routes considering the environmental situation along the route, and minimizing empty runs.

While most sustainability measures that attempt to quantify reverse logistics, benefits have been almost exclusively financial, with few environmental benefits evaluations included, this research proposes alternative tools for organizations to use in evaluating their reverse logistics operations from a social sustainability perspective. Examples of the four social sustainability dimensions (1. internal human resources, 2. external population, 3. stakeholders, and 4. macrosocial issues) and nonmarket goods valuation approach provide guidance for organizations in their implementation and justification of reverse logistics activities to internal and external stakeholders, stockholders, and to guide organizational strategic initiatives for reverse logistics and social sustainability.

The social sustainability implications of reverse logistics derive measurement concerns from several perspectives. Reverse logistics may improve social issues facing society. Reducing the demand for primary materials extraction may result in less pollution in developing areas. Because recycling is a very manual process, low skilled, less developed areas may benefit from the job creation. With less production and more recycling, pollution effects may be fewer. Environmental improvement can benefit public health and human security. Other social issues that may be influenced due to reverse logistics include the following: economic security (assured basic income), food security (physical and economic access to food), health security (relative freedom from disease and infection), environmental security (access to sanitary water supply, clean air, and a nondegraded land system), personal security (security from physical violence and threats), community security (security of cultural integrity), and political security (protection of basic human rights and freedoms).

Organizations must evaluate the greening or social sustainability of business, and to do this, they should consider social dimensions that are part of their reverse logistics planning. Reverse logistics can prepare organizations for pending regulations and laws and enhance a company's reputation as a socially responsible corporation. Such emphasis may allow an organization to have a strategic, competitive advantage over rivals. Choosing and measuring the benefits of processes that reduce pollution, reduce packaging and consider product disassembly are important to many stakeholders and shareholders alike. Thus, the business case for reverse logistics can be more nuanced, especially with respect to social sustainability concerns.

Measurement of performance of all reverse logistics activities is a growing area of concern for all stakeholders. Even automation is increasing in its utilization to improve reverse logistics performance. Automation can help remove manual steps saving both time and labor and can improve quality by reducing errors. Not every step of reverse logistics can be automated, and managers are urged to identify steps that might benefit from automation. Automation initiatives should improve the speed of return of waste streams and improve return accuracy. In their research on reverse supply chains in "Industry 4.0" or the next industrial revolution, Al-Shihmani et al. (2022) encouraged firms to adopt a modern technology and interdependent approach to manufacturing, and they agreed Industry 4.0 can support reverse supply chain activities. This is an important trend to watch during the ongoing maturation of reverse logistics.

## 9 Managerial Implications of Reverse Logistics in Key Functional Areas

There are overarching managerial implications of the move to reverse logistics in organizations, and these implications impact accounting/finance, marketing, and operations.

### 9.1 In Accounting

For accounting and operations, the implications focus on accounting standards and valuation methods. With the growth of reverse logistics and the practice of valuing wastes as an important asset that can be recovered and reused, it is important to note that the accounting standards have not kept pace with the green movement. Costing materials recovery and accounting for the profit from recycling has not made its way to generally accepted accounting practices or to the balance sheet and income statement. Several life cycle costing models have been proposed to aid management in their costing analysis. These models attempt to determine all the true costs to reclaim the goods – transportation, labor, storage, sorting, and processing.

Accounting too must focus on ways to present the benefits of reverse logistics in accounting documents and annual reports. With global growth of reverse logistics, measures and justifications of success must be adapted to an organization's reverse logistics life-cycle stages. Benefits of the environmental goods valuation approach are important to organizations, stakeholders, society, and the environment at large. This approach provides important information for corporate environmental and sustainability reports and is an alternative method of assessing corporate social responsibility success in reverse logistics and beyond.

### 9.2 In Marketing

For marketing, the implications focus of reverse logistics focus on alerting the customer or product user about the need to and value of recycling and starting the reverse logistics process in the backward flow. Determining ways for disassembly and selecting easy to recycle or minimal product packaging involves marketing and production teams on design. Marketing's focus is on messaging and ensuring clarity about the easiest way to recycle. Making the process easy and understandable for the consumer will ensure a steady supply of goods to be recycled or reworked.

Reverse logistics for recycling is growing for two reasons: (1) to reclaim value through returned products which are further reused for recycling; and (2) the environmental concerns and the lack of future landfill availability for disposal options. A successful reverse logistic operation initiates early product design in production process to facilitate further recycling of the reclaimed material and should include reverse logistics activities such as recyclable and returnable material collection. The recycling of old materials provides a longer life cycle and eliminates the need for future landfill spaces. The success of the recycling programs depends on two factors: (1) the development of a necessary infrastructure that supports recovery and collection efforts and (2) a viable market for old materials where prices paid for old materials are the outcome of the free-market operations and are cheaper than virgin content. The use of reverse logistic operation by firms in their management plans can bring added profits and create a more competitive environment for the firms. When recycling is designed as part of a product and not an afterthought, the model for reverse supply chain logistics is analogous to a customer or end user renting or leasing a product. Part of the purchase price includes the cost to recover the product, much of which is ultimately passed along to the consumer and should be part of the marketing message.

Future research is needed in key areas including exploring adaptations to incorporate economic nonmarket goods evaluation in reverse logistics and other organizational areas in a variety of industries. Research and cases from a variety of industries and organizations that explore the framework, challenges in justifying and documenting the nonfinancial and broader impact, and ways to implement the social sustainability environmental goods evaluation process will be important.

## 9.3 In Operations

For operations, the implications focus on ease of production and correspondingly disassembly of products. Packaging is also an issue and should be of minimal design but sufficient to protect the product for delivery and for return for recycling.

The implementation of internal reverse logistics programs often involves significant allocations of capital and/or resources for the construction of reclamation and redistribution facilities and purchasing of recycling equipment among others. Sustainable economic growth can be achieved when firms choose the production technology process that will reduce the amounts of pollution by-products produced and allow the final product to be used and reprocessed in further production processes. The usability and reprocessing characteristics of a used product may require initial planning and product design that will allow future reusability. The firm's incentives to design a more usable product will depend on whether such a change will require a changing of production technology that is costly. Sustainable economic growth and the reverse logistic could not have come any closer when both emphasized the need for changing production technologies to reduce the by-products of a particular final good. Sustainable economic growth is motivated by the need to improve environmental quality, and in doing so, firms must adapt to low waste or clean technologies that reduce hazardous by-products of production that are less detrimental to the environment.

Reverse logistic management of a product's life cycle is indeed promoting sustainable economic growth. Reverse logistic management calls for a more efficient design of product and the prior planning of product life cycle. This would lead to the recovery of used products in enabling the recovered material to be reused in further production of recycled content products. Recovery of products diverts the disposed products from finding their way to landfills or incineration and provides the firms with easy access to cheaper raw materials and lower input costs.

## 10 Summary and Conclusion

This chapter has provided an overview of reverse logistics and the current state of the topic as it is practiced in industry and studied by academicians. As we have seen, reverse logistics is an exciting and growing field of study for researchers and an area for implementation and continuous improvement for practitioners. It involves consumers and other end users as well to fulfill the goals and promise of reverse logistics and the circular economy.

There are financial benefits that may exist in the short run for organizations adopting reverse logistics activities, and computing financial benefits are difficult. Results may even be initially negative as organizations create new, expensive infrastructures for recycling or develop new educational programs for end-user or consumer recycling. But the strategic and intangible, nonmarket benefits may be substantial, especially from environmental and social sustainability dimensions (Weingarten & Longoni, 2015). Therefore, there is a need for methods to help more holistically evaluate and measure the impact and value of reverse logistics activities from an organizational perspective. The reverse logistics field continues to grow, evolve, and mature in an exciting trajectory.

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# Part IV

# Upstream Management

# Collaboration Within the Supply Chain

Vivian Osei and Disraeli Asante-Darko

## Contents



**Abstract**

A fundamental challenge for supply chain managers is how to compete effectively by coordinating and integrating business activities in the face of globally dispersed operations. Supply chain collaboration is often deemed as a critical strategy for ensuring that all independent firms work cooperatively to create a cohesive, singularly competitive supply network capable of improving overall performance. This view stems from the fact that it enables two or more independent supply chain partners to develop long-term relationships with the common goal of integrating and coordinating processes in anticipation of sharing success and benefits. A typical supply chain is a complex and multistaged network

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consisting of several firms and multiple functions. The complexity of these supply chain networks has emphasized the importance of supply chain collaboration more than ever in this century, particularly in the advent of the COVID-19 pandemic. The purpose of this chapter is to discuss supply chain collaboration and its role in enhancing business performance. It begins by defining supply chain collaboration; it then proceeds to discuss the various types of collaborations, their benefits, and their importance, before delving into the various levels of collaboration and emerging issues. The chapter concludes with a discussion of the implications of collaborations for business management.

**Keywords**

Supply chain management · Supply chain collaboration · Business performance

## 1 Introduction

Many large firms recognize that the increasing levels of competition, expansion of global markets, and constantly evolving customer demands require them to focus more on their core capabilities while partnering with valuable suppliers and key customers to achieve efficiency and operate successfully in today's business environment. Several attempts by businesses to improve the efficiency of business activities have frequently resulted in higher expenses and excessive inventory levels. Consequently, firms are outsourcing many business functions and partnering with other organizations to form supply chain networks to efficiently make and distribute products and services to customers.

A typical supply chain is a multistaged network comprising various companies with multiple activities and business processes spread around the globe. Most of the time, different supply chain elements – such as the business functions that allow for the supply of materials, production, and delivery of finished goods to customers – are owned by independent businesses and firms with different, and sometimes conflicting, goals (Chopra et al., 2013).

Business decisions aimed at increasing internal profits are frequently undertaken without regard for the end customer or other supply chain entities, resulting in greater end product costs, worse supply chain service levels, and ultimately decreasing end customer satisfaction. As each stage independently forecasts and plans its demand, there are information distortions and delays, resulting in actions that frequently reduce total supply chain profits. This approach has the potential to increase risk transfer, costs, and waiting time along the supply chain, exacerbating the complexities and challenges of successful supply chain management (Huo et al., 2015; Jiang & Ke, 2019).

A fundamental challenge for supply chain managers is to compete effectively by coordinating and integrating all business activities even though multiple owners of various demand-supply stages are globally dispersed. Supply chain collaboration has been promoted as a critical strategy for ensuring that all independent firms work cooperatively to create a cohesive, singularly competitive supply network capable of improving overall performance. It is regarded as a critical strategy because it enables two or more independent supply chain members to develop long-term relationships with the common goal of integrating and coordinating processes to achieve mutual benefits.

Supply chain collaboration allows two or more firms to share the duty of planning, managing, executing, and assessing supply chain performance information to gain a competitive edge (Cao & Zhang, 2011). Firms can benefit from collaborative relationships by sharing risks, gaining access to complementary resources, lowering transaction costs, and increasing efficiency, as well as improving their financial performance and competitive advantage over time (Um & Kim, 2019). Supply chain collaboration aims at leveraging the knowledge of individual firms and integrating the flow of products and information to collectively provide advantages for all collaborating firms (Afshan et al., 2018; Whitehead et al., 2019).

Lack of collaboration can have significant negative effects on the performance of each stage of the supply chain. Working in isolation from other collaborating organizations to forecast demand and plan supply can create distortions and reduce the overall supply chain performance. Moreover, potential coordination efforts to integrate demand and supply tend to become more difficult among the different stages of the supply chain.

A collaborative approach to supply chain management can improve performance by allowing firms to leverage the resources and knowledge of suppliers and customers to improve revenue, reduce cost, and increase flexibility toward minimizing uncertainty in demand and supply (Narayanan et al., 2015). The general idea is that many benefits can be gained from collaborating with supply chain partners to share information on sales forecasts, production scheduling, throughput adjustments, new marketing plans, and innovative product and service improvements. Rather than acting autonomously, collaboration helps different functions and stages of the supply chain to work together toward a common objective of improving the overall supply chain performance by sharing responsibility for solving problems and providing better customer satisfaction (Chen et al., 2017; Ho et al., 2019; Herczeg et al., 2018; Singh et al., 2018). Organizations that practice collaboration strategies in their supply chain gain large benefits as compared with the firms which operate in isolation. Many global firms including Dell, IBM, and Procter & Gamble have applied collaboration as part of effective supply chain management to create value and gain sustainable competitive advantage (Afshan et al., 2018).

Nevertheless, fairly widespread research shows that despite the wide recognition of the numerous advantages of supply chain collaboration, very few firms have truly capitalized on its potential (Cao & Zhang, 2011; Ho et al., 2019; Singh et al., 2018). Supply chain partners tend to have a lot of animosity among them because of mutual distrust and relationship problems before and during collaboration. Zhang and Cao (2017) stressed that many supply chain collaborations have failed due to a lack of proper understanding of the antecedents and complexities involved in the process for successful collaboration, resulting in incompatible corporate culture on collaborative values.

Supply chain collaboration is a broad concept whose success is dependent on many factors, including an understanding of the need for collaboration, determining which partners to collaborate with and over what activities to collaborate on, and actively seeking out new practices and elements of collaboration (Nimmy et al., 2019). Hence, a proper understanding of supply chain collaboration is needed to successfully achieve collaboration initiatives and maximize its potential benefits.

This chapter seeks to provide a discussion of the supply chain collaboration concept and its role in enhancing business performance. It begins by defining supply chain collaboration and its defining characteristics; it then proceeds to discuss the various types and forms of collaboration, its benefits, and their importance, before delving into the various levels of collaboration and emerging issues. The chapter concludes with a discussion of the implications of collaborations for business management.

## 2 Background

### 2.1 What Is Supply Chain Collaboration?

The term "supply chain collaboration" has been defined in a variety of ways. It is described as a business philosophy (Ralson et al., 2017) that allows two or more firms to achieve absorptive capacity (Whitehead et al., 2019). Fundamentally, previous scholars, for example (Cao & Zhan, 2011; Ho et al., 2019), have conceptualized it as either a relationship or business process construct. The process perspective is concerned with the design and management of supply chain operations. In contrast, relationship-focused definitions are mainly concerned with the maintenance of supply chain connections, including mutual benefit, risk, and reward sharing, as well as power and dependency management (Cao & Zhang, 2011). For instance, Fawcett et al. (2015) elaborated on supply chain collaboration as a business process through which companies involved in the supply chain responsively work together to achieve common objectives.

Collaboration has also been defined as a close form of relationship that enables the planning and execution of supply chain operations so that each partner can equitably share the gains, losses, and outcomes of the collaboration. Cao and Zhang (2011) provide a more comprehensive definition of supply chain collaboration as an interfirm process involving two or more independent firms that work closely together to design and manage the supply chain operations to share resources, information, rewards, and responsibilities, and jointly solve problems.

Supply chain collaboration in this chapter is defined as a form of a business process characterized by a long-term connection between supply chain members, with the aim of achieving mutual goals such as cost and risk reduction, as well as improved quality and market value. It is a mutual working relationship between two or more enterprises in a supply chain to meet the needs of end customers, with the primary goal of gaining a competitive advantage and increasing profit for all chain members. Within the supply chain, collaboration ensures real-time shared visibility and processes with supply chain partners, making problem detection and resolution easier. This goal is accomplished by integrating internal departments and coordinating with external partners to ensure that all areas of the supply chain, such as purchase order processing, forecasting, capacity planning, and quality management, run smoothly.

Ho et al. (2019) highlighted the need for firms to approach supply chain collaboration as a never-ending process that requires continuous improvement effort in developing key capabilities for the maintenance of ongoing relationships. It often begins from shallow transactional exchanges to become partnership relationships that rely on information exchanges to enable the best decision-making, and distribution of risk among the partners (Fawcet et al., 2015). As such, supply chain collaboration may be considered an intense form of relationship with a long-term focus, where individual firms look beyond maximizing their independent objectives to prioritize the overall goals of the supply chain. The processes and activities of the organizations in the supply chain are integrated within collaborative relationships to establish a single, jointly owned system with common aims. Collaboration in this sense implies sharing the responsibility of exchanging common supply chain management measures with other partners, to give the impression that they are one single entity.

The foundation of supply chain collaboration is the belief that a single company cannot compete successfully on its own. As a result, businesses must collaborate and work together over time to share risks and rewards and achieve better results than they could if they operated independently. As such, businesses in collaborative relationships are more concerned with the supply chain's overall growth and success than with the accomplishment of their internal objectives. In this way, collaboration guarantees that companies can achieve greater results by collaborating to conduct supply chain activities than if they worked alone (Singh et al., 2018).

## 2.2 Integration, Coordination, Cooperation, and Collaboration

The terms collaboration, integration, cooperation, and coordination are frequently used interchangeably in the supply chain literature to denote the same type or level of interfirm arrangements (Dubey et al., 2019). They each pertain to integrative efforts and interconnected coupling processes among supply chain partners, which often create confusion and ambiguities (Cao & Zhang, 2011). Although each construct is necessary for synchronizing operations and ensuring successful supply chain management, they differ in terms of the degree of communication with supply chain participants (Kotzab et al., 2019).

Generally, integration involves a unification of once separate parts or elements into a combined whole. Thus, integration within the supply chain involves combining key business processes and activities formerly carried out independently among several companies (Vlachos & Dyra, 2020), to enable dependencies and strategic developments and the flow of products within a supply network (Herczeg et al., 2018). Integration guarantees that all supply chain stages are linked to optimizing their aggregate performance in the manufacture and distribution of high-quality goods to fulfill customer demand (Danese, 2013).

The multidimensional nature of supply chain management necessitates a greater emphasis on the integration of essential functions and capabilities, and optimization efforts both within and between organizations, to maximize the overall performance goals of the supply network (Kotzab et al., 2019). This integration is based on different levels of interactions of the involved firms and processes, which results in different management and control of resulting dependencies including coordination, cooperation, and collaboration (Herczeg et al., 2018).

Cooperation entails working together to get the greatest potential results. Cooperation in supply chain management ensures that disparate entities join forces to improve overall performance. Companies begin cooperating when they share information with many suppliers and customers and have established long-term connections. The notion of working together in the context of cooperation does not suggest a close operational working relationship but rather having a positive attitude toward each other.

Coordination within the supply chain goes beyond just cooperating to communicate and exchange information as members of the same supply chain to aligning the actions of independent supply chain members with the supply chain's aims. It entails the harmonization or synchronization of corporate operations that must all work together toward a common objective and purpose. Coordination can be achieved when information technology (IT) is utilized to facilitate the exchange of critical data across supply chain parties and to facilitate an interactive, joint decision-making process in which distinct entities influence one other's actions cooperatively for maximizing customer value.

Finally, collaboration is a type of supply chain interaction that is founded on shared goals, mutual trust, risks, and benefits. It entails two or more entities cooperating, sharing resources, and pursuing common objectives to establish a long-term business connection. So, unlike coordination, collaboration goes beyond mere information exchange and resource sharing across the entire supply chain, and more toward team effort and joint decision-making and operations for mutual benefits.

Collaboration is more intense than coordination in terms of cooperative intensity since it usually encompasses all of the features of coordination. Thus, in a hierarchy of different levels of integration, collaboration is considered to be the highest. Indeed, Kotzab et al. (2019) stressed that collaborative relationships have the highest integration and are characterized by joint actions, decision-making, and information sharing toward strategic alliances beyond manufacturing and logistics.

## 2.3 The Elements and Characteristics of Supply Chain Collaboration

Despite the large body of literature on the subject, the actual nature and characteristics of supply chain collaboration are not well known or generally defined

(Narayanan et al., 2015). Several perspectives on important strategic features of collaborations that are linked to improved supply chain management have been shared in the literature. According to Singh et al. (2018), collaboration happens when supply chain partners have a high level of commitment, trust, and information sharing because it necessitates some level of shared strategic visions and collective decision-making, mutual recognition, and, in many cases, joint knowledge production among supply chain participants (Soosay & Hyland, 2015). Supply chain collaboration occurs when mutually dependent enterprises are bound together only by trust, shared objectives, and contracts entered voluntarily to form boundary-spanning partnerships toward shared success.

Taken together, supply chain collaboration is a broad concept that encompasses a variety of key themes and features. Essentially, the elements of supply chain collaboration can be broadly grouped into two – behaviors-attitudes of collaboration and actions of collaboration. Collaboration attitudes inform or drive the actions of collaboration. Alternatively, collaboration actions confirm or reinforce the attitude of collaboration in a looped manner.

Perhaps, the most fundamental antecedent for developing a supply chain collaboration is strategic intentionality, where firms decide to deliberately enter into a formal partnership relationship to voluntarily integrate human, financial, or technical resources with the sole purpose of creating a better business model that benefits everyone (Wu et al., 2014). Unlike integration that emphasizes central control or ownership of formerly independent processes by written contracts, supply chain collaboration captures a voluntary, joint relationship between separate supply chain partners (Cao and Zhang, 2011). It begins with the internal alignment of processes and cross-functional activities toward seamless workflows across the supply chain entity. As a result, organizations must have a shared understanding of the basis for collaborating in order to explicitly describe the precise business processes that need to be integrated, as well as the data needed to complete the processes involved (Ho et al., 2019). However, to develop a flourishing supply chain collaboration, the cultural elements within each independent supply chain channel must support key collaborative values like trust, goodwill, openness, honesty, mutuality, and information exchange.

Indeed, collaborative culture is considered a prerequisite for developing supply chain collaboration (Duong & Chong, 2020; Kumar et al., 2016; Zhang & Cao, 2017), indicating that for collaboration to exist, there must be process alignment, cross-functional activities, and joint decision-making. Although collaboration is considered a key strategy for effective supply chain management, many collaborative efforts have failed because firms have not understood how well embedding critical collaborative values in the organizational culture is necessary for its success.

According to Kumar et al. (2016), collaborative activities like market-based information sharing and operational resource planning and sharing are greatly influenced by collaborative culture, which also strongly and significantly determines the strength of collaborative connections. Without a collaborative culture that is highly oriented toward collectivism, willingness to develop enduring supply chain relationships with power equality, and high uncertainty avoidance inclinations, it is impossible to imagine a successful supply chain collaboration (Zhang and Cao, 2017). Companies with a collaborative culture are more inclined to collaborate with their supply chain partners based on trust, goodwill, and social norms rather than impersonal and legal contracts, hard rules, and set goals. This situation suggests that collaborative culture is a critical feature that occupies a central position in any collaborative effort (Yunus & Tadisina, 2016); it determines whether such a relationship is to be formed in the first place and whether the relationship will survive in the long term. As a result, supply chain collaboration necessitates a cultural shift toward a genuine desire to work with others and ensure interfirm dependencies in the design, planning, and execution of supply chain operations.

As a process, supply chain collaboration can be conceptualized as a construct characterized by seven interrelated activities including goal congruence, decision synchronization, incentive alignment, resources sharing, collaborative communication, information sharing, and joint knowledge creation (Cao et al., 2010). These defining characteristics provide a framework to assess and understand the main tenets for successfully maintaining the supply chain collaboration process once the relationship has been established. Notably, the individual objectives of the independent supply chain partners must be compatible with the overall objectives of the supply chain. Accordingly, the collaborating firms must agree and be convinced that joint work to achieve the overall supply chain goals can translate into superior performance for the individual firms. Strategic plans and decisions on sales forecast, inventory, production schedules, and order replenishment can be synchronized toward achieving these set goals (Zhang & Cao, 2017).

Overall, there should be a strategic direction toward mutual sharing of resources, and information as well as risks and rewards among truly collaborating firms. As such, it requires transparency, honesty, and the willingness to openly share relevant and accurately complete information on planning and control data, and product innovation information. All these shared information and resources can be leveraged by each of the entities within the collaborative relationship.

One of the key characteristics of collaborative supply chain relationships is open, frequent, balanced, multilayered communication and information sharing on strategic issues among supply chain partners (Jimenez-Jimenez et al., 2018). Mutually beneficial supply chain collaborations are associated with high levels of commitment to information sharing and interactions at the senior management level to identify opportunities and areas for improvement (Raweewan & Ferrell, 2018).

Critical market knowledge and other sensitive information about internal operations must be available and accessible in real time to reduce uncertainties and information distortions, which undermine supply chain efficiency (Raweewan & Ferrell, 2018; Wu et al., 2014). Moreover, frequent communication that allows the collaboration partners to establish trust, commitment, interdependence, shared vision, and cultural connection is important to lay the groundwork for information exchanges that benefit all the supply chain partners (Afshan et al., 2018; Whitehead et al., 2019). Knowledge co-creation and collaborative communication enabled by frequent exchanges and process integration are critical elements of collaboration. These characteristics facilitate the creation of the necessary synergy among the supply chain entities and sustain the collaborative relationship.

There should be mutual interdependence so that no single party completely controls all of the necessary conditions required to complete or reach a desired action (Herczeg et al., 2018). Mutual interdependence between supply chain parties, where one party does not entirely control supply chain operations, is an essential element that characterizes successful collaborations. High dependency has an impact on a company's long-term cooperation strategy, as it encourages a willingness to negotiate functional transfers, share essential information, and participate in collaborative operational planning.

Studies suggest that having a long-term orientation or commitment to exert effort in developing a long-term relationship is a key element for successful collaboration in the supply chain. Like many close relationships, achieving and managing successful collaboration requires time and mutual effort of all parties. They need to invest substantial resources into the relationship and jointly provide effective solutions to the inevitable problems that may occur in the process of integrating operational and product development activities. A long-term orientation is frequently demonstrated by devoting resources to the relationship, which might include time, money, facilities, and a range of assets, to a series of future transactions (Zhang & Cao, 2017).

Productivity gains in supply chains are possible when businesses are willing to make transaction-specific or relationship-specific investments that are important markers of their commitment to collaboration. Overall, there must be equity in ensuring that the costs arising from the collaboration and benefits that accrue to the relationship are distributed fairly among the participants to reduce any form of opportunistic behavior. The existence of intraorganizational support, corporate focus on supply chain collaboration, resource investment and commitment from senior management, and investment in the right technological tools are necessary for sustaining and improving supply chain collaborations.

## 2.4 The Necessity for Supply Chain Collaboration

Effective collaboration both within and across companies is essential to achieving effective supply chain management to ensure long-term competitiveness and improve performance both directly and indirectly (Singh et al., 2018). Collaboration is one of the main building blocks of the supply chain discipline. It is promoted in both practice and academic spheres as a driving force for ensuring internal firm efficiency as well as performance optimization of the entire supply chain. For instance, a lack of internal collaboration often creates unrelated functional directions when it comes to planning demand and supply activities without accounting for other internal functional activities leading to inefficiencies in internal supply chain activities.

Modern supply chains have become more dispersed with no single firm having complete ownership and control of the resources and processes of sourcing, manufacturing, distribution, sales, and marketing. Unlike vertical integration that characterized most supply chains, today's supply chains typically involve dozens of companies, all playing different roles in the demand and supply cycle.

Collaborations with external suppliers and customers are the only way to unify the supply chain.

In many cases, supply chains comprise a mix of supply enterprises, contract manufacturers, distribution and logistics providers, and other trading partners with different departments operating on diverse systems, measures, and priorities for improving performance. Without collaboration, the firms that own the stages of the supply chain become heavily focused on their specific plans for ensuring internal profit maximization, resulting in actions that often reduce total supply chain profit (Chopra et al., 2013). When there is a lack of collaboration within the supply chain, demand and supply information moving between stages is delayed and distorted as each company makes its own decisions to maximize internal profit objectives without recourse to the system-wide supply chain goals.

One outcome is supply chain inefficiencies brought on by the bullwhip effect, which causes order variations to grow as they move upstream in the supply chain. This situation eventually harms overall supply chain performance (Jiang & Ke, 2019). This result is because as each stage focuses on its objectives, information exchanges become difficult, causing distortions and exaggerations across the supply chain, since incomplete information exists between the stage. Consequently, one of the primary reasons for supply chain collaboration is to lessen the bullwhip effect, which causes order amplifications and information distortions, with each stage having a different demand estimate (Jiang & Ke, 2019).

The bullwhip effect is caused by intrinsic delays and miscommunication over demand forecasting, pricing information, and updates, which manifest themselves as fluctuations in important system parameters like inventory levels and utilization rates. Manufacturing expenses, inventory costs, replenishment lead times, transportation costs, and shipping and receiving labor costs all tend to rise as a result of bullwhip variations. Furthermore, product availability reduces, raising the danger of stockouts, and supply chain relationships are significantly impacted (Chopra et al., 2013).

Supply chain collaboration significantly reduces the bullwhip phenomenon by improving information exchanges across the supply network and allowing various entities to collaborate on common goals. It improves the agility and responsiveness of the supply chain and enables firms to coordinate their supply chains more effectively (Singh et al., 2018). With the scale and volume of market data, transactions, and physical materials flowing among the various stages of today's global supply chains, collaboration enables firms to leverage the necessary tools to share data from a unified platform, adopt the right processes to address inefficiencies, and organize supply chains to ensure a free flow of information, materials, and goods.

## 2.5 Benefits of Supply Chain Collaboration

The ability of a company to integrate its operations and manage a complex network of relationships with suppliers, customers, and other collaborating partners is crucial to its success. Organizations realize significant benefits in the form of improved efficiency and effectiveness from practicing collaboration in their supply chain as opposed to working independently without other entities.

Firms that adopt collaboration have lower costs, less inventory, short cycle time, more responsiveness, and the least error in forecasting (Singh et al., 2018). Supply chain collaboration benefits have caused organizations to adopt collaborative strategies to improve the performance of their supply chain. Supply chain collaboration simplifies the cooperation of supply chain members and acts as an important strategic driver which affects firm performance positively. It allows businesses to share profits and losses, take advantage of the resources of their external partners, reduce transaction costs, boost productivity, and boost profits. Successful collaboration is predicted not only to strengthen a buying firm's performance but also to reduce transaction costs (Um & Kim, 2019).

Supply chain collaboration has received significant attention from companies looking to gain a competitive advantage by incurring lower transaction costs (Chen et al., 2017; Fawcett et al., 2015; Soosay & Hyland, 2015). The ultimate goal of supply chain collaboration is to improve a company's competitive advantage and the performance of all supply chain members by allowing entities to make relationship-specific investments, share proprietary information, and engage in value-added activities that lower transaction costs (Ho et al., 2019).

Interdependent relationships fostered through strategic alliances and collaboration enable collaborative advantage, which is defined as the joint or collective strategic advantages gained over competitors in the marketplace through supply chain partnerships. Thus, strong collaboration among supply chain partners is an important way of sustaining a company's competitive advantage. It is regarded as a core capability for effective supply chain management (Zacharia et al., 2011). Exceptional supply chain collaboration has the potential to improve the customer experience while also facilitating profit generation, asset utilization, and cost-cutting performance (Yunus & Tadisina, 2016). Thus, a collaboration between upstream and downstream supply chain entities can improve the number of satisfied customers by reducing lead times, improving service levels, and decreasing costs.

Market diversity, transparent prices, shorter product life cycles, and increased competition have enhanced the need for supply chain collaboration more than ever because businesses must endeavor to respond to new market demands with agility and innovation. Increasing customer demand for product variety, shorter life cycles, and an increasingly dynamic and uncertain business environment have caused companies to seek greater supply chain collaboration to transfer knowledge and share critical resources. They do this by pooling and integrating the resources of their suppliers and customers – essential for innovation to achieve long-term competitiveness (Atalay et al., 2017; Narayanan et al., 2015).

Facing intensified global competition, firms strive for greater supply chain collaboration by leveraging the resources and knowledge of key suppliers and valued customers (Segarra-Ciprés & Bou-Llusar, 2018), to reduce uncertainty, lower transaction costs, build core competence, and capitalize on opportunities for learning and knowledge creation (Pouwels & Koster, 2017). These external partnerships act as a sustainable source of knowledge on innovative practices (Rodriguez et al., 2017;

Roper et al., 2017) for the supply chain to create products and services that are competitive differentiators, reducing the cost of new product development, engineering changes, and product defects while enhancing the competitive position in global markets (Jamaluddin & Saibani, 2021; Pouwels and Koster, 2017).

Supply chain collaboration, enabled by information technology (IT), directly impacts incremental and radical product innovation (Jimenez-Jimenez et al., 2018). Thus, it has been recommended that firms seek strategic supply chain partners and form innovative synergies, as they could significantly contribute new ideas, and collaborative creativity, and engage in the co-development of innovative products (Bellamy et al., 2014; Sumo et al., 2016).

Supply chain collaboration is important in managing the risks and reducing the uncertainties that occur within the supply chain. Collaboration increases the supply chain's resilience and lessens the severity of interruptions caused by disruptive occurrences such as shipping delays or pandemics, natural disasters, etc. (Jamaludin & Saibani, 2021). Supply chain collaboration enables supply chain entities to coordinate in the complex chain beyond and across organizational boundaries so that concerted efforts can be used to devise mitigation strategies against disruptive occurrences.

Collaboration increases the sensitivity of the supply chain in detecting potential threats and enhances its recovery capabilities. Even when disruptions occur, interactive and effective collaboration increases the resilience of the supply network by increasing the supply chain's agility and responsiveness in handling and recovering from disruptive events.

Collaborative planning and resource allocation, as well as coordinated forecasting and replenishment, are all important strategies for improving supply chain flexibility and reducing the impact of disruptions (Ivanov et al., 2017). By sharing information effectively, supply chain collaboration provides capabilities to ensure that all parties coordinate together to optimize processes within the supply chain and resolve problems in the most efficient and timely manner, resulting in better order fulfillment processes in terms of cost, quality, speed, and flexibility (Duong & Chong, 2020).

According to recent studies, collaborating with upstream and downstream partners in the supply chain is a viable way to meet environmental, social, and economic sustainability goals (Cloutier et al., 2020; Jamaluddin & Saibani, 2021). Supply chain collaboration has moved beyond internal production and supplier control issues to include a broader variety of stakeholders as well as a wider spectrum of environmental and social challenges that affect the value chain (Chen et al., 2017). Collaborating with supply chain partners such as suppliers and customers can enhance the company's resources and capabilities for sustainable development (Luzzini et al., 2015). It ensures that sustainability efforts are successfully coordinated both within the organization and across the supply chain, and suitable capabilities are applied to ensure sustainability targets. Collaboration can assist in developing both tacit and explicit knowledge to enhance supply chain competitive advantages and sustainability outcomes.

## 2.6 Types of Supply Chain Collaboration

Supply chain collaboration has been divided into two major categories: vertical collaboration and horizontal collaboration. The third form of collaboration is lateral collaboration, which denotes activities that combine the other two types to achieve more flexibility. Vertical collaboration occurs when companies from different levels or stages of the supply chain share resources, responsibilities, and performance data in order to serve consumers that have comparable needs. It encompasses collaboration with suppliers, manufacturers, and customers, as well as collaboration within the organization's many departments. An example is a long-term relationship between a buyer and a supplier of components and materials.

Horizontal collaboration occurs when firms at the same level or stage but of different supply chains collaborate toward a common goal (Singh et al., 2018). It includes relationships with competitors, internally, and with noncompetitors. Coopetition, the interplay of competition and collaboration (Gernsheimer et al., 2021), may be considered a form of horizontal collaboration that allows organizations at the same stage of the supply chain to share the burden of demand and optimize costs. Often, the organizations in a horizontal collaboration are competing firms at the same level of the supply chain, producing similar products or different components of the same product that come together to share complementary resources (Vasco et al., 2015). Thus, competitive interactions both with and within organizations that allow simultaneous collaboration and competition at various levels can help in pursuing goals to create value for mutual benefits.

Vertical collaboration usually involves economic exchanges while horizontal relationships are largely concerned with knowledge and information exchanges (Ho et al., 2019). Horizontal collaboration among producers has been found to reduce supply chain risk exposure, increase real-time decision-making, and lower total supply chain costs (Singh et al., 2018). Most research has placed a greater emphasis on vertical collaboration rather than horizontal collaboration, especially with competitors and other non-profit-making organizations. The reason for this is that many companies prioritize relationships with entities within their supply chain over relationships with organizations outside of their supply chain, even though such collaborations can provide significant value to the supply chain. Both vertical and horizontal collaboration can support effective supply chain collaboration.

Two other collaboration dimensions may be considered: internal collaboration, which entails cross-functional collaboration involving different departments within the same firm, and external collaboration involving external partners. According to Singh et al. (2018), virtual collaboration, cooperative arrangement, joint venture, and strategic alliance are all forms of external collaboration. An initial focus on ensuring internal collaboration of operations and functions can further support successful external collaborative activities both within the upstream and downstream of the supply chain.

## 2.7 Levels of Collaboration

There is a wide range of collaborations in the literature, indicating that supply chain collaborations can take many forms. Some consider these forms as a spectrum of relationship types (Ho et al., 2019). From low-cost connections to high-level supply chain collaborative exchanges, the literature posits many different ways to engage in supply chain collaboration and several levels of collaborative engagements. The distinguishing factors on the levels of supply chain collaboration pertain to the intensity or depth of the mechanisms that determine the form or level of a particular collaborative engagement. These factors include the degree of closeness, collaborative communication, resource sharing, information sharing, joint decision-making, incentive alignment, etc. (Duong & Chong, 2020).

The level of interdependence, trust, decision-making process, and goal congruence can also be used to evaluate collaboration levels. The key dimensions used to differentiate the forms of collaboration include the number and frequency of transactions, the longevity of the relationship, and the degree of closeness of the parties. Several levels of supply chain collaboration including communication, coordination, intensive collaboration, and partnerships have been suggested. Nevertheless, each collaborative relationship has specific variables that motivate drivers and govern the supply chain environment, and the closeness of the relationship between supply chain partners varies over time (Ho et al., 2019).

Largely, the degree to which one firm collaborates with a partner is determined by the company's position in the supply chain (Chen et al., 2017). The depth of relationships in collaborations can vary as well as the approaches or ways of engaging in collaboration depending on the structure of the supply chain and the nature of the channels involved. The essential force necessary to keep collaborative partners together is the strength or intensity of their collaborative relationship, which cannot be created overnight, rather it must be honed gradually through the implementation of collaborative actions.

The form of a collaborative process and power dynamics of the resulting relationship depends on the roles of individual entities, whether as a collaboration leader or initiator of the whole relationship, the collaboration coordinator, or a collaboration member without any specific role. Additionally, the duration of the relationship is an important predictor of the intensity of interorganizational collaboration. The length of a relationship's history raises expectations of continuation, which in turn influences the level of interaction in terms of communication, involvement, planning, and shared problem-solving, all of which are good markers of a successful partnership. Thus, a party's long-term orientation and relationship-specific investments are likely to be affected by the length of an existing relationship. The rationale and purpose for the collaboration determine the form and nature of the collaboration. Internal and external pressures, stakeholder demands, product and service quality, and the growing need to manage demand and supply risks force firms to engage with other supply chain organizations.

The intensity of collaboration determines the level of collaborative engagements within the relationship, ultimately impacting the supply chain performance at various levels (Kumar et al., 2016). Studies reveal that because there is a high association between levels of collaboration and various performance outcomes, the level of collaborative engagement plays a critical role in achieving diverse impacts on performance (Ho et al., 2019). Thus, performance changes under different levels of collaboration, indicating that higher levels of collaboration involving frequent communication and information sharing, trust, interdependence, joint decision-making, etc., provide better performance outcomes for the firms within a collaborative relationship. For example, Sheu et al. (2006) focused on supplier-retailer interactions and discussed three degrees of collaboration, low, medium, and high, based on the amount of joint planning and problem-solving activities performed by the supplier and its retailers. They found that the intensity or levels of collaboration provide different levels of performance outcomes.

Duong and Chong (2020) and Cloutier et al. (2020) provided evidence of how the extent of collaborative mechanisms related to contractual and economic practices, joint practices, relationship management, technological and information sharing practices, governance practices, assessment practices, and supply chain design contribute to supply chain efficiency. They also focused on how this efficiency and the collaboration factors help organizations deal with disruptions and achieve sustainability-oriented initiatives.

Taking all these dimensions and characteristics into account, it can be clearly understood that collaboration within the supply chain may take many formats, depending on the different levels or strengths of the relationships that exist within the supply chain. The relationship and power dynamics between collaborating partners can be radically different, as different members may be interested in very different things from the collaboration. Although the general outlook from the literature suggests that the traditional arms-length relationships of the past are making way for much closer collaborations because of the assumption that such relationships yield larger benefits, some scholars have argued that collaborative relationships are not appropriate for the entire supply chain and that some transactional relationships may still be appropriate for some contexts.

It has been proposed that firms must segment customers and suppliers into different categories and only develop close, advanced relationships with only a few strategically important segments while keeping the rest on an arm's length and purely transactional basis. Thus, full collaboration must not be developed for all supply chain stakeholders, rather the type of collaboration should be tailored to the level of supplier and consumer reliance.

Strong collaboration does not apply to all supply chains, especially in circumstances of shared resources or limited capacity. Intense collaborative practices should only be exploited when there is high demand uncertainty and should be limited when customer demand is known to be relatively stable. Selective collaboration with key suppliers and critical customers is a valuable strategy for truly capitalizing on the potential of collaboration (Kumar & Nath Banerjee, 2014).

A key decision for all organizations is deciding on which parties to keep at arm's length, what forms of collaborative relationships to develop with key suppliers and critical customers, and when such relationships are appropriate. Although supply chain cooperation has numerous advantages, it is critical to define the purpose for collaborating to establish the individual mechanisms required for the level of collaborative engagement, as well as determine the individual actors and firms within the supply chain that should be approached about forming a partnership. This process can assist in defining the specific parameters and legitimate framework for the collaboration, laying out the business processes to be integrated, and ensuring that potential partners are aware of what to expect from the connection to establish a trusting environment.

It is necessary to identify the critical supply chain partners for each of the focal firm's products and services that ensure the effective sale and delivery of end products to ultimate customers. Over time, companies establish long-term relationships with these trade partners through successful business dealings.

## 2.8 Supply Chain Collaboration Technologies and Approaches

Supply chain collaboration is driven by information sharing, transparency, and communication with understanding. Therefore, a firm's IT capabilities and the level of IT competence used to support supply chain–related operations are considered vital to facilitate and increase interorganizational collaboration (Fawcett et al., 2015).

IT capabilities were found by Afshan et al. (2018) as a vital enabler of supply chain collaboration relational dimensions. IT provides the resource infrastructure in the form of IT hardware, software, networks, and data management that enable the integration of supply chain processes, quality information sharing, and effective communication required for seamless global supply chain collaborative practices.

Internet-based IT, particularly interorganizational systems (IOS), is a critical antecedent of collaboration within the supply chain, as it reduces the cost of communication while expanding the reach and electronic integration of information, as well as the degree of interdependence between partners by creating joint, interpenetrating processes (Zhang & Cao, 2017). Formal ICT systems (like e-mail) play a vital connectivity role in facilitating the transmission of real-time supply chain information among the supply chain partners engaged in collaborative projects (Jimenez-Jimenez et al., 2018).

A variety of platforms and IT applications supporting supply chains exist and include electronic data interchange (EDI), enterprise resource planning (ERP), warehouse management systems applications, point of sale (POS) devices, collaborative planning, forecasting, and replenishment (CPFR), efficient consumer response (ECR), vendor-managed inventory (VMI), and other IOS applications. These systems and technologies are used to integrate different functions, connect disparate systems, and make it possible for businesses to collaborate. They allow for sharing of various types of information regarding inventory, POS data, forecasts, orders, capacity, and consumer demand information that have strategic implications throughout the supply chain.

This information and data make it possible for supply chain partners to effectively plan future production and purchases and grow in collaboration. ERP, for example, provides a single platform for linking multiple corporate operations to promote correct data and information exchanges, improve responsiveness, and boost competitiveness (Ram et al., 2014). Similarly, through the VMI, a supplier can manage the inventory and replenishment policies of customers. In the same way, supply chain partners can jointly forecast customer demand and plan to better match demand with supply through the CPFR system.

Recently, blockchain technology has been highlighted as an important, revolutionary technology for supply chain collaboration, particularly to increase the speed with which supply chain issues can be traced and to enable improvements in product safety, authenticity, and delivery (Angrish et al., 2018). Fundamentally, blockchain technology is a distributed database system that maintains transactional data or other information through a consensus process among all participating blockchain agents (Saberi et al., 2019). It is considered a technological collaboration tool that provides the supply chain network with more decentralized, dependable, and secure information as well as relationships that are smartly executed (Cole et al., 2019). The capabilities of blockchain technology support the real-time monitoring of supplier actions and behaviors against opportunistic activities. By addressing supply chain information security issues, blockchain increases supply chain parties' trust and confidence. Notably, blockchain technology can ensure the veracity of information and promote trust through transparency and traceability (Bai & Sarkis, 2020), which is essential for the coordination of activities required for effective and efficient supply chain management.

Although there are numerous types of supply chain collaboration systems, organizations must select the best applications and software that have the capabilities and traits that enable seamless supply chain collaboration to realize maximum benefits and boost competitiveness. The greatest foundation for collaborating supply chain entities in making collaborative decisions is by linking various data sources. Therefore, for efficient collaboration practices, supply chain collaboration applications and software must include the crucial feature of facilitating real-time data sharing so that all parties have access to the most up-to-date data. The supply chain collaboration application must guarantee the visibility of the whole supply chain to understand where a company's inventory is located and respond to the challenges that its suppliers are experiencing, and any possible capacity or forecasting mismatches before they spiral out of hand.

The information architecture must enable configurations that allow the functions or business processes and workflows of the collaborating parties to be aligned and integrated into the platform so that supply chain partners can coordinate with each other more efficiently. Advanced systems and cutting-edge technology should be included in supply chain collaboration applications, allowing for faster risk assessment and resolution recommendations, as well as empowering users to make timely decisions together with supply chain partners.

Supply chain partners can integrate the various elements of a supply chain and create a common foundation for data by properly utilizing IT capabilities. This can improve a company's ability to adapt to demand changes and disruptions, allowing them to make decisions more quickly. The use of technology in collaborative exchanges fosters closer working ties and lowers transaction costs inside and across organizations. By combining real-time data, IT enhances the accuracy of predictions and capacity plans, allowing businesses to manage risk more effectively.

## 2.9 The Obstacles of Supply Chain Collaboration

Despite the obvious benefits of collaboration for supply chain members, the literature reveals that several obstacles cause many supply chain collaboration attempts to fail. There are obstacles at each stage of the collaboration process (Lehoux et al., 2014). As such, very few companies attain their practical value in reality despite the significant initial cost (Fawcett et al., 2015; Ho et al., 2019; Mahmud et al., 2021). Few firms are actually engaged in collaborations at the level required to realize their real potential because the main internal and external obstacles and barriers have not been properly understood and addressed (Singh et al., 2018). Several studies have explored the reasons why collaborations either succeed or fail and one key finding is that a long-term relationship upon which trust has been built is common in many if not most successes. This dimension suggests that an important reason for the failures of many collaboration initiatives is a lack of trust and fear of partners becoming competitors (Raweewan & Ferrell, 2018).

One of the great enablers but also a powerful potential obstacle for collaboration in the supply chain is mutual trust. Although trust is required in collaboration to facilitate coordination, it is very difficult to develop due to the historically adversarial relationships among supply chain parties. It is founded on a partner's trustworthiness, as well as the idea that the partners will keep their promises, complete their commitments, and act honestly. Lack of trust could result in the inability and hesitation of many companies to share sensitive data that could be beneficial for the relationship and to participate in joint knowledge creation and planning and execution of supply chain activities.

Firms interrelate primarily based on their mutual interests. Without trust, opportunism and moral hazard could threaten business relationships. The success of a collaboration depends on the willingness of firms and managers to establish a climate of trust and build solid relationships among their partners. The credibility of supply chain partners determines the ultimate success of their collaboration efforts, indicating that information assurance issues and security threats may increase opportunism. For this reason, shared information in the supply chain must be accurate and accessible to all participants in order to reduce opportunism tendencies, moral hazards, and the failure of collaborating relationships.

A trust-based, long-term relationship also requires commitment from the parties involved to succeed (Chen et al., 2011). So without trust, there would be a low commitment from the partners to cooperate without opportunistic behavior and provide the necessary resource investments required to develop and ensure successful collaborations. Successful supply chain collaboration cannot be achieved without asset commitment since plans for satisfying demand cannot be carried out without it, and the collaboration may eventually fail. The lack of trust also affects the supply chain's resilience against disruptions (Hou et al., 2018).

Moreover, relatively low interdependence, mutuality, and power asymmetry have also been presented to be major obstacles to collaboration (Taqi et al., 2020). Successful collaborative engagements must be mutually beneficial for all the firms involved. The distribution of resources, costs, responsibilities, risks, and rewards among the collaborating firms must be coordinated to make the collaboration sustainable. This is important because most collaborative partners are unequal in terms of influence or bargaining power.

Therefore, significant obstacles can occur when there are incentives for firms to neglect the overall benefits and take unscrupulous actions – opportunism – that aim at capitalizing on their relatively stronger position and maximizing the individual performance outcomes to the detriment of other collaborating partners (Taqi et al., 2020). Companies in a collaborative relationship rely on each other's reliability and trustworthiness to share objectives, make joint decisions, and align incentives to manage risks and increase resilience (Fan et al., 2020). Thus, conflicts are bound to occur with any unpredictable behavior of supply chain partners that can create mistrust and resistance, contributing to information distortions that influence the bullwhip effect (Chopra et al., 2013) and the lack of commitment within the relationship (Fawcett et al., 2015).

Information-related barriers pertaining to reluctance in sharing critical market-based information and poor information quality have been identified as key obstacles to collaboration (Raweewan & Ferrell, 2018). Reluctance to share information increases coordination costs and keeps supply chains from gaining competitive advantages, leading to deterioration in performance outcomes (Huo et al., 2015). Quality information is necessary to improve collaboration relational dimensions such as trust and commitment, to facilitate meaningful discussions, joint planning, and consensus building (Afshan et al., 2018). Hence, the exchange of poor quality information that lacks accuracy, timeliness, credibility, and adequacy can affect the trust and commitment required for successful collaboration. This poor information magnifies information distortions that weaken the foundation of the supply chain and can increase the bullwhip effect (Jiang & Ke, 2019). Besides, a dearth of market-based information sharing creates difficulties in forecasting customer demand and creates distortions in planning and controlling supply chains.

Related to information sharing is the structure of the supply chain activities or coordination of key stakeholders for successful collaboration. Lack of proper IT infrastructure, obsolete technology, and disparities in technology which create poor system connectivity for communication and information sharing also disrupt coordination within the supply, affecting the success of collaborative engagements. The resulting insufficient communication exchanges and inefficiencies make the integration of processes, products, and information to facilitate the joint execution of supply chain activities very difficult. In particular, communication difficulties to share relevant information with other collaborating firms can reduce the agility of the supply chain in responding to disruptions and other crises that distort the collaboration in a supply chain.

Beyond the technological barriers, other factors related to conflicting organizational culture, goals, and values can weaken collaborative decision-making among supply chain members (Zhang & Cao, 2017). Differences in cultural values, norms, and belief systems shared by supply chain partners weaken trust and information exchange, create misalignment of goals, and affect the joint performance of supply chains (Wu & Chiu, 2018).

Lack of organizational support and commitment, resistance to changes, and inadequate training and skills of senior managers toward collaboration often create inadequacies that result in less collaboration (Fawcett et al., 2011). Other issues related to nonstandardized, inconsistent performance metrics, unfavorable government policy interventions, inflexible pricing policies, lack of resource sharing, lack of adaptation, short-term orientation, and lack of commitment to delivery times have also been identified as major factors affecting supply chain collaboration performance (Singh et al., 2018; Mahmud et al., 2021).

Developing and maintaining close, collaborative relationships is one of the most difficult aspects of supply chain management, although there is no consensus regarding the most critical obstacles to supply chain collaboration efforts (Mahmud et al., 2021). Several studies reveal that creating collaboration is a difficult undertaking for supply chain partners, and it comes with many challenges. The difficulties are exacerbated by the fact that collaboration efforts seek to align separate, independent processes and firms that usually have different priorities for attaining competitive advantage due to variations in prevailing market conditions (Wu & Chiu, 2018). Conflicts between the collaborating partners are inevitable, and great skills are required to properly handle them. Nevertheless, formalized, explicit rules and regulations may be necessary to regulate decision-making, define roles and responsibilities, and standardize deliverables for successful collaboration execution. Having a collaborative cultural mindset and the willingness of top managers to collaborate are important to overcome apathy, align incentives, and enable supply chains to take advantage of the full benefits of collaboration.

## 3 Current Concerns and Needs

Research on supply chain collaboration has evolved and gained much acceptance and popularity since the early 2000s, as more organizations recognize the need for collaboration, with the support of modern technologies that allow firms to share information, integrate systems for seamless supply chain activities, and enable better communication.

The literature has grown substantially, with an increasing number of studies covering several aspects of collaboration to aid a better understanding of the concept (Singh et al., 2018). Generally, the literature has established the necessity for collaborations within the supply chain and the performance implications of such engagements. However, a significant gap in understanding exists between supply chain collaboration theory and practice, indicating limited levels of collaboration in reality.

Past studies have concluded that collaboration is not easy to achieve in reality due to mistrust, conflicting objectives, and misaligned goals. Given the high-cost implications of supply chain collaboration, additional studies focused on investigating the level of application of the concept and resulting implementation outcomes in various jurisdictions and supply chain contexts can provide in-depth insights into the complex nature of collaboration. These studies also need to address the existing ambiguities about how to establish collaboration in practice.

Studies have thus focused on identifying the antecedents, drivers, and barriers of collaboration, as well as the strategies and requirements for achieving successful collaboration. Meanwhile, the risks associated with supply chain collaborations appear to have been somewhat ignored, despite the proliferation of research on the subject. Researchers are now beginning to investigate the most critical contextual factors that make collaboration viable and difficult within different supply chain types (Mahmud et al., 2021). However, more research is needed in this area to understand the idiosyncratic nature of supply chain collaborations.

The current literature and practices show that as far as internal and external collaboration is concerned, the relationship between internal collaboration and performance is under-researched. Compared to external collaboration, there is less emphasis on internal collaboration in the literature, although internal collaboration is important for successful external collaborations.

There is a dearth of research on the nature of other external or horizontal collaborations beyond supplier collaborations (Ho et al., 2019; Singh et al., 2018). Aside from the dyadic relationship with suppliers which has characterized many previous studies, multitier external collaborations with different types of customers, competitors, and other horizontal partners have received very little attention in the literature (Chen et al., 2017; Soosay & Hyland, 2015).

Although collaboration with upstream and downstream partners is mostly discussed in the literature, Chen et al. (2017) found that collaboration with competitors and other organizations at the same level needs to be considered. Future research that sheds light on how internal collaboration positively impacts various types of external collaborations will be helpful to address current concerns and drive further collaborative value creation.

There have been calls to investigate the governing mechanisms that may be appropriate for ensuring successful interorganizational collaboration in other non-traditional supply chains, especially humanitarian supply chains (Dubey et al., 2019; Soosay & Hyland, 2015).

A key concern in current studies is the scarcity of empirical studies that focus on the consequences of various collaborative practices for different performance outcomes (Chen et al., 2017) including innovation (Jimenez-Jimenez et al., 2018; Pouwels & Koster, 2017) and sustainability performance improvement (Chen et al., 2017; Cloutier et al., 2020). For example, Herczeg et al. (2018) considered the feasibility of supply chain collaboration mechanisms in industrial symbiosis toward the circular economy to improve environmental sustainability performance.

However, many of these studies are in the form of a literature review, so further empirical studies are required to validate the propositions and findings from these studies.

A notable issue of concern in the literature pertains to the recovery of supply chain collaborations from the disruptions introduced by the onset of the COVID-19 pandemic. More empirical research is required to provide better insights into the mechanisms for increasing the resilience of supply chain collaborations and enhancing the recovery from disruptions (D'Adamo & Lupi, 2021; Duong & Chong, 2020). In particular, there should be more research aimed at explaining how various modern technologies and digital systems can be used to further develop resilience (Soosay & Hyland, 2015) and ensure supply chain collaboration recovery in the face of the pandemic.

## 4 Emergent Concerns, Outstanding Research, and Future Directions

In recent times, a substantial amount of research has been dedicated to studying supply chain collaboration as a means of gaining a competitive advantage. This number has risen exponentially in the wake of the COVID-19 pandemic with supply chain collaboration seen as a panacea for endemic supply chain disruptions (Duong & Chong, 2020). Unfortunately, an in-depth analysis of existing research on supply chain collaboration shows a body of work rife with multiple terms, diverse foci, and differing topics. Even though there are several reviews covering specific aspects of supply chain collaboration, there is a dearth of meta-level analysis that can provide a holistic overview of the area and strategic direction for the future.

Reviews of extant literature show a focus on specific aspects such as collaborative logistics in supply chain collaboration (Verdonck et al., 2013), readiness to collaboration (Singh et al., 2018), certain contexts or industries (e.g., Aktas et al., 2020; Badraoui et al., 2019; Kim et al., 2020), sustainability (e.g., Chen et al., 2017), or collaborative techniques (e.g., Nimmy et al., 2019).

Nonetheless, the supply chain collaboration literature topic is rather large, cross-disciplinary, and has grown significantly in recent years (Nitsche et al., 2021). Thus, the narrow focus of past research does not provide a complete overview of supply chain collaboration and its effect, usefulness, and challenges affecting its implementation. This does not help provide a cogent, coherent body of work with a central aim of clearly depicting the holistic benefits of supply chain collaboration. Moreover, it fails to address how the dynamics of collaboration and the level of engagement can be properly managed as the relationships progress and mature over time.

There should be more studies conducted to holistically study supply chain collaboration and also branch out to study under-researched aspects of supply chain collaboration. Although the implications of different supply chain collaborative practices like trust, commitment, information sharing, IT capabilities, etc. have been well researched, Ma et al. (2018) point out that extant literature is predominantly focused on coordinating contracts with resource sharing being neglected. Against the backdrop of the rise of the resource-sharing economy nowadays, it seems intuitive to focus attention on studying the resource-sharing component of supply chain collaboration.

The role of blockchain technology cannot be contested in the current era of smart technologies being implemented in supply chains to facilitate collaborations with other stakeholders (Rejeb et al., 2021). By enabling the integration, coordination, and monitoring of actions, as well as the real-time sharing of information among multiple stakeholders, blockchain capabilities offer substantial opportunities for enhancing firm efficiency and supply chain performance (Saberi et al., 2019). As an emerging disruptive technology, blockchain is touted to help resolve some supply chain collaboration issues (Nandi et al., 2020), such as transparency, accountability, opportunistic tendencies, and especially the issue of trust, which is essential for successful collaboration by facilitating information exchanges between parties who may not necessarily trust each other (Bai & Sarkis, 2020). Depending on the blockchain's design, organizations utilize the technology to facilitate supply chain collaboration activities with external network partners. IBM, Walmart, and Everledger, among others, have successfully adopted the technology to improve their supply chain performance.

Despite gaining popularity through the digital currency bitcoin, blockchain technology is beginning to transform numerous industries, with applications expanding beyond the financial sector to include the humanitarian sector, real estate, retail, and transportation, among others. Particularly, the technology has significant implications for supply chain collaborative efficiency, innovation, and sustainability development (Bai & Sarkis, 2020). Despite its benefits for sustaining connectivity and dependability among participants involved in a collaboration scheme, research studies are uncommon in the academic literature, except for anecdotal evidence. To validate the theoretical arguments, it would be necessary to research how the key characteristics of blockchain technology influence the various dimensions of supply chain collaboration. Also, blockchain technology–facilitated collaboration exacerbates the vulnerability of the supply chain to IT-related risks (Rejeb et al., 2021). Studies that consider the threats associated with the adoption of blockchain specifically for collaboration within the supply chain would be important to deal with them and aid further application of the technology.

The main focus of supply chain collaboration research has also been on its financial impact and benefits to the organization. As sustainability concerns grow especially in the business world, it is important to study how supply chain collaboration can aid in sustainability. Some studies have looked at supply chain collaboration as a driver for sustainability, but these studies have focused on economic and environmental considerations mostly without focusing on social concerns (Chen et al., 2017). Studies that look at the social sustainability of supply chain collaboration will also greatly help the push for supply chains for sustainability and provide new insights to help the social sustainability drive.

## 5 Managerial Implications

Collaboration is undoubtedly important for an effective supply chain and individual firm performance. It helps companies to collaborate beyond their internal boundaries to develop and manage innovative, valuable cross-functional, interfirm processes that better meet customer demands. So when organizations fail at collaborations, they risk not only on missing out the prospective benefits they can provide, but also stifling future initiatives, both inside their own companies and with their trading partners.

The analysis in this chapter has several practical implications for managers to plan and execute successful collaboration in terms of selecting supply chain members to collaborate with, deciding on the level of collaboration, the areas to be selected for collaboration, and determining the governing framework that will improve business outcomes.

First, the findings demonstrate that despite the substantial prospective benefits, there are major costs to collaborative initiatives; they require time and significant asset and resource investment efforts. Hence, when firms are considering entering into collaboration with other firms, managers must select the collaborators according to expectations, suitability, and perceived benefits.

Managers must choose suitable collaborators based on the other partner's capabilities, strategic goals, and value potential. There should be a sufficient demonstration of the potential value in collaborating with a prospective partner to justify the investment efforts and deliver sustained returns. In deciding on whom to collaborate with, firms must prioritize and select valuable partners with desirable competencies for performance improvement, mutual strategic interests for collaboration, and cultural orientations that fit into their specific trajectory over time. Even for the initiating firm, internal cultural changes and process redesign may become necessary to remove any constraints that may limit value creation in collaboration. The reason is that collaboration is only feasible where both parties have a shared knowledge of the potential benefits of collaboration and demonstrated a high level of goodwill and trust over time.

As firms seek to collaborate with valuable partners with the requisite capabilities, they can optimize the resources and leverage the knowledge of the collaborating partners to fulfill the gaps in internal competencies and compensate for the shortcomings in existing processes. This is why it is important to establish the purpose for any collaboration initiative to realize its full potential. Once suitable partners have been identified, managers must carefully clarify expectations, roles, and responsibilities, with the other parties to ensure that priorities at the individual entity level align with the overall priorities for the supply chain collaboration.

Due to the intricacies of the supply chain, collaborating partner expectations alter regularly over time. To avoid opportunism and mistrust that can finally collapse the collaboration, goals, investment priorities, costs, and advantages of collaboration must be periodically reexamined and new expectations are honestly stated.

After deciding on the specific collaborating partners, managers must select the main internal processes and supply chain activities on which collaborations are needed. A key finding from this analysis is that successful external collaboration depends on the internal integration of cross-function and coordination of internal processes. This finding implies that managers must assess and improve the integration and coordination of internal processes to facilitate successful external collaboration. Yet, as indicated earlier, developing and managing supply chain collaboration can be very difficult to achieve in reality. Although the most critical enablers and obstacles may be context driven and industry specific, managers must understand the drivers and develop strategies to address the barriers to achieving collaboration within the supply chain.

Managers must decide on the level of intensity of the relationship after identifying the activities for collaboration. The findings of the review suggest that there are different forms and approaches to collaboration, with varying performance implications. But close, intensive collaboration and equal partnership engagements are not always necessary nor ideal for all trading partners. The degree of collaborative engagements must be tailored to trading partners and specific processes based on the supply chain design, as well as the strategy and priorities of the organization.

Thus, a successful or good collaboration is not necessarily an intense or strong one, but it is determined by the nature of underlying design arrangements and collaborative mechanisms and the extent of efforts that are put in place by the parties to make the relationship function successfully. Besides, the findings show that each form of collaboration has specific factors that govern the engagements of the collaborating partners.

Practically, managers should ensure that appropriate supporting infrastructure is put in place to facilitate the collaborative effort. This entails robust internal IT systems to improve interactions and information sharing for collaboration as well as the commitment and willingness of top management to offer support to the collaboration process by dedicating adequate resources for each new collaboration effort over the long term.

Trust must be well managed once the relationship has been established by ensuring critical elements like mutual dependence, shared benefits, risks, and power are appropriately handled to make supply chain collaborations function effectively and efficiently. New collaborations take time to deliver real strategic value, hence entities must build a long-term perspective into the goals and expectations for collaboration so that joint planning can be conducted to realize the beneficial impacts of collaborative efforts. Nevertheless, the collaborating entities must agree on an effective performance management system with common indicators to monitor progress and targets for the collaboration.

## 6 Conclusion

The purpose of this chapter is to gain a comprehensive understanding of supply chain collaboration for improving business performance. As a result, efforts have been made to explain supply chain collaboration, including its importance and benefits, describe what it comprises, and highlight some of the significant difficulties. It also reviewed existing challenges and areas where new knowledge is needed, as well as identified some significant emerging priorities for future investigation. It identified a variety of supply chain integration activities involving collaboration, coordination, and cooperation, identifying collaboration as a critical business activity that encompasses all of these integration activities at their most advanced level.

Overall, supply chain collaboration has been identified as a complex concept with several nuances; it can be summarized as the joint working relationship between supply chain entities involving foundational elements such as information sharing, trust and transparency, coordination and joint planning, and mutual benefit and risk sharing between supply chain members, as well as joint recognition of mutual interdependence with shared goals that are aligned with company goals. Besides, various types of collaboration and levels of collaborative engagements are discussed, and recommendations about how much collaboration is warranted under different circumstances are provided.

Several managerial implications have been identified to enable effective planning, implementation, and management of supply chain collaboration. It is recognized that although supply chain collaboration projects can provide a significant competitive advantage and increase individual supply chain members' performance, many obstacles can cause these programs to fail rather than succeed. When organizations take a purposeful, intelligent approach to selecting supply chain entities with which to engage, however, collaboration can considerably increase performance. At the same time, supporting cultural and technological infrastructure, as well as corporate attitude shifts and process redesigns centered on collaboration, can improve supply chain collaboration effectiveness.

There are also some interesting emergent areas of concern and potential research gaps to drive future investigations and add to the existing body of knowledge. These include research that compares the practical use of collaboration in diverse supply chain environments, as well as studies that look at other external partnerships than supplier-based connections. Additional studies on the impact of supply chain collaboration activities on many outcomes, particularly social sustainability performance, innovation, and supply chain resilience, would also be beneficial.

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# Coordination in Supply Chains

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## Contents



**Abstract**

The need for supply chain coordination is far greater today than ever before after witnessing the repercussions on economic activity and business adversities when there are disruptions in global supply and distribution. Supply chains are complex systems characterized by interrelated functions within a network structure with high interdependencies between firms. These involve various interfaces across procurement, production, logistics, and retail; all of which require effective coordination. This chapter provides a review of coordination in supply chains highlighting various concepts, theories, and research conducted into the area. A majority of existing studies on supply chain coordination tend to focus on various processes and functions between firms based on experiments, analytical modeling, numerical analyses, and heuristics to derive optimal solutions to problems. New directions for further research are needed particularly for more empirically oriented studies and qualitative approaches, which can provide deeper and richer

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insights about contemporary issues and the realities of operations systems that impact coordination in supply chains. Future research will also need to extend beyond dyadic relations and incorporate more holistic approaches of supply chain coordination. Concepts of system dynamics, systems thinking, and complex adaptive systems are highlighted as possible theories underpinning future research, as well as the need for collaborative approaches between firms. The results from such studies will also provide greater implications for industry practitioners in making more informed decisions as well as in designing effective supply chain structures and coordination mechanisms.

**Keywords**

Supply chain coordination · Literature review · Systems approach · Collaborative approaches

## 1 Introduction

Supply chains are increasingly seen as complex systems requiring highly integrated processes and synchronized activities among organizations across tiers and dispersed in various geographic locations. This perspective requires effective coordination particularly with the growth of outsourced activities, elevated levels of raw materials and components sourced from overseas suppliers, and new product offerings extended into global markets. Supply chain coordination has long been considered important for managing interdependencies among organizations to achieve optimal performance and to remain competitive. It is also about aligning the strategies and objectives of individual organizations to that of the supply chain.

This chapter provides a review of coordination in supply chains highlighting the various concepts, theories, and research conducted into the area. It also identifies the gaps evident in the literature and offers new directions for further research based on contemporary issues and emerging themes which provide implications for both theoretical and managerial insights.

## 2 Coordination in Supply Chains

### 2.1 Definition and Concepts of Supply Chain Coordination

Thomas Malone who first wrote about coordination theory in 1988 prescribes that coordination is the additional information processing performed when multiple connected actors pursue goals that a single actor pursuing the same goals would not perform. This theory lays out principles about how the activities of separate actors can be coordinated, and has been applied in various disciplines, including sociology, economics, computer science, psychology, management, and organization theory (Malone, 1988: 6). But he also espouses its relevance when applied within organizations to understand the dynamics in teams and departments. The most widely accepted view of coordination is the act of managing dependencies between entities and their joint efforts in working together toward mutually defined goals (Malone & Crowston, 1994). For example, research from an economic perspective includes mechanisms for allocating resources amongst the actors, while research from a management perspective explores information flows between actors. This theory can be used to explain inter-firm coordination, which is most relevant in supply chain management. Additionally, Burgess et al. (2006) articulate the need for stronger theoretical approaches when investigating supply chain management concepts, where coordination theory could be utilized to explain the smooth functioning of organizations within the network.

A supply chain typically entails the sourcing of raw materials and components that get transformed throughout various stages to become finished products, where each organization or echelon in the chain co-creates some form of value. This network of firms is viewed as a unified system requiring effective coordination and management. However, supply chains are challenging to coordinate because of the complexities accrued to the numerous activities involved in various functions and across many organizations simultaneously. It is necessary to consider the processes, activities, and responsibilities aligned with the overall objective of the entire supply chain to draw together multiple functions and organizations, as well as the continuous evolving dynamic structure of the network, which may be formidable for an effective system coordination (Arshinder et al., 2008).

There seems to be no standard definition of supply chain coordination in the literature (Gao et al., 2018). This lack of consensus in definition could be due to how the concept of supply chain coordination has been framed by researchers, and whether their studies were conducted at the micro- or macrolevel. For instance, supply chain coordination is sometimes discerned in the context of an activity (function in a process), or a process (series of related activities), or as a unified system (networks, process, and frameworks). Treating supply chain coordination as an individual function in a process will result in it being viewed as a minor operational function, whereas taking a systems perspective would lead to it being viewed as a more holistic approach for an integrated network of firms (Burgess et al., 2006).

Ballou et al. (2000) explain three levels of coordination: namely, *intra-functional coordination*, which is the administration of activities and processes within the logistics function in an organization. This is to optimize product flow, shipment consolidation, or cost control for instance. The second type of coordination is *inter-functional coordination*, which takes place among the functional areas within the organization, such as between logistics and finance, marketing, and/or production departments. These authors explain the need to balance the impact of logistics to ensure benefits for the organization as an entity. The third type of coordination is *inter-organizational coordination,* which involves boundary spanning activities, where managers liaise with other firms for effective product and information flows and seek to lower costs or improve service levels. If the benefits of coordination and cooperation accrue to the parties, this coalition will likely prevail and continue in the long run (Ballou et al., 2000).

Moreover, with many firms prioritizing their core competencies and outsourcing various activities to external organizations, coordination becomes increasingly important to stay competitive. Market mechanisms are often inadequate for managing the interdependencies among firms, thereby warranting more explicit consideration when designing appropriate coordination mechanisms for managing these inter-organizational relationships (Gittell & Weiss, 2004: 127).

The research on supply chain coordination stems from various perspectives, providing insights into defining the concept of coordination, identifying its levels of coordination and types of coordination. Several authors in the literature appear to treat supply chain coordination synonymously with supply chain management. They consider coordination as an all-encompassing aspect integral to supply chain management. For instance, Mentzer et al. (2001: 18) establish the definition of supply chain management as "the systemic, strategic ***coordination*** of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole." Thomas and Griffin (1996) espouse that effective supply chain management is about the planning and ***coordination*** of various channel members including manufacturers, retailers, and their intermediaries. Similarly, Narasimhan and Carter (1998) state that a well-integrated supply chain involves ***coordinating*** the flows of materials and information between suppliers, manufacturers, and customers.

The Council of Supply Chain Management Professionals (CSCMP), which is a leading network source of over 9000 supply chain management professionals, students, academics, and experts in the field, define supply chain management as encompassing the "planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes ***coordination*** and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies" (CSCMP, 2023). Coordination is undoubtedly quintessential in supply chain management as various authors embrace this macroview.

A systematic literature review was conducted by Arshinder et al. (2008) which unpacked the concept of supply chain coordination and its various aspects. These authors firstly posit that terms such as "integration," "collaboration," "cooperation," and "coordination" are complementary to each other and considered part of supply chain coordination. Their assumption can be followed without loss of generality as "integration (combining to an integral whole), collaboration (working jointly) and cooperation (joint operation) are the elements of coordination" (Arshinder et al., 2008: 317). They derive that supply chain coordination is a prerequisite to supply chain integration. This view was also upheld by Gao et al. (2018) in another systematic literature review. A key concern here is the alignment of individual decisions of firms with the entire supply chain objectives, and this could be addressed through vertical integration, coordination, and collaboration to achieve optimal outcomes and efficiencies as a whole (Tiwari et al., 2013). Notwithstanding the numerous and different activities involved in the supply chain, coordination requirements will also vary depending on the complexities involved.

Fugate et al. (2006) recognize three approaches to coordination. The first entails centralized decision-making. This is from a single entity who has access to information and makes the system optimal decisions, often with the use of economic modeling. However, the decision-maker may have private information and not share this with others, thereby resulting in suboptimal systems performance (Sahin & Robinson, 2005). The second approach is decentralized decision-making involving team-based cooperative efforts among supply chain members to coordinate activities for system optimization. For this form of decentralized decision-making, it is important to discern whether the types of coordination are structured or unstructured, formal or informal, and what the norms or mutual understanding between supply chain members are. The third approach to coordination is nexus-of-contract decision-making by aligning supply chain members' incentives through contracts (Fugate et al., 2006). This has spawned a vast number of research studies, particularly in the area of supply chain coordination mechanisms.

## 2.2 Supply Chain Coordination Mechanisms

The stream of research on coordination mechanisms has been growing exponentially over the past twenty-five years. Many scholars have investigated coordination mechanisms to address specific coordination problems with the objective of achieving desirable solutions and eliminating suboptimization within the supply chain. These mechanisms are tools used, predominantly in the form of contracts. There are studies addressing the various arrangements for the reallocation of decision rights, rules for sharing the costs of inventory and stockouts, and policies governing pricing to the end-customer or between supply chain partners. These are evident with the number of studies that model materials flows and other complex factors, such as uncertainty in the supply or demand of products, forecasting and the possibility of revising those forecasts, constrained production capacity, and penalties for overtime or expediting (Tsay et al., 1999: 302).

Because of the diverse problems inherent in complex networks, coordination mechanisms are numerous and varied. Major areas of coordination mechanisms can include price, non-price, buy-back or returns policies, quantity flexibility, and allocation rules (Sahin and Robinson 2005). A simplified and consolidated version of coordination mechanisms includes three distinct categories, namely, price, non-price, and flow coordination mechanisms (Fugate et al., 2006). Each of these three categories is further discussed in the next three subsections.

### Price Coordination Mechanisms

Price coordination mechanisms allow organizations to generate aggregate expected profits through a variety of pricing strategies and contractual arrangements between supply chain partners. Researchers have viewed this price approach as a method to alter the behavior of one or both parties, or to eliminate system suboptimization.

One pricing area is ***quantity discounts*** as a means of price coordination and considered one of the most popular incentive mechanisms used in coordinating a supply chain (Tiwari et al., 2013). The buying firm may be enticed to order a quantity that can increase the supplier's net profit with this method, but there can also be benefits to both parties (Huang et al., 2021).

***Two-part tariffs*** are another form of price coordination mechanism where the contract stipulates a fixed per unit wholesale price together with a set fee, therefore allowing buyers to determine their order quantity levels based on internal cost structure, the wholesale price, and the fixed fee offered in the contract. This approach is considered more superior to quantity discounts as it is less complex and separates the coordination problem from profit-sharing, which results in fewer disputes (Alcívar Espín et al., 2022). Moreover, the fixed fee determines the allocation of profits between the supplier and the buyer, and the contract is flexible because any allocation is possible.

***Buy-back and return policies*** on the other hand establish who bears responsibility for unsold inventory and to what extent, after demand has been observed (Tsay et al., 1999). A buy-back contract specifies that the supplier buys back any unsold inventory for some agreed upon buy-back price (Chopra, 2019). The price is usually lower than the wholesale price to render the contract feasible. This deal could be offered for perishable items or products that have short shelf life or demand life or products with uncertain demand such as those in the publishing industry, that is, newspapers, magazines, books, and even pharmaceutical products. This form of price coordination allows retailers to mitigate the risk of overstocking and return any portion of the unsold products to the sellers at a pre-specified price and the retailer's inventory level can be restored to a supply chain optimum.

There are five types of return policies: full returns for full credit, full returns for partial credit, partial returns for full credit, partial returns for partial credit, and no returns (Wang et al., 2007). These contract mechanisms can enable better coordination pricing and quantity decisions for products (Dai et al., 2012). However, there are also studies highlighting the drawbacks of this contract mechanism. Supply chains with price-sensitive and stochastic demand with buy-back contracts or buy-back related hybrid contracts (e.g., with revenue-sharing contract or with sales rebates) could impede supply chain coordination (Wang et al., 2021). There is a possibility of firms overselling and over-ordering with buy-back contracts, and that upstream firms may inflate their sales in the current period and compensate "over-buying" downstream firms by using a buy-back contract as a camouflage (Lai et al., 2011). Moreover, retailers may be constrained by cash availability to buy the system optimal level of products in a single purchase. These contracts may not be viable if the costs of physically returning the products are high or when supply chain members have different salvage values for unsold products (Tiwari et al., 2013).

Another form of price coordination mechanism is ***revenue-sharing*** contract, where a seller grants a lower or wholesale price per unit that is usually less than the per unit cost of production, but receives a fraction of revenue generated in return from the sales at the retail level. This is as an incentive mechanism (Cachon & Lariviere, 2005) where sellers can benefit and this form of contract coordinates the supply chain when there are buyers competing based on their purchase quantities – such as competing newsvendors with fixed price. But there are also drawbacks in this form of contract mechanism. It may not be feasible when there are buyers competing on both purchase quantities and price. Secondly, the additional administrative expenses associated with revenue-sharing contracts in some instances may outweigh the gains when compared to using a straightforward wholesale price contract (Cachon & Lariviere, 2005). The benefits accrued to various supply chain partners may vary owing to the impact of demand variability and price-sensitivity (Yao et al., 2008). Retailers may not be incentivized to improve product sales when they have to forgo a fraction of the revenue generated under this type of contract (Tiwari et al., 2013).

### Non-price Coordination Mechanisms

Non-price coordination mechanisms can take various forms in coordinating the supply chain. ***Quantity flexibility*** is used subject to stipulated conditions allowing buyers to deviate from a previous estimate and to purchase a different quantity of products. Quantity flexibility is also used when the supplier agrees to provide a full refund for returned unsold items up to a set quantity. This can occur during periods of demand uncertainty, the need for inventory buffers, or scheduling of machine and labor capacity. It provides substantial flexibility to the buyer but increases the supplier's risk. The study by Epen and Iyer (1997) investigates this in the fashion apparel industry taking into account the selling season and buyer commitment in the context of backup agreements.

A ***minimum order quantity*** can be stipulated depending on the relative strategic power of the parties, where a seller may offer forms of inducement, such as a lower unit cost on items purchased under the contract. This lower bound on the quantity purchased is common in many settings upon the consideration of the buyer's economic order quantity (EOQ) framework. There are also contracts requiring a supplier's guarantee in delivering a fixed (or maximum) quantity of goods.

In relation to minimum order quantities, ***allocation rules*** are sometimes applied by suppliers as a measure based on their capacity levels and, for instances, where they are unable to meet excess demand. Such circumstances may arise when multiple buyers compete for a product that is rendered scarce by the seller's production capacity or stock availability (Tsay et al., 1999). This rationing of products in the supply chain can possibly induce competition among buyers and result in inflated orders and demand distortion (Cachon & Lariviere, 2001; Lee et al., 2004).

***Credit period or payment delays*** are also used as incentives to manage inventory and as a marketing strategy (Tsao, 2010). Cost analysis based on the credit period granted by the supplier to determine the buyer's EOQ to avoid the cost of interest payments has also been forwarded as an analytical technique. Credit period can be viewed as a decision variable to help sellers expand sale size and promote competitiveness, but also relieve the pressure of customers' cash flow (Mu et al., 2022). It has been found that a quantity discount contract is more efficient; however, if the supplier's cost of capital is lower than the buyer's, then trade credit is a better incentive mechanism to coordinate the supply chain (Sarmah et al., 2007).

Other forms of non-price coordination mechanisms entail promotional allowances, cooperative advertising, exclusive dealings, and exclusive territories. ***Exclusive dealing*** is a common practice in many markets, where manufacturers may restrict their distributors or sellers from carrying competing products or prevent them from free riding on the services (such as customer promotions and distributor training) that they provide. By placing conditions in the form of exclusive dealing arrangements, manufacturers can capture the full value of their services and remain motivated to do so (Heide et al., 1998).

In the area of ***cooperative advertising***, studies have explored vertical collaboration between manufacturers and retailers sharing advertising costs (e.g., Lu et al., 2019). There are also scholars who have examined horizontal cooperation contracts between firms at the same level in the supply chain (e.g., Lozano et al., 2013). For instance, cooperative advertising among manufacturers who produce complementary products can be beneficial (Karray & Sigue, 2018). Cooperative advertising has also been explored between retailers (Li et al., 2022), such as online retailer's cooperative advertising contract designs with a physical showroom retailer. This type of agreement attracts consumers to examine the product in person at the showroom and thereafter purchase online. Under an asymmetric information situation, the online retailer can adopt two different contract strategies, where in one of which, information asymmetry does not reduce profit of the online retailer or efficiency of the overall supply chain (Li et al., 2022).

### Flow Coordination Mechanisms

The third category pertains to flow coordination mechanisms, which is a broad area covering various initiatives implemented to enable material flows and information sharing in the supply chain. Information sharing and physical flow coordination enhance supply chain performance (Chen, 1998; Cachon & Fisher, 2000).

The degree of information sharing can have an impact on the overall supply chain physical flow coordination. Full information sharing is achieved when the following are made available (Sahin and Robinson 2002): production status and costs, transportation availability and quantity discounts, inventory costs, inventory levels, various capacities, demand data from all channel members, and all planned promotional strategies. However, this is improbable in many supply chains today because of their decentralized nature, information asymmetries, misaligned incentives, and self-serving behaviors, which give rise to the bullwhip effect.

This phenomenon, also known as the Forrester effect (Forrester, 1958), stems from a seminal work on demand amplification. It occurs when suppliers receive orders that include replenishment quantities to restock actual units sold, as well as adjustments to safety stock and inventory currently in the pipeline needed to countervail changes in demand patterns. These adjusted or overstated stock orders are thereafter transmitted to the distributor, who perceives the system demand as amplified. The replication of this process upstream results in information distortion, where all parties in the supply chain subsequently get a false sense of actual demand patterns and resulting in a system-wide inventory management failure (Forrester, 1958).

In bullwhip situations, a small variation in customer demand can surprisingly spur high variances in demand and supply experienced upstream causing manufacturers to expand capacity and procure additional materials to produce more products. But they eventually end up as excess inventories when this situation stabilizes, and the parties downstream subsequently reduce their order quantities. It will cause manufacturers to cut back on their capacity and suppliers and to decrease production. But this will inevitably spark another cycle thereafter.

Such bullwhip problems can cause issues in upstream players experiencing "excessive investment, poor customer service, lost revenues, misguided capacity plans, ineffective transportation, and missed production schedules" (Tiwari et al., 2013: 119).

The bullwhip effect arises due to the strategic interactions among rational supply chain members and there are four main causes. The first is the impact of price fluctuations because of discounts or sudden exacerbated costs that trigger shocks in demand. The second is rationing or shortage gaming, where buyers order more than required due to a fear of scarcity. This can create imbalances in the supply chain (Lee et al., 2004; Tiwari et al., 2013). Another factor causing the bullwhip effect is demand signal processing. This situation involves forecasting techniques used by the parties to estimate and update the mean and variance of demand as well as order lead times (Chen et al., 2000).

Batch ordering can also lead to bullwhip effects (Tiwari et al., 2013). In this situation, companies batch their orders to decrease costs of ordering. This is only beneficial in the short term, because upstream suppliers can misinterpret the market and anticipate similar reoccurring orders, which may not materialize later on. Other causes of the bullwhip effect include "seasonal retail sales variation, random fluctuations in sales, advertising and price discount policies, factory capacity limitations that encourage over-ordering in times of shortages, order cycle lead-time that delays transmittal of timely demand information, and traditional purchasing and inventory policies that over-react to perceived changes in the demand pattern" (Sahin & Robinson, 2002: 511).

Information and communication technologies (ICT) used to capture information such as point of sale data and shared in real-time (using EDI for example) with supply chain members is valuable in helping to alleviate bullwhip problems. Other measures include time compression, adjustments in order policies, and channel integration (Lee & Whang, 2003).

Flow coordination mechanisms are important areas of investigation and application. For example, Vizinger and Zerovnik (2018) employed stochastic demand modeling and a multiobjective optimization approach to study the coordination of distribution flow in a fruit supply chain with the objective of reducing transportation and warehousing costs, overstocking, and maximizing customer service levels. They derived a set of solutions and estimations to obtain an optimal distribution plan for the supply chain. There are implications from these findings for possible integration and collaborative strategies with external suppliers as well as with end customers.

Flow shop scheduling and coordination for manufacturers acquiring materials from upstream suppliers, with delivery to its downstream retailers and the costs of holding inventory, are also approaches for supply chain coordination (Yeung et al., 2011). Various dynamic algorithms and tools have been developed to optimally solve these problems to attain enhanced profitability with channel coordination.

Information sharing and coordination mechanisms for reducing uncertainty in supply chains can also be pursued. But care needs to be taken, where material flow coordination and a centralized information structure are ineffective without widespread information sharing and dissemination, despite increased frequency of information flow (Datta & Christopher, 2011). Centrally coordinated material flow and centrally controlled decision-making on supply chain member activities can deteriorate the performance of supply chains under uncertain demand. Information sharing alone or coordination alone is likely insufficient in addressing uncertainties (Datta & Christopher, 2011).

Managers are more favorable toward flow coordination mechanisms as compared to price and non-price mechanisms. For example, managers from manufacturing, distribution, and first-tier and second-tier suppliers revealed their supply chains as being more aligned and achieving enhanced performance from flow coordination mechanisms (Fugate et al., 2006). Care should be taken, given that it was found that both price and non-price coordination mechanisms can result in a negative impact for firms and their trading partner performance. Interviews with managers showed that price coordination mechanisms may have some short-term benefits only, while non-price coordination was essentially detrimental to performance. Flow coordination mechanisms are more beneficial instead (Fugate et al., 2006).

Various factors can make for effective flow coordination. The first is engagement of various personnel from both upstream and downstream firms in the design and implementation of the flow coordination mechanisms. Adopting vendor managed inventory (VMI) – a business model where the upstream supplier takes full responsibility for maintaining inventory levels in the chain – can be an effective flow coordination mechanism. However, VMI requires a significant level of trust and investment in ICT systems for real-time inventory monitoring (Sainathan & Groenevelt, 2019). Another factor for successful flow coordination is to have more streamlined transactions, formats, and processes that can reduce supply chain complexities.

Flow coordination mechanisms are fostered by information sharing and dependent on supply chain characteristics. Apart from demand and product variability, and the degree of customization, the level, timeliness, and quality of information shared are also important for effective supply chain planning and coordination. However, supply chain members can have conflicting interests and do not necessarily aim for mutual outcomes, given that opportunistic behaviors or goal misalignment may occur. Moreover, there can also be differences in perceptions of reality or constraints in inter-organizational relationships when engaging in joint decision-making. Despite the perceived benefits of having a coordinated chain, there may be high costs of interface using inter-organizational information systems, where some firms in the supply chain may actually suffer from sharing information under different operational conditions (Sakar & Kumar, 2015). This could be attributed to the different interdependencies and power imbalance among firms.

Coordination theory has been used to evaluate supply chain coordination. For example, this theory was used to evaluate two Finnish manufacturing companies who served as brand owners in their supply chains (Kaipa, 2009). The analyses derived some interesting results, which invokes further contemplation. Many researchers uphold information sharing as a panacea for effective supply chain performance, but they fail to recognize the additional costs associated with it. There are scholars who advocate for transparency and the need to share information throughout the supply chain; but Kaipa (2009) renders otherwise and suggests that this strategy should only be targeted toward those situations and for products that require them the most.

Coordination mechanisms should be applied upon determining the degree of inflexibility of material flows in the supply chain and secondly, whether there is a need to increase or decrease resources and physical operations, and thirdly that the level and frequency of information should be shared only where relevant. Capacity-intensive industries are not capable of responding to the requirements of consumer-product producers and that a high level of flexibility should be used particularly for new products introduced or for those products with volatile demand (Kaipa, 2009: 159). The argument is that the flow coordination mechanism used (based on the volume of information shared and production flexibility) may cause "planning nervousness" in firms and result in a bullwhip effect.

A supply chain with flexible material flow will benefit from frequent planning updates and information shared. This situation also relates to the earlier argument about the complexities and uncertainties inherent in supply chains and how they can affect specific coordination requirements accordingly.

## 2.3 Coordination Between Supply Chain Functions

Many studies examine coordination between supply chain functions. The application of contracts has been studied using model-based research with analytical, mathematical, or decision modeling techniques. They include areas such as quantity discounts, quantity flexibility, commitment of purchase quantity, credit options, and buyback and return policies. These models typically apply to discrete activities and mainly from a dyadic perspective – an organization and its immediate supply chain member upstream or downstream – or sometimes as a three-echelon supply chain. There are studies including coordination between procurement and manufacturing; procurement and inventory management; manufacturing and distribution; manufacturing and inventory management; distribution and inventory management; and manufacturing and retail.

Stock elasticity in contracts results in a range of retailer and manufacturer preference variation (Saha & Goyal, 2015). There exist at least three different forms of coordination contract mechanisms, namely joint rebates, wholesale price discounts, and cost sharing under stock dependent demand. Underpinned by bargaining theory and using numerical analysis, findings show the importance of stock elasticity in determining which coordination contract to select, and that retailers with higher bargaining power will prefer wholesale price discount contracts.

Geismar and Murthy (2015) examine the coordination between production and distribution via systems scheduling with minimal inventory between the two. The findings, using formal analytical modeling, show how the distribution cost can be minimized given a production's schedule and a further overall cost reduction when coordinating these functions using system scheduling.

Manufacturer and retailer supply chain coordination mechanisms can incorporate environmental and economic factors (Chen et al., 2017), especially if consumer demand includes environmental sensitivities such as carbon emissions sensitivity in addition to price sensitivity. In these settings, the manufacturer's optimal wholesale price and unit carbon emissions can occur under various equilibria and contexts where findings provide insights into the effects on supply chain decisions and sustainability performance. For example, various contracts such as a two-part tariff contract that incorporates relevant parameters of price and green technology investment can coordinate supply chains.

Internationally, there can be coordination mechanisms for global supply chains. For example, research by Zheng et al. (2019) explored the coordination mechanism between procurement and retail in the context of the fresh produce supply chain in China under the government's proposed Belt and Road Initiative (BRI), which connects businesses with countries in Asia, Europe, and Africa. The study compared two scenarios consisting of independent procurement between multiple retailers and a single supplier, versus a joint procurement (i.e., bulk purchase to enable quantity discount) approach between multiple retailers and a single supplier. Based on mathematical modeling, their findings underscore the higher profits reaped with joint procurement and the guaranteed win-win outcomes.

Additionally, a centralized network with 3PLs responsible for planning and executing processes is one of the most efficient models for coordinating transportation planning in distribution networks and inventory management. This was affirmed by Kmiecik (2022) based on time series exponential smoothing, ARIMA, machine learning, and neural-network-based methods applied to 29 logistics networks.

## 3 Future Research Agenda and Emerging Themes

### 3.1 Extending Beyond the Dyad

Many studies have focused on coordination mechanisms through nexus-of-contract decision-making that are generally applied to dyadic relations, with majority of them focusing on discrete activities or problems in the supply chain based on two decision-makers or actors. This two-stage model or dyadic perspective describes the supply chain at a highly aggregated level. Moreover, it is perceived that researchers are loosely using the term "supply chain" when they are in fact examining buyer-supplier aspects and fail to take a multitier approach. Additionally, many models on coordination contracts tend to concentrate on a single component and do not provide the full picture of wider supply chain issues occurring further upstream or downstream.

Although with limitations, dyadic studies do contribute to an understanding into the problems for a broad variety of contract structures with their analyses focusing on operational details, thereby requiring more explicit modeling, such as analytical, mathematical, and optimization decision tools (Tsay et al., 1999). These are deemed appropriate to analyze factors (such as for inventory) to overcome uncertainty in the supply or demand of products, forecasting and the possibility of revising those forecasts, constrained production capacity, and penalties for overtime and expediting, where mathematical models and solution methods can be useful tools for solving a vast array of traditional supply chain problems (Sarkis et al., 2019). However, there is a need for more studies to transcend beyond these buyer-supplier relationships and expand theoretical and practical study boundaries. This perspective is based on the complexities of practical situation, as modeling studies tend to incorporate simplifying assumptions such as a single period problem or newsvendor setting to render their analyses more tractable. Moreover, Tiwari et al. (2013) point out that most of the models assume that a supply chain partner has complete information (including cost, demand, lead time, etc.) about the other partner. This is unrealistic particularly in decentralized supply chains, where there are often information asymmetries present.

Extending beyond a dyadic perspective because only focusing on relationships in a pair of firms (e.g., buyer-supplier) ignores the fact that these firms are also embedded in a larger network. Choi and Wu (2009) institute the concept of structural embeddedness, where the smallest unit of a network is made up of three nodes or a triad. They encourage researchers and managers to move away from dyadic approaches and view supply networks starting with a triad as a reference point. Expanding the focus is the first step to understanding the underlying relationships, thus taking a more practical and realistic view of supply chain coordination thereafter, where every action can potentially take on unintended consequences and new relationship arrangements.

The dependency of one firm in a buyer-seller relationship is inevitably contingent on the availability of the alternative third firm, which could be either another supplier, buyer, or the buyer's customer (Choi & Wu, 2009: 264). There have been studies nevertheless on coordination mechanisms that embraced three-stage supply chain models. For example, supplier, manufacturer, and retailer in the area of price discounts (Aljazzar et al., 2017); cost reduction in a logistics network of manufacturer, distribution center, and seller (Xu et al., 2023); economic lot size models to minimize multilevel integrated supply chain costs (Lee, 2005); and inventory models for a three-level supply chain comprising a supplier, warehouse provider, and retailer (Lee & Moon II, 2006). On the other hand, Pourakbar et al. (2007) applied an integrated four-stage supply chain model incorporating a single supplier with many producers, distributors, and retailers to determine optimal order quantities and minimized costs using heuristic solution procedures and genetic algorithms.

Extending supply chain models beyond this is still quite limited and requires further and more nuanced consideration and investigation. Only few studies have considered this approach to date. For instance, there are some researchers that have drawn from the general framework to develop complexity-specific models such as Zou et al. (2023) using multiagent simulation modeling and another study by Timperio et al. (2022) using a combination of data analytics, visualization, and simulation.

### 3.2 Adopting Qualitative Perspectives

There is scope for empirical work on supply chain coordination to use other methodologies. Fugate et al.'s (2006) research is one of the few studies that addresses supply chain coordination stemming from a qualitative method of inquiry and using a multitier perspective. Based on in-depth interviews, the study uncovered the antecedents and outcomes of coordination mechanisms by gathering managerial perspectives from organizations representing different tiers of a supply chain, that is, original equipment manufacturers, distributors, first-tier and second-tier suppliers. A salient finding that arose was the fact that practitioners view flow coordination mechanisms as far more beneficial than the other forms of contract mechanisms.

More recently, Zeidan et al. (2020) adopted an inductive grounded theory method to investigate supply chain coordination failures in the Brazilian beef industry. Interviews were conducted to seek companies' perspectives on the challenges faced in terms of the changes and investments made to achieve environmental targets of reduced greenhouse gas emissions. They highlight ways to establish a rigorous inductive-based methodology through qualitative interviews. Three insights were inductively derived pertaining to coordination failures, low-value equilibrium, and consumers' unwillingness to pay for greener (or more sustainable production of) beef.

There is unquestionably a need to supplement existing modeling and simulation studies with qualitative studies in this area – from a research perspective. Practical managerial views from multiple evidence sources can furnish data rich in detail about real world events and the realities of operations systems and coordination issues faced in supply chains. Such findings enable researchers to develop better and more complete theories about them to support industry practice. There is also the necessity to dislodge the notion that "true research" depends on the skills of numeracy and statistical analysis, while McCutcheon and Meredith (1993: 239) noted "the gap between what academics were assuming and the real conditions of operations led to growing disparities between OM [Operations Management] research's perspective, advice and workable solutions for managers."

Although experiments, analytical modeling, numerical analyses, and heuristics are useful, they may not necessarily cover all the constraints, cost parameters, product families, or demand patterns involved in real-world settings. It is deemed that the combination of field experiments with qualitative interviews soliciting business perspectives or incorporating external validation to findings can be a new contribution to the field. Results from such studies will also provide greater implications for industry practitioners in making more informed decisions as well as in designing effective supply chain structures and coordination mechanisms.

### 3.3 Embracing a Systems Approach

A holistic view to understanding the economics of coordination in complex networks and its theorizing are still scarce in the supply chain management field. Achieving supply chain coordination entails a systems approach in line with the objectives and principles of supply chain management. A systems approach views the supply chain network as an open system consisting of interrelated and interdependent parts that interact as subsystems. This approach assesses overall system rather than the effectiveness of subsystems. It is about discerning the various aspects that form the supply chain, including the supplier's suppliers upstream to the customer's customers downstream, which can provide additional benefits. This perspective allows for the application of systems concepts across the supply chain, rather than focusing on the objectives and performances of different organizations or subsystems therein. This approach is widely believed to be beneficial in managing complexities and uncertainties inherent in supply chains.

One systems approach and perspective is through "supply chain orientation." This perspective proposes systemic, strategic implications of the tactical activities involved in managing the various flows in a supply chain both upstream and downstream across several companies directly connected. An organization "may implement individual, disjointed supply chain tactics, such as Just-In-Time delivery, or Electronic Data Interchange with suppliers and customers; but this is not Supply Chain Management unless they are coordinated (a strategic orientation) over the supply chain (a systemic orientation)" (Mentzer et al., 2001: 11).

A supply chain orientation view is underpinned by characteristics of trust, commitment, cooperative norms, dependence, organizational compatibility, and top management support (Gligor et al., 2022) – each of which contribute to coordination and need further development and investigation.

#### Complex Adaptive Systems

Another systems theoretical approach is complex adaptive systems (CAS). There is a growing interest in research studies conceiving supply chain networks as complex adaptive systems (Tewari & Wilding, 2022). Conceptualized by Holland (1995), CAS is a system that adapts to the conditions of its environment and organizes itself without any control or intervention and emerges over time to become a coherent form. This may appear inconsistent and contradictory to supply chain management entailing deterministic approaches such as planning, organizing, controlling, and coordinating various activities. However, Choi et al. (2001) offer a paradigm of how the system can be discerned as the supply network of firms collectively supplying parts and components to a buying firm, with the environment comprising end consumer markets affecting demand, and the economic, institutional, and cultural systems that define the dynamics and behavior of firms through their interdependencies and inter-relationships maintaining a quasi-equilibrium or new emergence state. The application of this theory is still relatively limited in the supply chain management domain with a relatively small number of studies conducted to date (Dooley, 2022).

CAS has potential to serve as a theoretical foundation in underpinning various aspects of supply chain management, including coordination. CAS can be used to study adaptative behaviors of organizations in a supply network. For instance, Wycisk et al.'s (Wycisk et al., 2008) study highlights how "supply chain and logistics systems adapt, reconfigure or evolve to their environment and to other signals originating from agent interactions. The adaptive behavior is demonstrated in reconfiguration or alteration of network structure, operational processes, or by a shift in agent strategies or behaviors" (Tewari & Wilding, 2022: 406).

CAS can also be applied to model adaptation, network-level dynamism, and interdependencies. Nair et al.'s (Nair et al., 2009) work is one of the few studies that uses the CAS view to explain how individual behaviors at the agent or firm level could manifest in network-level outcomes or that there are network-level interdependencies that shape cooperation, coordination, and exit strategies of firms in the supply chain network (Tewari & Wilding, 2022).

### System Dynamics

System dynamics was introduced by Jay Forrester (1961) as a theory of a system's structure and behavior to encourage holistic thinking. Originating from a control-engineering field, this theoretical approach assists in analyzing and representing the various interactions that affect the dynamic behavior of complex socioeconomic systems both mathematically and graphically by using computer-aided software to solve complex problems.

System dynamics differs from other modeling methods as it considers the system's non-linear aspects with various feedback loops, stocks, and flows; and analyzes them with graphic user interfaces and simulation software. System dynamic models have greater explanatory power than traditional static models because they can incorporate a large number of variables to analyze long-term views of problems as well as subjective aspects that govern managerial decisions and policy planning. System dynamics can also take into account the dynamic characteristics of a supply network (such as lead time slippages or demand fluctuations) which traditional static models typically do not, and they illustrate both linear and non-linear relationships using diagramming techniques and mathematical representation.

It is a technique that can provide alternative and deeper clarity into the understanding, conceptualization, and analysis of coordination problems (Rabelo et al., 2007 as cited in Tiwari et al., 2013). However, the number of empirical studies incorporating system dynamics as the dominant methodology in determining ways of managing and coordinating supply chain networks is still relatively low, despite its long and influential history in the supply chain management field (Wilden et al., 2022).

The study by Bam et al. (2017) contributed to this area by evaluating the effectiveness of supply chain policies in reducing the shortage and costs of essential tuberculosis medicines in South Africa. A system dynamic model simulation was used to assess downstream activities in terms of reliability, responsiveness, and agility. A total of 141 scenarios representing various combinations of supplier characteristics, forecasting methods, and inventory management strategies were performed to derive optimal supply chain policies in reducing the medicine shortages and total costs.

Another study adopting system dynamic modeling is by Minegishi and Thiel (2000) which examined a perishable poultry supply chain in France for symptoms of instabilities in the logistics aspects particularly relating to poultry breeding, slaughtering, carving, packaging, and forwarding activities. A system dynamic model was derived to study the behaviors which helped to identify and modify symptoms of instabilities in production systems. They also focused on the problems of coordination between variables controlling various activities in the supply chain pertaining to short lead times and product quality, which provided implications for poultry breeding policies upstream in the chain.

Similarly, Bala et al. (2017) applied system dynamic modeling and simulation on rice milling in Bangladesh to address supply chain management scenarios for policy planning and design. The milling systems comprise paddy farmers, paddy traders, wholesalers, and retailers. They incorporated factors such as food security, climate change impacting rice production, which can create artificial inventory crises and price volatility in the supply chain, and the need for firms to be demand driven. Simulations were carried out under various "what if" scenarios. These provide greater insights and considerations for various supply chain cooperation, control and coordination activities associated with inventory levels, the bullwhip effect, availability of storage facilities, procurement, lead times, and overall costs in the network.

The system dynamics literature has also expanded in understanding sustainable supply chain management (Rebs et al., 2019). It has practicality in identifying the causes and mechanisms of climate change and related environmental pressures where system dynamic modeling can be used to test and evaluate between alternative policies for a desired system behavior to ultimately support decision-making. Overall, there has been a lack of studies adopting system dynamic modeling on intra- and inter-organizational supply chains, where a majority of studies have focused on the general macrolevel only. Systems thinking and system dynamic models in sustainable supply chain management are an important scope for further research.

### Systems Thinking

The term "systems thinking" was coined by Barry Richmond as the art and science of making reliable inferences about behavior, by developing an increasingly deep understanding of underlying structure (Richmond, 1994). This definition and theoretical perspective has been widely accepted and applied in many disciplines, where it is interpreted as an approach to perceiving the constituent parts in a system, their interrelation, and how systems work over time and within the context of larger systems.

Systems thinking has been proposed as being a system in itself with eight main considerations (Arnold & Wade, 2015). "Systems thinking is a set of synergistic analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviors, and devising modifications to them in order to produce desired effects. These skills work together as a system" (Arnold & Wade, 2015: 675).

Systems thinking is closely aligned with system dynamics and recognizes the interconnections between parts of the system and thereafter identifying any causal loops and how they impact the behavior of the system. It also entails understanding the interconnections of system structure elements, the operationalization of stock resources and their flows within the system, and variables affecting them. There are also aspects of linear and non-linear relationships evident that influence dynamic behavior, and one must possess the ability to conceptually model and discern the system in different ways so as to reduce complexity (intuitive simplification) and recognize different scales of systems and systems of systems (Arnold & Wade, 2015).

Systems thinking in supply chain management coordination still requires further study and understanding. Studies by Moon and Kim (2005), Hildbrand and Bodhanya (2017), and Wilden et al. (2022) uphold system-wide endeavors that result in positive strategic and tactical outcomes. The study by Moon and Kim (2005) examined how systems thinking abilities in individuals impact supply chain management practices. These authors adopted surveys, tests, and simulation methods to investigate the bullwhip effect based on decisions made on inventory management involving 159 participants. The findings depict a positive correlation between those who had systems thinking capabilities and their supply chain performance.

A study underpinned by systems thinking specific to supply chain coordination is by Mello et al. (2017). This study investigated coordination in an engineer-to-order supply chain in the shipbuilding industry. A soft systems methodology was used comprising semi-structured interviews, workshops, field observation, archival and secondary data as well as companies' procedures, flowcharts, and project documentation to gain a holistic view of the roles of firms, interdependencies between the activities and how these could enhance supply chain coordination. The study found that to deploy effective coordination mechanisms, a systems view is necessary where they derive a systems model to highlight the number of linkages across the boundaries of each company and the importance of managing this interface. While the findings provide avenues for coordination improvements at an operational standpoint, there are opportunities to enhance relational approaches at a strategic level in the supply chain, thereby encouraging greater transparency and collaborative and integrative efforts.

It is evident that systems thinking is an important skill that enables individuals and organizations to better understand and embrace concepts at broader levels, such as supply chain integration, collaboration, coordination, supplier networks, supply chain ecology, dyads and triads to name a few (Wilden et al., 2022).

### 3.4 Collaborative Approaches to Supply Chain Coordination

There is also scope for future development into the role collaboration plays in supply chain coordination. It is established that the coordination of information, processes, and material flows relies on the cross-enterprise collaboration with suppliers, manufacturers, distributors, and retailers. Soosay and Hyland (2015, 614) state "supply chains, being inter-organizational and inter-functional, are known to be more effective with the coordinated and collaborative efforts among partners. . .. Rapid developments in technology, globalization and competition have heightened the interest and opportunities for inter-organizational relationships as firms seek productive efficiencies in sourcing, production, distribution, retail and other supply chain functions."

Resources can be optimized in the most rational way along the value chain, based on functional and structural integration, cooperation, and coordination throughout (Ivanov & Sokolov, 2010).

A majority of supply chains operate in decentralized environments where there are information asymmetries present and that the coordination of supply chains comprising legally separate parties cannot be achieved without collaboration. The concept of collaborative supply chain planning entailing joint decision-making processes for aligning plans of individual supply chain members can support achieving coordination and removing a silo approach in decision-making (Wang et al., 2023). *A Framework for Intelligent Supply Chain Collaboration* (FRISCO) has been proposed outlining methods and tools for designing and modeling collaborative planning concepts (Kuppers, 2015). Agent-based simulation for the use of case-driven and quantitative evaluation of supply chain coordination performance is part of this FRISCO approach.

Additionally, collaborative planning, forecasting, and replenishment (CPFR) is regarded as a highly effective approach to coordinating and integrating the supply chain through the collaborative management of inventory with improved demand forecasting and production scheduling. Many manufacturers around the world – such as Unilever, SAP, Wal-Mart, Nabisco, Zara and Target – have adopted this process to better model and coordinate their supply chains.

CPFR is a formalized process and systematic solution for improving supply chain performance. CPFR includes high levels of information sharing and decision-making. The CPFR process consists of eight planning tasks, which can be subsumed under four main activities: strategy and planning, demand and supply management, execution, and analysis (Albrecht, 2010).

Since its adoption by firms in 1998, there have been challenges reported about the low uptake of this initiative across whole industries with many retailers unwilling to make long-term commitments or engage in the required openness of information sharing. It was found that retailer IT capability, goodwill trust, and competence trust in the manufacturer were positively related to information sharing. The interaction between retailer IT capability and goodwill trust was negatively related, whereas the interaction effect of retailers' IT capability and competence trust was positive (Zhang et al., 2022). Yet, the benefits of CPFR do exist. The significant benefits and positive impact that CPFR has on financial and operational performance have been shown to exist (Hill et al., 2018) – supporting the idea that coordination is critical for long-term strategic competitive benefits.

It can be inferred that one of the most effective ways of alleviating information asymmetries in supply chains is through establishing long-term collaborative relationships built on trust. Greater and in-depth studies examining the association between collaboration and its resultant impact on a more coordinated supply chain network is needed.

Collaboration could be discerned as structural, process, or relationship-based (Cao et al., 2010) or modeled as non-linear aspects of duration, breadth, strength, and degree of relationships between firms. There are also other factors, which could be explored in terms of technology sharing with integrated planning and control systems, collaborative governance processes, and the supply chain structures impacted by strategic alliances, joint-ventures, and vertical, horizontal, and lateral integration (Soosay & Hyland, 2015).

## 4 Managerial Implications and Concluding Remarks

This chapter has raised salient points related to supply chain coordination, which provide implications for industry practitioners and supply chain managers. There are various methods, strategies, and processes of how firms can cooperate and negotiate with their suppliers and customers for optimal outcomes and to better coordinate organizational and supply chain activities and goals concurrently.

Some actions include identifying potential bottlenecks and establishing avenues for relationship building, collaborative efforts, and joint-decision-making with certain strategic suppliers and customers where key activities and operations can be better synchronized and managed. Supply chain practitioners must understand that coordination often requires the resolution of trade-offs that impels firms to change their traditional practices and work toward the greater interest of the supply chain for the most part.

Recognizing the roles that each organization plays and their impact on the wider supply chain is fundamental in addressing one the most prominent problems faced in many supply chains today, which is information asymmetry – a major barrier to supply chain coordination. This situation can take the form of information delay, distortion, or variability that impede smooth seamless flows. It therefore raises the need to harness existing competencies within and across firm boundaries and design appropriate contract mechanisms and incentives that can facilitate win-win outcomes.

A growing number of supply chain disruptions today are attributed to various events, such as natural disasters, global health pandemics, political uncertainty, economic upheaval, cyber and terrorist attacks, supplier threats, and rapid fluctuations in consumer preferences and demand. The impacts of these disruptions have raised concerns over logistics bottlenecks that impact global trade causing many industries to experience drastic changes in inventory levels, shipping capacities, and consumer purchases. Similarly, supply shocks and demand variations resulting from disruptions compel many manufacturers, distribution centers, warehouses, logistics providers, and retailers to reassess their strategies, supply chain operating structures, and dynamics. The need for supply chain coordination is far greater today than ever before, and it clearly underscores the importance for managers to look at the bigger picture and discern other firms in the supply chain which they do not have direct business relationships with that could impact or be impacted by such circumstances. More holistic approaches are required when planning and coordinating their supply chains given these complexities.

In view of this, managers will have to stretch their peripheral and tunnel vision beyond the dyadic relations with immediate customers and suppliers and discern the larger context of supply chains as complex systems, in which their organization is embedded. This expansion of perspective requires a shift in mindset and understanding the complexity and dynamism inherent in the network. Hence, possessing the knowledge and skills to apply systems thinking is integral in comprehending the system dynamics that affect firm interdependencies, nature of relationships, and rationale of behaviors apparent in supply chain environments.

Moreover, the inter-organizational and interpersonal networks that culminate in these systems can engender flexible structures and effective communication channels, which serve as platforms for sharing information using relevant technologies and other resources. It is unclear to what extent businesses are willing to share information, given the trust levels, power dynamics, and governance structures evident in supply chains; and the fact that firms are often involved in multiple supply chains. Nevertheless, it is about the flexibility and capacity of businesses to adapt and harness their evolving relationships and activity coordination within supply chains network that will enable greater competitiveness.

This chapter posited a number of perspectives, theories, and practices from past, current, and emerging knowledge. The chapter serves as an important reference for multiple interested parties where coordination in supply chains is a critical issue they face.

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# Relationships Between Disruptions and Unethical Procurement and Supply Chain Practices: Insights from the Covid-19 Pandemic

Adegboyega Oyedijo

## Contents




**Abstract**

Various disruptions to supply chains have occurred over the years, distorting the flow of materials, goods, services, and money. The COVID-19 pandemic, for example, has had an unprecedented impact on supply chain activities, and the current Russian invasion of Ukraine has also resulted in massive disruptions in food, oil and gas, and other commodities around the world. Such challenges can result in new realities, shifts in relationships and network structures, behavioural adjustments, and unexpected actions by supply chain actors, all of which can contribute to unethical behaviour. This chapter presents and overview of how



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unethical practices are likely to emerge when supply chain disruptions occur and how supply chain partners combat such practices. We focus on supply chain disruptions, responsible and ethical procurement and supply chain management, and behavioural supply chain management. The following emerging unethical practices are examined as a result of disruptions caused by the COVID-19 pandemic: (1) supply chain fraud, (2) supply chain opportunism, and (3) display of unfair and unjust behaviour. This chapter also describes three ways to combat such practices: (1) long-term collaborative relationship formation, (2) investment in technology and new methods of operation, and (3) investment in human resource development in supply chains. The insights provided may assist practitioners in developing capabilities and strategies to improve ethical practices in their supply chain relationships.

**Keywords**

Disruptions · Ethical practice · Procurement · Supply chain management · Covid-19 pandemic · Supply chain relationships

## 1 Introduction

In today's business environment, most firms experience increasing procurement and supply chain disruptions on a yearly basis. When such events occur, they disrupt the flow of goods, materials, and services (Xu et al., 2020). The adverse impact of disruptions in the supply chain context has become even more important in recent years. Adverse weather including flooding, wildfires, typhoons; blackouts such as power outages; labour strikes, supplier bankruptcy, and conflicts (the invasion of Ukraine by Russia; political instability, such as terrorism); and disease outbreaks (Covid-19) can each aggravate disruption in procurement and supply chain activities. These challenges lead to new realities, changes in relationships and network structures, behavioural alterations, and unforeseen actions by another party, which may create room for the exhibition of unethical practices.

Unexpected and unanticipated disruptive events may naturally cause procurement and supply chain practitioners to act in ways that their counterparts may perceive as unethical or unjust. Such acts of self-interest may include but are not limited to the need to hoard resources (or finished products) to take advantage of or be protected from a disruptive crisis. It may also lead to the delivery of poor quality of materials or service levels, cancellation of orders already placed or paid for in full, poor tolerance levels by buyers, unfair fines and sanctions, deliberately delaying payments to suppliers, forced labour and unsafe working conditions, and bribery or corruption. A complex supply chain structure, where one party may be more powerful than another, may also trigger the manifestation of unethical practices during disruptive times (Huo et al., 2017). This chapter considers how disruptions can lead to unethical and relational behavioural issues in supply chain relationships.

Interruptions in procurement and supply systems have behavioural and attitude implications that must be addressed, especially given the growing importance of business-to-business (B2B) ties for the fulfilment of customer requirements during times of disruption (Zhang et al., 2018). From this perspective, procurement and supply chain managers who act as boundary spanners in their inter-organisational relationships require strong relational skills to deal with some of the issues that arise as a result of disruptions (Dekker et al., 2019). Changes in the trade environment caused by disruptions may have an impact on boundary spanner perceptions, attitudes, and behaviours with traits such as honesty, openness, trust, and benevolence often missing. Supply chain firms today are beginning to place high significance on some of these softer considerations which could bring about success during disruptive times or result in ultimate damage (Katsaliaki et al., 2021). This issue is the focus of this chapter, with research and practice insights summarised.

In summary, the reader will be exposed to issues around the following two questions:

- During supply chain disruptions, what unethical practices are likely to emerge?
- In the face of disruptions, what can supply chain partners do to combat unethical practices?

Unethical and behavioural issues are *social* and *softer* supply chain themes. The questions in this chapter are primarily presented from qualitative findings which seek to provide insights to unethical practices generated by supply chain disruptions, using the Covid-19 outbreak as a unique case. Therefore, this chapter helps the reader understand the role of human behaviour in managing supply chains during disruptions. It provides unique perspectives on how disruptions affect the perceptions, attitudes, and behaviour of boundary spanners when managing supply chain relationships. Secondly, it provides a better understanding of boundary spanner dynamics in supply chain relationships during disruptions and how opportunistic acts can be exhibited by supply chain partners. Given that supply chain partners form relationships and interact with one another on the basis of benefit realisation (Emerson, 1976), readers of this chapter will learn how disruption can affect the quality of relationships between supply chain partners. Thirdly, it also provides procurement and supply chain practitioners with a better understanding of how unethical practices might affect their inter-organisational relationships when disruptions occur, as well as developing ways to deal with such difficulties, should they arise, thereby reducing the likelihood of relationship breakdown.

The rest of the chapter is structured as follows. A background on disruptions in supply chains, unethical practices in supply chains, and the role of boundary spanners is presented. Following that, the method and findings were summarised, emphasising their implications for the literature, practice, and future research directions.

# 2 Background

## 2.1 Disruptions in the Supply Chain Context

Relationships between suppliers and their buyers have been identified as one of the major strategic key success factors in the modern economy (Tangpong et al., 2010) as well as key predictors of organisational performance (Revilla et al., 2013). Supply chain disruptions are not a new phenomenon, and they even have evidence in early supply chain literature. However, over the last few decades, academics have paid increasing attention to supply chain disruptions, resulting in an increase in the amount of literature devoted specifically to supply chain disruptions (Dolgui & Ivanov, 2021).

Supply chain disruptions are caused by unanticipated triggering events, and the resulting consequences jeopardise the flow of materials supply chain activities significantly. In other words, a supply chain disruption is a sudden and harmful occurrence in the supply chain process caused by circumstances beyond the management's control. Many studies have also highlighted the impact of disruptions on firms, which can occur in a variety of ways, including disruptions caused by (1) institutionalisation (e.g. disruption of the institution and its impact on innovation) (Vargo et al., 2015); (2) innovation and new technologies (e.g. disruptions caused by 'the internet of things' or digital servitisation) (Falkenreck & Wagner, 2017); (3) changes in relationships and networks (Bello et al., 2010).

Other causes of supply chain disruptions have also been identified in the relevant literature. For example, Rodrigue and Wang (2020) noted that it can occur due to a lack of supplied inputs and disruptions during operations. It has also been argued that disruptions can occur due to a lack of raw materials, funds, trained labour, or less efficient production processes caused by natural or man-made disasters, such as the COVID-19 pandemic (Attinasi et al., 2021). Changes in international or interstate border controls; the unavailability of transportation systems such as roads, ports, canals, or cargo space; and labour capacity shortages can all lead to disruption in the supply. According to Fahimnia et al. (2015), disruptive triggers can be classified as natural (earthquake, flood, fire, etc.) or man-made (e.g. terrorist attacks, accidents, supplier bankruptcy, etc.). Scholars agree that as supply chains have become more complex, organisations are now more vulnerable to supply chain disruptions.

Disruptions in various aspects of the supply chain have the potential to spread throughout the connected value chain network (Novoszel & Wakolbinger, 2022). As a result, such disruptions have a devastating impact on firm performance as well as the global supply chains to which they are linked. The consequences of such disruptions have been extensively documented in the existing literature. For instance, Hendricks and Singhal (2005) discovered that companies that experienced even minor disruptions experienced significant declines in sales growth, stock returns, and shareholder wealth. Furthermore, these effects lasted at least 2 years after the initial disruptive event. Most recently, scholars have recently documented the enormous impact of the COVID-19 pandemic, a crisis that has shocked and disrupted global supply chains (Sarkis, 2021). For example, Scala and Lindsay (2021) noted that COVID-19 disrupted critical supply chain activities such as logistics, procurement, and production and had a number of effects on logistical activities, including a worldwide disruption in goods distribution. In particular, it led to stock outs, shipping delays, production shutdowns, increasing commodity prices, and inventory fluctuations which had significantly influence the operational and financial performance of supply chains (Breen & Hannibal, 2021). Consumers also witnessed a severe tissue paper drought, a scarcity of personal protective equipment (PPE), and a shortage of key food items such as rice, wheat flour, and chicken (Paul & Chowdhury, 2020), all of which made headlines in the news. Since the COVID-19 crisis has altered the current thinking of procurement and supply chain management, many important perspectives have gained traction in the literature, such as how supply chain systems can be resilient in the face of disruptions and how disruptions affect supply chain performance.

However, one important issue that previous studies have overlooked relates to how disruptions can lead to unethical and relational behavioural issues in supply chain relationships. Majority of studies published on procurement and supply chain in the disruptive context have omitted the role of boundary spanners in the discourse, especially how their actions are affected by disruptions. A boundary spanner is an economic agent who represents their firms contractually and works towards achieving specific objectives (Aldrich & Herker, 1977). They are simultaneously exposed to competing expectations from their own organisation and from their supply chain partners because of their unique position (Perrone et al., 2003). A disruption which interrupts processes and systems in the supply chain may lead to the exhibition of opportunistic and unethical practices by boundary spanners (Bhattacharya et al., 2013). However, the relevant literature has been less specific about how disruptions affect supply chain partners' relationships in their business-to-business transactions or dealings.

## 2.2 Unethical Practices in Supply Chain Relationships

Ethics is an important concept in organisational behaviour, as it promotes the establishment of codes of conduct for individuals and the overall organisational environment. The importance of ethics for organisations is reflected in the amount of attention devoted to it by management, business, and organisation scholars (Zorzini et al., 2015). Ethical codes of conduct have been widely recognised as a panacea for improving the social and environmental processes of organisations. On the other hand, unethical practices pose serious challenge to their supply chain processes, even though they might benefit one organisation at the expense of other actors in the supply chain (Ellram, 1991). Despite its disruptive features, unethical practices are a prevalent reality within many organisations, as well as a major barrier for organisations to ensuring an efficient supply chain. Thus, it is important to identify what constitutes unethical practice within the context of organisations' supply chain.

Scholars have discovered a slew of unethical practices affecting supply chains. Actors in supply chains frequently engage in unethical practices in order to gain an unfair advantage over their competitors (Carter, 2000a). Outright fraud, unfair competition and communication, non-respect for agreements, and unfair attitudes and treatment of stakeholders are all examples of unethical behaviour. Such unethical practices can aid in achieving a selfish goal, but it disrupts the supply chain relationship in such a way that business growth within an organisation may be hampered in the long run. For example, in response, a more powerful party may decide to engage in price gouging and profiteering, which may violate social and moral norms in the supply chain relationship to the detriment of all parties involved (Fassin, 2005). Phillips and Caldwell (2005) also reveal that smaller and less powerful members of large and complex supply chains believe that the more powerful and larger parties in the chain are responsible for ethical behaviour.

In the supply chain context, unethical practices can be triggered by a variety of factors, including disruptions. In such cases, one party may act in ways that another party interprets as unethical. A more powerful party, for example, may decide to engage in price gouging and profiteering, which may violate social and moral norms in the supply chain relationship (Carter, 2000b). Unethical practices such as sourcing non-standard supplies, favouritism and partiality in supplier selection and tendering processes, bribery and corruption, unfair trading practices (e.g. the just distribution of rewards, mutual respect and understanding, reasonable procedures, policies, and contract terms), rebidding past a deadline, and so on have been highlighted in the literature (Maloni & Brown, 2006).

In disruptive markets with uncertain and volatile conditions, procurement and supply chain managers – the boundary-spanners who are usually at the forefront of relationship management – may begin to exhibit a less sincere and more self-serving attitude towards profit-making and acting in their own firm's interest. The prevalence of unethical procurement and supply chain practices can result in the enrichment of an individual firm, which would detract from the supply chain level collaboration required to compete in today's market. Because unethical issues in the supply chain are a concern, scholars have begun to investigate solutions from various perspectives, and this topic is gaining prominence in the literature (e.g. Husser et al., 2014). However, little research has been conducted on how disruptions affect individual supply chain managers' views, attitudes, and behaviours when managing supply chain relationships. This is an intriguing concept that merits further investigation, particularly in today's market, where COVID-19 appears to be extending and negatively affecting international and local businesses.

## 2.3 The Role of Boundary Spanners in Supply Chain Relationship

Boundary spanners are those who have or take on the responsibility of managing the interface between organisational relationships and their environs and the organisation's internal network with an external source of information (Zhang et al., 2011). The significance of individual boundary spanners in inter-organisational relationships as a key element of the supply chain system has previously been highlighted in business studies. In the business-to-business setting where the behaviours of individual boundary spanners and their supplier relationships are layered within respective organisations, interactions take place not only between individuals but also between organisational agents in boundary-spanning positions (Sood & Sharma, 2015).

In an uncertain market, each firm seeks to maximise its profit; as a result, this behaviour affects the relationship performance and efficiency of global supply chains. There is no guarantee that managers will only act in the best interests of their partners (Villena & Craighead, 2017). Individual boundary spanners are also unsure whether their ethical expectations will be met, whether the partner will act in the best interests of the supply chain relationship, and whether the relationship's value will be distributed fairly, positively, or negatively. Some activities are frequently associated with negative thoughts and emotions, which leads to unethical practice. Thus, unethical behaviour in the supply chain relates to actions that do not conform to acceptable business operation standards, failing to do the right thing in any situation.

Individual managers may find themselves in a vulnerable position as a result of their reliance on one another. Scholars (e.g. Grawe et al., 2015) examined how unethical practices can affect inter-organisational relationships, but they did not examine how boundary spanner (individual managers) behaviours, which are frequently influenced by disruptions (e.g. COVID-19), can result in some unethical practices.

## 3 Method

Using interpretivist research methodology (Creswell & Poth, 2016), the investigations in this research offer substantial and useful insights into unethical supply chain practices from the subjective perspectives of the primary actors in the supply chain relationship (purchasing and supply chain managers). Data were gathered through semi-structured interviews with procurement and supply managers in the United Kingdom (UK) (see Table 1 for respondent characteristics). Manufacturing companies and their suppliers export 42% of goods worth £275 billion, generate £191 billion in economic output, and account for 80% of the economy, up from 69% in 1990 (Rhodes, 2018). In 2020, the 27 member countries of the European Union received 49% of the UK's exports and 52% of its imports (UK Parliament, 2021). However, the COVID-19 pandemic posed significant challenges for the manufacturing industry, making it an ideal setting for research into how supply chain managers dealt with unethical practices. In total, 15 manufacturing firms in the UK provided insights, with interviews lasting between 50 and 90 min. The verbatim interview transcripts were analysed using the Miles and Huberman (1994) thematic data analysis method, providing significant insights useful for developing a better understanding of the topic.

## 4 Observations from Current Practice

This section is structured in accordance with the two questions posed in the introduction. These questions are as follows: during supply chain disruptions, what unethical practices are likely to emerge; and in the face of disruptions, what can supply chain partners do to combat unethical practices?

**Table 1** Interviewee details and respondent characteristics

| Company | Category | Position of interviewee | Interview length (minutes) |
|---|---|---|---|
| Firm A | Manufacturing: healthcare | Supply and Distribution Manager | 60 |
| Firm B | Manufacturing: materials | Procurement Manager | 55 |
| Firm C | Manufacturing: packaging | Procurement and Supply Manager | 60 |
| Firm D | Manufacturing: technology and related products | Procurement Director | 60 |
| Firm E | Manufacturing: food | Supply Chain Manager | 50 |
| Firm F | Manufacturing: furniture and related products | Purchasing and Supply Director | 55 |
| Firm G | Manufacturing: electronics products | Supply Chain Executive | 60 |
| Firm H | Manufacturing: clothing and apparel | Supply Chain Director | 65 |
| Firm I | Manufacturing: food | Supply Manager | 60 |
| Firm J | Manufacturing: beverage | Senior Sourcing Manager | 60 |
| Firm K | Manufacturing: machinery | Head of Procurement | 60 |
| Firm L | Manufacturing: appliances and components | Purchasing Manager | 60 |
| Firm M | Manufacturing: food and beverage | Supplier Relationship Manager | 55 |
| Firm N | Manufacturing: electronics products | Procurement and Supply Chain Manager | 50 |
| Firm O | Manufacturing: heavy equipment | Operations Manager | 60 |

## 4.1 Factors Facilitating the Exhibition of Unethical Practices in Supply Chain Relationships

The first issue that this study set out to address was identifying the unethical practices that emerge in supply chain relationships during disruptions based on the COVID-19 outbreak. However, in addressing that, three significant issues emerged, which were initially viewed as enablers of unethical practices. They are the distance between supply chain partners, supply chain visibility, and supply chain auditing.

One of the main factors that led to the exhibition of unethical practices in supply chain relationships was the issue of *distance between supply chain partners* which are often socially, physically, and even economically distant in nature. Though supply chains are interconnected networks with the primary goal of satisfying the needs of end consumers, they also consist of individual firms that are geographically dispersed and sometimes have different orientations. As a result, the already existing issue of distance may allow for unethical and opportunistic behaviour, because disruptive times frequently influence raw material and production costs, as well as profit margins (Craighead et al., 2020). The following exemplary quote by a supply and distribution manager explains:

> Because we had majority of our supplies coming from outside the UK, the distance played a major role with a lot of unknowns and some suppliers using the uncertainty as an opportunity to hike prices. Some also blamed it on Brexit and we had no choice considering how desperate we were at the time. (Supply and Distribution Manager, Firm A)

*Visibility in the supply chain* context refers to the ability to access or view relevant logistics and supply chain data or information (Tohamy et al., 2003). In other words, visibility allows supply chain partners to track or monitor supply chain processes to stay proactively informed about the status of products and services in transit, limit disruptions, and mitigate risks. Another major source of unethical practice in the supply chain was discovered to be a lack of visibility in supply chain processes caused by socioeconomic distances imposed by the COVID-19 pandemic. According to one of the interviewees, a major source of opportunistic behaviour was a lack of visibility into the supply chain. This idea was expressed in the following exemplary quote by a procurement manager:

> Since we don't have visibility down the chain, it was difficult for us to understand how the sudden changes occurred, and we also struggled to deal with them when we were notified, particularly with the unexpected price hikes from our suppliers. (Procurement Manager, Firm B)

Since supply chain partners still have trouble accessing and sharing information about their strategies and operational operations, the issue of visibility has been discussed in the literature (Muhammad et al., 2021). Another critical issue is determining which supply chain processes are most impacted by visibility, as this factor influences tasks like planning, supply, and evaluation (Caridi et al., 2014). This study discovered that visibility is crucial to the planning and transactional activities between supply chain partners. This point is illustrated by the following example quote by procurement and supply manager:

> We encountered situations where we were unable to thoroughly verify anything, from product quality to quotes provided by our suppliers, and we felt that some of them were acting opportunistically by seizing the moment of disruption. In part, this was due to our lack of visibility prior to the disruption. (Procurement and Supply Manager, Firm C)

The data also revealed that the lack of *supply chain auditing* was another major source of unethical practice in supply chain relationships. Supply chain auditing allows for detailed examination of supply chain process, helping in risk identification and detection of issues that may affect supply chain performance. Disruptions such as the COVID-19 pandemic crippled such viable mechanisms used by supply chain partners as explained in the following exemplary quote below:

> As we had limited supply chain audits in publicly funded contracts, you may be exposed to many unethical practices, especially during times of disruption as we've experienced. (Procurement Director, Firm D)

Additionally, the data shows that a lack of incentives through the exchange relationship process between buyers and suppliers can lead a party to act opportunistically, since they have probably never gained much from the other party and are unsure when their next opportunity will arise. This point is crucial and stresses the need for incentive alignment in supply chains (Wiengarten et al., 2010). The following exemplary quote by a supply chain executive illustrates this issue:

> Sometimes I wonder what the incentives are when you have to pursue them in order to get them to pay you or simply do what they promised to do in the contracts. (Supply Chain Executive, Firm G)

The above points out how important it was for supply chain partners to exchange relevant data and take into account pertinent information exchange properties, such as accuracy and trustworthiness, in order to manage their relationships and ensure that they are adhering to the supply chain agreement's requirements. There are going to be opportunistic tendencies for some supply chain partners in situations where the supply chain process is disrupted, as was the case during the COVID-19 epidemic. In essence, a key cause of unethical behaviour in the supply chain connection is a lack of meaningful visibility measures. Furthermore, despite the supply chain disruptions caused by the COVID-19 pandemic, some unethical practices went unchecked due to a lack of viable supply chain auditing. This implies that the COVID-19 disruptions were simply a catalyst for the display of previously prevalent unethical practices among supply chain partners. Table 2 summarises the unethical practices that are likely to appear in supply chain relationships during disruptive times based on the research's findings (using some interview excerpts) and how those findings relate to the perspectives already present in the pertinent literature.

## 4.2 Unethical Practices Emerging During Supply Chain Disruptions

The findings show that supply chain partners engage in unethical practices such as *fraudulent and corrupt practices* during supply chain disruptions. Interviewees believe that disruptions create opportunities for supply chain partners to profit and that this desire is often a reaction to a changing business environment where certain processes might have been altered. In times of disruption, when firms may need to look out for their own interests first, the concept of the supply chain as a loosely coupled system applies (Orton & Weick, 1990). Based on the evaluation of rewards, such scenarios may result in the display of practices that another party may interpret as unethical (Adams, 1965). Social exchange (Blau, 1964), in which individuals or cooperative firms interact for rewards and the avoidance of punishment, also plays

**Table 2** Linking some interview excerpts to the existing literature

| Research issue | Illustrative quotes | Descriptive category | Theme (link to literature) |
|---|---|---|---|
| ***Unethical practices which emerge in supply chain during times of disruption*** | 'One example involves instances of paperwork fraud by a supplier, and obtaining approval for work over a period of time that was totally false, at significant cost. So, once again, it was a greedy and opportunistic act' (Supply Chain Manager, Firm E) | Fraudulent and corrupt practices | ***Supply chain fraud*** |
| | 'During the COVID-19 period alone, we had two instances of fraud. One of them was regarding the quality of some materials supplied, which we also failed to detect on time due to demand pressure but later discovered after several complaints from our customers' (Purchasing and Supply Director, Firm F) | | |
| | 'As we knew the pandemic caused several problems in the supply chain, especially in sourcing materials for one of our key product categories, we were disappointed with a particular supplier who went rogue, especially with quotes that lacked real justification' (Supply Chain Executive, Firm G) | Intentional and extreme price increase | ***Opportunism in supply chain management*** |
| | 'In our line of work, these third-party logistics providers are critical for on-time delivery of our products, and we discovered that they were only willing to ship items if we paid them exorbitant fees' (Supply and Distribution Manager, Firm A) | | |

(continued)

**Table 2** (continued)

| Research issue | Illustrative quotes | Descriptive category | Theme (link to literature) |
|---|---|---|---|
| | 'Regardless of the type of relationship you have in place and the contracts that were signed at the beginning of the relationship process, you must always remember that things don't happen in a systematic manner during times of disruption and that it is the best opportunity for things to be altered, especially by people' (Supply Chain Director, Firm H) | Exploiting and making alterations for self-interest | |
| | 'Despite the fact that our agreement clearly stipulates a payment timeframe, we truly struggled because some of our buyers just refused to pay on time for material supplied to them' (Supply Manager, Firm I) | | |
| | 'Although we sought longer production timelines, our buyers did not care about the difficulties we were having and were threatening to charge us; as a result, we eventually received fines for a few late delivery dates' (Supply Manager, Firm I) | Exhibition of unfair and unjust behaviour | ***Fairness and justice in supply chain relationships*** |
| **Research issue** | **Illustrative quotes** | **Descriptive category** | **Theme (link to literature)** |
| ***Combating unethical practices in times of disruption*** | 'I think we realized that our relationship was not strong enough and that the foundation was not solid per se because it was never collaborative, so we learned from that to ensure that we build collaborative relationships in the future' (Purchasing Manager, Firm L) | Formation of long-term collaborative relationships | ***Supply chain collaboration*** |

(continued)

**Table 2** (continued)

| Research issue | Illustrative quotes | Descriptive category | Theme (link to literature) |
|---|---|---|---|
| | 'Having classified suppliers by categories and volume of spend, we found that suppliers with whom we had never really developed a collaborative relationship were less eager to go the extra mile for us than those with whom we had developed one, so collaboration is definitely important tackle such issues' (Supplier Relationship Manager, Firm M) | | |
| | 'Since we lacked transparency to clearly see through some behaviours as a result of the lockout from COVID-19, I genuinely believe we need to consider technology as a potential answer to some of these unacceptable issues' (Procurement and Supply Chain Manager, Firm N) | Investment in technology and new methods of operation | ***The role of technology and innovation in supply chain management*** |
| | 'There were reports of unethical labour practices with a few of our third party providers who have not yet invested in smart distribution, which I think could have helped reduce labour strain due to the high demand at the time' (Operations Manager, Firm O) | | |
| | 'We should provide short courses on a range of topics related to ethical and sustainable practices either quarterly or annually, and these courses need to address many of these concerns we encounter constantly | Investment in training and development focused on ethical and sustainable practices | ***Human resource development in supply chain management*** |

(continued)

**Table 2** (continued)

| Research issue | Illustrative quotes | Descriptive category | Theme (link to literature) |
|---|---|---|---|
| | and not only during times of disruption' (Procurement and Supply Chain Manager, Firm N) | | |
| | 'Rather than doing things from a one-sided perspective, I am working with key suppliers to set up joint educational events that allow us to learn from each other' (Procurement and Supply Manager, Firm C) | | |

an important role in disruptive times, as supply chain partners form judgments based on interactions. This point on the exhibition of unethical practices was illustrated by a supply chain manager in the following exemplary quote below:

> One example involves instances of paperwork fraud by a supplier, and obtaining approval for work over a period of time that was totally false, at significant cost. So, once again, it was a greedy and opportunistic act. (Supply Chain Manager, Firm E)

Because there was no viable measure of verifying the authenticity of their claims, some supply chain partners took advantage of the COVID-19 pandemic to engage in fraudulent practices in the supply chain relationship. The following exemplary quote by a purchasing and supply manager illustrates the issue of fraudulent practices during the COVID-19 period:

> During the COVID-19 period alone, we had two instances of fraud. One of them was regarding the quality of some materials supplied, which we also failed to detect on time due to demand pressure but later discovered after several complaints from our customers. (Purchasing and Supply Director, Firm F)

Moreover, many interviewees stated that suppliers *intentionally increased their service and product prices*, using the COVID-19 pandemic disguise. As previously stated, higher commodity prices were unavoidable due to production cuts, creeping inflation, and so on. However, interviewees believed that some supply chain partners went too far, using the disruption as an excuse to stockpile key production materials for personal gain rather than collective gain. A supply chain executive explains this point in the following example quote:

> As we knew the pandemic caused several problems in the supply chain, especially in sourcing materials for one of our key product categories, we were disappointed with a particular supplier who went rogue, especially with quotes that lacked real justification. (Supply Chain Executive, Firm G)

The above extract illustrates a situation where the financial cost of supply chain services has been unregulated, possibly because supply chain regulatory agencies were incapacitated by the COVID-19 pandemic or because alternative supply chain avenues were crippled and monopolistic tendencies exacerbated. Another interviewee stated that the cost of transportation services in the supply chain had increased, which was exacerbated by the lack of viable alternative service providers as a result of the COVID-19 disruptions. A supply and distribution manager noted in the following example that transportation and logistics providers were opportunistic in terms of what they demanded:

> In our line of work, these third-party logistics providers are critical for on-time delivery of our products, and we discovered that they were only willing to ship items if we paid them exorbitant fees. (Supply and Distribution Manager, Firm A)

Another interviewee acknowledged that price increases could be driven by the rapid changes brought about by the pandemic rather than an unethical motive. It was the feeling, however, that supply chain members could easily *hijack the disruption and use it as an excuse for personal gain*. This is not surprising given the loosely coupled nature of supply chains, where supply chain members are initially individual organisations before becoming partners to satisfy the end consumer.

> Regardless of the type of relationship you have in place and the contracts that were signed at the beginning of the relationship process, you must always remember that things don't happen in a systematic manner during times of disruption and that it is the best opportunity for things to be altered, especially by people. (Supply Chain Director, Firm H)

Additionally, the findings found that firms in the supply chain exploited the crisis in order to *obtain goods for a lower price and deliberately delayed payments*. Some of these acts were motivated by the desire to profit from higher bank interest rates. This is not surprising given that many small businesses have long complained about delayed and late payments and unfair practices by more powerful parties in supply chains (Oyedijo & Akenroye, 2023). Tesco in the UK, for example, purposefully delayed payments to suppliers in order to strengthen its own financial position. This issue was highlighted by supply manager in the following exemplary quote:

> Despite the fact that our agreement clearly stipulates a payment timeframe, we truly struggled because some of our buyers just refused to pay on time for material supplied to them. (Supply Manager, Firm I)

This issue also has to do with the deliberate practice of fining suppliers who are unable to reach production goals, buyer's demand, or delivery dates as a result of the disruption. The findings show that certain buyers are not flexible, and because of this, they might easily impose penalties and late delivery fees on suppliers or third-party delivery services. The following is an example quote:

> Although we sought longer production timelines, our buyers did not care about the difficulties we were having and were threatening to charge us; as a result, we eventually received fines for a few late delivery dates. (Supply Manager, Firm I)

The above points are related to what has been debated in the relevant literature with questions about the role of ethics, since firms don't always have the urgency to act ethically, unless it serves the purposes of their firm (Friedman, 1970). Some scholars (e.g. Phillips & Caldwell, 2005) have argued that the relevance of ethics depends on a firm's supply chain position, since smaller firms assume that ethical responsibilities lie in the hands of larger and more powerful firms in the chain.

## 4.3 What Can Supply Chain Partners Do to Combat Unethical Practices in Times of Disruption?

Modern supply chains are prone to disruptions, owing to the widespread distribution of supply chain partners in various geographical locations. As a result, supply chain partners must understand how to combat unplanned behaviours such as unethical practices that may emerge during such disruptive times. Before addressing what can be done, it is important to understand the perceptions of boundary spanners in relation to changes in supply chain relationships caused by disruptions.

When such changes occur, supply chain partners experience a *sense of loss of control*, particularly during the negotiation or bargaining process where buyers and suppliers in the chain source for or deliver products to one another (Oyedijo & Akenroye, 2023). Given that supply chain relationships typically involve one more powerful party, whether it is the buyer or the supplier, the use of power during disruptive times may give the impression that one party is being unfair. The following exemplary quote by a senior sourcing manager illustrates this point:

> I think it felt less and less like we had control over negotiation processes during that time, and we just had to bow to their terms if we wanted to get things moving, which we didn't have a choice given that we had only used just in time previously and had never considered local sourcing because of how hard it is to get them locally. (Senior Sourcing Manager, Firm J)

Some interviewees believed that the disruption caused by COVID-19 allowed some supply chain members to take advantage of others because some firms were under pressure to find alternative products. Some supply chain members even had counterfeit products moving along the chain because adequate inspection procedures in manufacturing plants were lax due to a labour shortage. As a result, some parties *felt exploited* because they were particularly vulnerable to the exhibition of such practices due to their position in the supply chain or the breadth of their bargaining power. This point was illustrated by a procurement head in the following illustrative quote:

> We have major and powerful players in our industry, and they had some form of leverage given their distribution end position, so they would usually dictate, and we just felt exploited because we didn't have any other reliable options. (Head of Procurement, Firm K)

It is critical to understand how these feelings will influence the actions and decisions of boundary spanners who are at the interface of supply chain relationships as well as the subsequent practices' they will exhibit in the relationship development process. If boundary spanners continue to feel a loss of control over negotiations and believe that they are being exploited by their more powerful supply chain partners, such perceptions could have serious consequences for the development of non-transactional relationships.

To avoid these feelings, it is critical to consider what supply chain partners can do to combat unethical practices during times of disruption. One strategy involves the *formation of long-term collaborative relationships in supply chains*. Although transactional and adversarial types of relationships have their place in supply chains, particularly with regard to certain product types, our findings show that collaborative efforts by supply chain partners (e.g. buyers and suppliers) will reduce the tendencies for the exhibition of practices that may be interpreted as unethical. The relevant supply chain collaboration literature (e.g. Oyedijo et al., 2022) has emphasised the role of collaboration as a tool for leveraging capabilities between firms, building trust, reducing the negative use of bargaining power by a more powerful party, and depicting opportunistic acts. However, the findings of this study show that such collaborative approaches are even more important in minimising unethical practices during times of disruption, because partners will be motivated to work together to solve problems and help each other, rather than the individualistic personal gain motive that may arise. In relation to the concept of loose coupling theory, the coupling element necessitates more effort in terms of resource interdependence and joint initiatives and goals between parties, which can be facilitated through the formation of long-term collaboration. A purchasing manager illustrates this concept in the following illustrative quote:

> I think we realized that our relationship was not strong enough and that the foundation was not solid per se because it was never collaborative, so we learned from that to ensure that we build collaborative relationships in the future. (Purchasing Manager, Firm L)

Another supply chain manager affirmed this point by making a distinction between adversarial relationships and those with a close collaborative approach, and how they both had different outcomes based on reactions to disruptions caused by the COVID-19 pandemic:

> Having classified suppliers by categories and volume of spend, we found that suppliers with whom we had never really developed a collaborative relationship were less eager to go the

> extra mile for us than those with whom we had developed one, so collaboration is definitely important tackle such issues. (Supplier Relationship Manager, Firm M)

In order to maintain a stability in supply chain relationships during disruptive times such as the COVID-19 pandemic, supply chain managers should consider building long-term cooperative supply chain relationships beforehand. Supply chain collaboration fosters synergies among supply chain partners by facilitating joint planning and encouraging data exchange (Whipple & Russell, 2007). Although collaboration may appear difficult during disruptive periods such as pandemics, supply chain managers must ensure that they take advantage of available opportunities to create collaborations with supply chain partners so that they can remain connected to collectively address challenges during disruptive periods.

In order to deal with market shifts and high demand when disruptions occur, the respondents also stressed the importance for supply chain partners to *invest in new technologies and methods of operation*. Of course, as mentioned in the suggestion beforehand, a conscious investment in new supply chain practices calls for collaboration from chain partners. This investment may begin with the more powerful parties by concentrating on R&D projects that can give supply chain partners the competencies they need to potentially perform better with information sharing and resource sharing. This argument is best shown by the following illustrative comment from a procurement and supply chain manager:

> Since we lacked transparency to clearly see through some behaviours as a result of the lockout from COVID-19, I genuinely believe we need to consider technology as a potential answer to some of these unacceptable issues. (Procurement and Supply Chain Manager, Firm N)

Furthermore, previous research has demonstrated how conventional linear models are too rigid to respond to extremely dynamic situations (Deloitte, 2012). In order to improve collaboration between companies in the supply chain, new technologies may open up new opportunities for activity execution, which will ultimately increase efficiency and allow for the transparent sharing of data. The following illustrative quote from an operations manager serves to highlight this idea:

> There were reports of unethical labour practices with a few of our third party providers who have not yet invested in smart distribution, which I think could have helped reduce labour strain due to the high demand at the time. (Operations Manager, Firm O)

Based on these findings, supply chain partners may need to work together to consider cutting-edge technologies that have the potential to change supply chains and contribute to strong responsibility and sustainability, as suggested by Gurzawska (2020). One of these technologies is blockchain, a decentralised online database that enables various parties to securely access a master ledger of data and transactions (Pilkington, 2016). Blockchain, for instance, has the potential to change the way we make, advertise, buy, and consume our commodities and alter the supply chain. The blockchain technology may be able to address several ethical and sustainable procurement and supply chain management concerns, since it is capable of improving communication with suppliers, traceability, covering information gaps, and strengthening transparency, regardless of geographical distance or complexity (Gurzawska, 2020). By ensuring more equitable power distribution among supply chain partners, such technology can help address some of the unethical practices identified in this research, including abuse of power, opportunistic acts, and intentional delay of payments. With this technology, every supply chain member has access to the same data and can verify transactions through the block, which is particularly useful for developing trust, information sharing, and collaboration (Queiroz et al., 2020). Blockchain technology also has the ability to improve adherence to ethical standards by eliminating power asymmetry (Gurzawska, 2020). By confirming the accuracy of the claims made by these certifications, blockchain technology's smart contracts, which execute business transactions and agreements automatically and enforce all parties' obligations without the use of intermediaries, also uphold standards of fair trade (Abeyratne & Monfared, 2016). Though technologies in general have raised several concerns, including blockchain technology (Dutta et al., 2020), supply chain partners may benefit from investing in this technology in order to address unethical practices that may arise during times of disruption, especially in supply chain relationships.

Another recommendation relates to *investment in training and development relevant for addressing general unethical trading practices in the supply chain*. The findings show the necessity for supply chain partners to work on specific programs that capture the necessary skills and knowledge for boundary spanners to start displaying ethical practices that will satisfy sustainability standards. This research found that firms in the supply chain don't put enough emphasis on the importance for individuals, particularly those in the supply and procurement departments, to receive regular training in ethical behaviour so they don't endanger themselves, their firm, or the supply chain. This notion is emphasised by the following illustrative quotation from a procurement and supply chain manager:

> We should provide short courses on a range of topics related to ethical and sustainable practices either quarterly or annually, and these courses need to address many of these concerns we encounter constantly and not only during times of disruption. (Procurement and Supply Chain Manager, Firm N)

Making ethical decisions can be aided by such training courses, and they can also serve as a check and balance tool. Aside from creating awareness, they also refresh knowledge on how to deal with unethical practices in the supply chain. In order to develop ethical practices from an individual firm and supply chain perspective, as well as how to sustain ethical practices including that in long-term collaborative supply chain relationships, it is important to create an enabling environment through the help of other relevant functional teams such as human resources. As stated in the following exemplary quote, this may require a collaborative effort between supply chain partners, especially those in a close partnership-like relationship:

> Rather than doing things from a one-sided perspective, I am working with key suppliers to set up joint educational events that allow us to learn from each other. (Procurement and Supply Manager, Firm C)

To summarise, training and development can also provide room for creativity in addressing unethical procurement and supply chain practices and motivating individuals to act ethically. Based on the research's findings, Table 2 summarises what supply chain partners may do to prevent unethical practices using some excerpts from interviews conducted and explains how these conclusions relate to the perspectives already present in the relevant literature.

## 5 Discussion

### 5.1 Summary of Issues and Findings

The purpose of this chapter was to provide insight and understanding into how unethical practices emerge in supply chains during disruptions, as well as how supply chain partners can combat unethical practices in their inter-organisational relationships. By considering these issues in this chapter, the readers are offered interesting perspectives relevant to the ongoing debate about the consequences of unethical procurement practices and violations of social norms in a disruptive context. Most studies have traditionally considered unethical practices in a normal market condition from the perspective of power imbalance (Reimann & Ketchen Jr, 2017) or equity and social exchange (Trada & Goyal, 2017), but this chapter provides readers with an overview of how this issue is also relevant in a disruptive market condition. This chapter provides a better understanding of factors that facilitate unethical practices based on a model that discusses disruptions in supply chain relationships, as well as the role of boundary spanners in transmitting these practices. It also makes a specific observation about how supply chain participants can address unethical practices.

During the COVID-19 pandemic, prevalent unethical practices in supply chain relationships comprised the following: fraudulent practices, intentionally raising service and product prices, hijacking the disruption and using it as an excuse for personal gain, obtaining goods at a lower price, and deliberately delaying payments. These issues are all part of the concept of supply chain relational risk, which can include both suboptimal collaboration and opportunism-related behaviour (Jia & Rutherford, 2010). The concept of supply chain relational risk takes into account the possibility that either party in a supply chain relationship will not fully commit to joint efforts due to cooperation issues and associated opportunistic behaviour. Because the nature of risk changes as the likelihood of disruptions increases, this chapter emphasises the importance of considering the motivational and behavioural factors that lead to fraudulent activities when such disruptions occur (DuHadway et al., 2020; DuHadway et al., 2021). Based on this study's findings, supply chain partners viewed the disruption caused by the COVID-19 pandemic as an opportunity to engage in fraudulent practices. Unless adequate monitoring or incentives to elicit ethical behaviour are implemented in advance, opportunistic behaviours are more likely to occur in situations of asymmetry between distance and information.

The issue of supply chain fraud was brought to light in the first quarter of 2013, when a scandal in Europe revealed that horsemeat was being sold as beef, with some cases containing 100% horsemeat. The obvious difference between beef and horsemeat indicated that the attempt to dilute was not accidental. This case revealed that fraud occurs in supply chains, but despite being identified as a significant issue, the issue has received little attention. According to an Oceana study, 33% of the 1215 fish samples collected at restaurants, sushi vendors, and other food outlets were mislabeled (DuHadway et al., 2020). Another case of a Mattel supplier deliberately using cheaper lead-based paint from an unapproved supplier, despite strict quality control measures, demonstrates that this issue is not uncommon in supply chains. To reinforce the issue of supply chain fraud, Aston Martin decided to recall more than 17,000 vehicles (affecting an estimated 75% of cars manufactured between 2007 and 2012) because a sub supplier had been using counterfeit plastic material in the accelerator arms. Because both perpetrators and victims of supply chain fraud tend to conceal it, the issue has become difficult to address. As a result, this study was able to emphasise this issue as an unethical practice that is prevalent in supply chains, particularly during disruptive times, and it contributes to a diagnostic model for addressing unethical practices in supply chains.

The findings about unethical practices emerging from supply chains during disruptions also align with established themes in the literature, where it has been emphasised that disruption risk sharing protocols should be incorporated into sourcing and procurement contracting. Moreover, social sustainability initiatives are needed in order to address vulnerability and misuse of power by supply chain partners (Oyedijo et al., 2021). The study's findings also help readers understand the critical role of boundary spanners as fundamental drivers of sustainable practices, as they are responsible for maintaining micro-macro linkages (Jia, Stevenson, & Hendry, 2021a). Another major concern is how unethical practices in supply chain relationships can be reduced through collective actions implemented by supply chain partners, such as investment in training and development, which will improve learning, creativity, and motivation for ethical practice (Jia, Wei, et al., 2021b). This step, however, is only possible with a collaborative mindset.

## 5.2 Implication of Findings for Practitioners

The findings of this study can assist procurement and supply chain practitioners in understanding how unethical practices emerge in supply chains during disruptions. It also provides practical advice on how supply chain partners can combat unethical practices in their inter-organisational relationships. Practitioners are encouraged to form long-term collaborative relationships that can foster ethical sourcing, stronger ties, trust, and information sharing. This step may also help supply chain partners address behavioural motivations for unethical practices, especially during disruptive times, and allow buyers and suppliers to compete on a supply chain versus supply chain basis rather than acting opportunistically.

Furthermore, supply chain partners are encouraged to invest in new technologies and methods of operation (e.g. blockchain technology) that will allow for effective collaboration. This type of investment may also aid in the development of supplier relationship management capabilities (Oyedijo & Yang, 2017), which can aid in determining each supply chain partner's contribution to success and developing strategies to improve their performance (Khan et al., 2022).

In conclusion, this study highlights the importance of developing knowledge and creativity, as well as the potential to address unethical practices in supply chains through significant investment in training and development. Such collective learning can aid in keeping ethical practice at the forefront of decision-making. It may also help supply chain partners, particularly those in non-transactional relationships, to instil an ethical culture through the relationship management process. This is especially important because supply chains are managed by humans, who are frequently influenced by emotions and other desires. Training and development with the assistance of colleagues in human resources is another useful tool for updating practitioners' skills. This can be accomplished through the development of continuous professional development (CPD) programs or by obtaining professional membership status with recognised bodies who push the ethical trading agenda such as the Chartered Institute of Procurement and Supply (CIPS) and the Chartered Institute of Logistics and Transport (CILT).

## 6 Future Concerns and Conclusion

Are unethical procurement and supply chain practices triggered by disruptions? This study's findings indicate that they do. However, regardless of disruptions, unethical practices are bound to be unveiled in supply chains. A key observation is that disruptions may actually create more opportunity for such practices to be implemented by supply chain partners. This presents unique opportunities for future research on this topic.

Researching unethical supply chain practices naturally limits potential participants because many respondents do not often feel comfortable sharing their thoughts on this somewhat sensitive subject. To elicit detailed responses from respondents, a qualitative method was chosen. However, the study's qualitative methodology and purposive sampling (based on chosen interviewees) with a total of 15 interviews limits the breadth of the findings. As a result, future studies will need to conduct more research with a larger respondent pool and dissect the opinions of buyers and suppliers, or even go further to consider the upstream tiers, which are usually ignored in the discourse.

This study also concentrated on the manufacturing industry in the UK, which may be another limiting factor because what works in one industry may not work in another. Because unethical trading practices are not limited to a single industry (as demonstrated by the examples in Sect. 5.1), a future concern is comparing the depth of unethical practices in different sectors using a comparative analysis or over time using a longitudinal approach. Additionally, unethical practices, fraud, corruption, and modern slavery, for example, are prevalent in many developing economies (Akenroye et al., 2023), influencing the nature of inter-organisational exchanges between supply chain actors. It would, therefore, be interesting to learn from supply chain actors in countries with weaker regulatory frameworks and institutions to see if the implications of this topic differ in such settings.

Another future concern is a consideration of the antecedent factors that shape unethical behaviour (see Carter, 2000a) and how different theoretical perspectives theories can improve our understanding of this topic. Scholars can go back to the beginning by considering the ethical beginnings, where rules, preferences, and principles influencing decision-making can be explored further (see Rodgers, 2009). Future concerns can also expand on the supply chain relational risk concept to better understand how supply chain partners can manage opportunistic risks collectively. It is interesting to think about how the social dimension, which includes components like cultural diversity, religion, values, and belief systems, affect ethical behaviour in the supply chain context. In this study, all responses were taken into account from the perspective of supply chain partners (e.g. either buyers or suppliers). In order to identify whether unethical practices are more prevalent in the upstream or downstream segment of the supply chain, future studies may need to more accurately categorise the unit of analysis.

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# Multi-tier Sustainable Supply Chain Management and Blockchain Technology Solutions

Yu Gong and Shenghao Xie

## Contents



**Abstract**

More organizations are realizing that implementing sustainability strategies cannot rely on internal operations or first-tier suppliers alone; they also need to engage cross-tier suppliers to coordinate sustainability initiatives. However, a

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multi-tier sustainable supply chain (MT-SSCM) involves complex network structures, and sub-suppliers are often perceived as the 'iceberg', creating invisible threats to promoting sustainability practices and supplier compliance. Brands usually do not have direct leveraging power over sub-suppliers, including lack of contractual relationships and limited information, resulting in the limited rollout of sustainable initiatives. Blockchain technology (BCT) offers innovative solutions to disrupt traditional MT-SSCM. The inherent transparency, immutability, decentralized, and smart contract features of BCT are expected to tackle the bottlenecks of MT-SSCM implementation. However, research on BCT is still in its early stages, and there is even less about the BCT application in SSCM from a multi-tier perspective. Therefore, this chapter explores how BCT drives effective MT-SSCM implementations. This chapter first reviews the existing MT-SSCM research, including conceptual frameworks, empirical practices, and theoretical perspectives. This is then followed by discussions of the underlying concepts of BCT, SSCM applications, and potential MT-SSCM solutions with a case study.

**Keywords**

Multi-tier supply chain · Sustainable supply chain · Blockchain technology · Case study

## 1 Introduction

Sustainable capabilities are central for organizations to remain competitive and balance economic, environmental, and social concerns to achieve better triple bottom line performance (Seuring & Müller, 2008; Sarkis et al., 2019). Expanding sustainability from a sustainable supply chain perspective (SSCM) requires the development of sustainable strategies and operational practices. These effects are more profound from a cross-tier or multi-tier supply chain context, which leads to the concept of the multi-tier sustainable supply chain (MT-SSCM) (Mena et al., 2013; Wilhelm et al., 2016a; Gong et al., 2021). The MT-SSCM extends the traditional dyadic supply relationship to focus on sustainability from multiple tiers which may consider upstream suppliers, sub-suppliers, Tier-1 suppliers, focal companies, distributors, and final consumers (Tachizawa & Wong, 2014; Villena & Gioia, 2018; Wilhelm et al., 2016b).

Sustainability challenges are more salient at the MT-SSCM level, which can be reflected in several examples. In 2013, the horsemeat scandal seriously affected consumer confidence in food processing, and subsequent inspections pointed to the complex food production chain involved (Smith & McElwee, 2021). Nearly all suppliers and producers are skirting responsibility, claiming to be 'victims', and placing the blame on upstream companies and suppliers. In the garment industry, sweatshops and illegal child labour are commonplace. The Brazilian government accused *Zara* of illegal working conditions in its production, but *Zara* responded that it could not be held responsible for sub-suppliers authorized by its supplier AHA (Wilhelm et al., 2016a). These 'chain liability' effects not only lead to supply chain disruptions but ultimately lead to negative publicity for brands and undermine consumer confidence, which again highlights the importance of MT-SSCM (Hartmann & Moeller, 2014).

In practice, the uncertainty of the supply chain environment contributes to these challenges. For brands, distance and diverging institutions influence their management of suppliers, especially those that are dispersed in the globalization context (Sauer & Seuring, 2018). Also, many focal companies have limited control over their upstream suppliers – e.g. no formal contractual relationship with sub-suppliers – reflected in limited information and executing influence (Tachizawa & Wong, 2014). Alternatively, brands often request Tier-1 suppliers to convey sustainability concepts but are subject to sub-supplier resources, exerting power, and institutional environment (Wilhelm et al., 2016a). Several studies called for the need to extend the SSCM to the upstream tiers (Vachon & Klassen, 2006; Hartmann & Moeller, 2014), followed by conceptual framework-building discussions (Tachizawa & Wong, 2014; Mena et al., 2013). More empirical studies further explored supply network level (Villena & Gioia, 2018; Wilhelm & Villena, 2021) and supply chain learning diffusion (Gong et al., 2018; Mena & Schoenherr, 2020) from the perspective of Tier-1 suppliers (Wilhelm et al., 2016a, b).

The technological driven solutions such as blockchain technology (BCT) sparked an emerging trend in SSCM studies. The application of BCT in SCM set off a new wave of research, which offers more possibilities for effective implementation of MT-SSCM with the traceability, transparency, and decentralization (disintermediation) features (Kshetri, 2018; Saberi et al., 2019; Hastig & Sodhi, 2020). Specifically, traceability can provide full-chain visibility and transparency to help SSCM monitoring (Xie et al., 2022), and disintermediation can reduce malicious intermediary behaviour, such as exploiting information asymmetry for profit (Schmidt & Wagner, 2019). These potential applications seem to be able to be naturally applied to MT-SSCM. However, current research has rarely explored BCT from an MT-SSCM perspective (Najjar et al., 2022); thus, this chapter aims to target this research gap to explore how BCT can drive MT-SSCM and supplier compliance.

This chapter is structured as follows. First, it discusses the concept of MT-SSCM and the related theoretical and empirical studies; second, it introduces the BCT essentials, reviews current research on BCT applications in SSCM, and proposes potential applications in MT-SSCM. Finally, the chapter illustrates a practical BCT application in the textile industry from the MT-SSCM perspective.

## 2 Background: Multi-tier Sustainable Supply Chain Management

### 2.1 What Is MT-SSCM?

Multi-tier sustainable supply chain management (MT-SSCM) can be viewed as an extension of SSCM. In their seminal research, Seuring and Müller (2008, p. 1700) defined SSCM as ‘management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e. economic, environmental and social, into account which are derived from customer and stakeholder requirements'.

In other words, SSCM requires comprehensive consideration in terms of triple bottom line effects when managing the three flows. Managing this series of chain effects requires upstream and downstream coordination, rather than the dominance of a single focal company. As the early research by Vachon and Klassen (2006) claimed, it is imperative to extend green practices across the supply chain via a 'collaborative paradigm' by upstream and downstream integration. Similarly, through a systematic literature review, Gimenez and Tachizawa (2012) identified that collaboration and assessment have positive impacts in achieving SSCM, while extending sustainability to suppliers is critical. Although these studies did not directly indicate the concept of 'multi-tier', these integrated processes which involve multiple layers are core elements of MT-SSCM. Based on Seuring and Müller's (2008) definition, MT-SSCN can be further defined as:

> a complex supply chain network system, which involve multiple relationships between buyers, suppliers and customers, to coordinate material, information and capital flows with the overarching aim to achieve the sustainable development of economic, environmental and social perspectives.

The relational perspective can reflect the MT-SSCM to some extent. Some early studies took a dyadic relationship perspective, i.e. one-tier buyer and seller, which may only focus on the relationships with first-tier suppliers and overlooked the full-chain effects (Vachon & Klassen, 2006; Carter & Rogers, 2008). Some studies extended the simple dyadic relationships to buyer–supplier–supplier or supplier–buyer–customer (Wu et al., 2010; Choi & Wu, 2009), extending the initial supply relationship involving only the buyer and the seller to a triad perspective.

From the network perspective, which can be viewed as a complex adaptive system, Wu et al. (2010) believed that it is not realistic to control the entire supply network and relations; rather, there has to be a compromise over how much needs to be controlled. These relationships involving multiple stakeholders can generate cascading effects, i.e. multiple buyer–supplier–sub-supplier (Tachizawa & Wong, 2014; Sauer & Seuring, 2018). Therein, the MT-SSCM practices need to consider the various stakeholders and align the overarching objectives of multiple stakeholders.

## 2.2 Why Does MT-SSCM Matter?

As the branch of SSCM, MT-SSCM extends the unit analysis of SSCM to lower tiers, aiming to address challenges between sub-supplier compliance with focal company sustainability objectives and, ultimately, the successful deployment of SSCM (Sauer & Seuring, 2018; Mena et al., 2013). The MT-SSCM effectively recognizes the important role of upstream suppliers or lower tier suppliers – i.e. suppliers' suppliers. The complex nature of upstream suppliers deserves more attention, as Meinlschmidt et al. (2018, p. 1889) described them as the iceberg, 'whose greatest threat remains invisible when regarded from seemingly safe distance'.

The nature of the complexity can be summarized as suppliers dispersed across different geographic areas, functioning in diverse product chains, and operating under different cultural norms and regulations (Villena & Gioia, 2018). Today, most suppliers are globally dispersed as focal companies tend to choose superior suppliers, whether for price, quality, or strategic considerations. In particular, some upstream suppliers are from developing economies, where labour-intensive industries can reduce manufacturing costs (Wilhelm et al., 2016b). These geographic barriers such as distances and diverging institutions make sustainable management difficult, which constitutes supply chain uncertainty (Sauer & Seuring, 2018) and supplier sustainability risk (Villena & Gioia, 2018). Moreover, opaque institutional fields often create additional institutional pressures from supply chain members and external stakeholders, such as limited supplier compliance regulations (Hofmann et al., 2018).

Focal companies often lack direct control over low-tier suppliers – for example, contractual relationships between buyer firms and low-tier suppliers. Many original equipment manufacturers are not even aware of their lower-tier suppliers due to their low visibility (Wilhelm et al., 2016a, b). When focal companies have such limited information about their low-tier suppliers, the means of exerting influence would be minimal. These upstream suppliers are often sheltered from the public because most of the public will only accuse the focal company of not fulfilling sustainable practices (Meinlschmidt et al., 2018). For example, *Nike* was accused of employing child labour although it vehemently denied it, which implicitly pointed to the fact that focal companies might have very little control over their sub-contracted factories. *Nike* then needed to expend more sustainable efforts to maintain its brand image; however, the large numbers of small textile mills (upstream suppliers) constitute icebergs that were often overlooked. Thus, these misbehaving low-tier suppliers can easily fail to comply with the code of conduct or sustainability standards, e.g. ISO14001 and SA 8000 (Gong et al., 2018). In addition to the voluntary efforts to maintain reputation or corporate social responsibility (CSR) compliance, focal companies also face supply chain due diligence along MT-SSCM (Hofmann et al., 2018). More recently, tougher due diligence requirements have been introduced by enforcement authorities to reduce risk and enhance supply chain resilience. For example, brands need to safeguard the labour rights and environmental protection of their suppliers, such as proof of a fair working environment and proof of the percentage of recycling used in the production process (Schleper et al., 2022).

The phenomenon that consumers drive the focal companies' need to be accountable for the sustainable behaviour of their upstream suppliers is exemplified by the notion of 'chain liability' (Hartmann & Moeller, 2014). In other words, sub-suppliers' non-compliance with sustainability standards can ultimately lead to negative publicity and reputation risk for brand companies.

Focal companies may also face additional external pressures, such as from NGOs and the media (Dou et al., 2018); consumers may resist buying products if they perceive that the brand companies which they trust are deviating from CSR expectations. Some focal companies rely on their suppliers for sustainability concept diffusion and supportive supervision. However, first-tier suppliers may not require their suppliers (sub-suppliers) to comply with the standards to which they are subject, so sustainable performance may be decreasing in tiers (Villena & Gioia, 2018). Also, merely tracing responsibility to upstream suppliers will not eradicate the problem. As Hofmann et al. (2018) identified, fragmented suppliers can create governance gaps, whereby some companies claim oversight through third-party audits but can still abuse human rights without being sanctioned. These issues of unclear division of responsibilities perpetuate the problem of social sustainability.

Furthermore, paradoxical tensions are common in MT-SSCM (Zehendner et al., 2021; Grimm et al., 2022). Tensions often arise from different factors that conflict with achieving socio-ecological goals in SSCM (Zehendner et al., 2021). Companies may pursue short-term profit goals at the expense of long-term socio-ecological sustainability. Also, MT-SSCM stakeholders may have conflicting value goals that the supply chain leaders need to reconcile in order to embrace and acknowledge the tensions (Jia et al., 2019), and this emphasizes the value of 'paradox thinking'. Ironically, the dominant focal company may have the ability to reconcile these conflicts but may lack the motivation to do so. Conversely, some peripheral players (e.g. small-sized low-tier suppliers) are deeply motivated but do not have sufficient resources and capabilities to do so (Grimm et al., 2022).

Generally, the consequences of ignoring MT-SSCM are disastrous. Some studies suggest that sustainability issues often go beyond internal governance, while sustainability efforts for internal companies may not fundamentally change the sustainability performance at the supply chain level (Sauer & Seuring, 2018; Zehendner et al., 2021). In addition to acknowledging the complexity of involved multi-tier suppliers, there is a need to be aware of the chain liability effects. Upstream suppliers often do not appear in public – i.e. supplier disclosures are limited. In this case, other sustainable efforts made by brands may be questioned.

Without full awareness of the importance of these Tier-1 and upstream suppliers, brands may unwittingly incur higher sustainability costs, such as additional regulatory costs and financial sustainability risks (Villena & Gioia, 2018). For example, brands may recall a product with sustainable issues or even stop manufacturing the product. The result is extra resource waste (recalls cause unnecessary emissions) and damage to the brand's production efficiency. To remedy the consequences of ignoring MT-SSCM, focal companies need to conduct additional sustainable practices to achieve commitments, e.g. establishing learning teams and providing equipment and resources for suppliers (Gong et al., 2018). In addition to relying on learning mechanisms, the implementation of MT-SSCM also requires the absorptive capacity of suppliers. Through a longitudinal multi-case study, Jia et al. (2022) found that the uptake of SSCM practices by suppliers is reflected in a gradual process, from passive acceptance at the beginning to active transformation at a later stage. Also, the learning knowledge can be leveraged to build new competencies. However, it is difficult to estimate the extent to which these extra sustainable efforts can restore customer trust and brand image.

## 2.3 Conceptual Frameworks on MT-SSCM

Theoretical conceptual frameworks provide essential understanding of MT-SSCM. Mena et al. (2013) offered the initial theoretical structure of a multi-tier supply chain. They extended the dyadic logic of supply relations to the multi-tier system or a triad. The triad can be viewed as the simplest structure of a supply chain network (Choi & Wu, 2009; Wu et al., 2010).

Mena et al. (2013) suggested that the triad structure of SSCM can be classified into three types. In the first triad, an '*open*' structure refers to the linear flows between the three organizations, and the buyer and supplier's supplier have no direct connections. By contrast, a '*closed*' structure represents a different approach when the buyer has direct connections with the supplier's supplier – such as joint product development, close collaborations on sustainable initiatives. A *transitional*' triad, which is an intermediate approach, is when a buyer is starting to build connections with their sub-suppliers and is in between the open and closed triad structure.

A governance mechanism can be mediated by three themes of power, interdependence, and relationship stability, respectively. Specifically, 'power' refers to the structural position in the triad, including the influence and bargaining power of the three organizations. In some cases, the buyer may have a strong source of power, such as the reachability to global suppliers; or the supplier's supplier has unique product advantages with high structural power. 'Interdependence' is expressed in the tightness of the relationship between organizations in the triad and the degree of acceptance to operate as an entity. For example, these organizations may share the same values and sustainable pursuits, and their relationships are close with higher interdependence. 'Relationship stability' is expressed in the degree of tension among members of the triad, which can be influenced by the tensions of cost and contract (Mena et al., 2013).

Tachizawa and Wong (2014) extended the simple triad structure to more realistic lower tiers as a focus only on the first tier does not go far enough. They conceptualized a seminal MT-SSCM framework with four types of governance mechanisms: direct, indirect, work with third parties, and 'don't bother'. Several contingency variables – including power, stakeholder pressure, material criticality, industry, dependency, distance, and knowledge resources – can influence the choice of governance type. The '*direct*' approach, which covers both transitional and closed approaches of Mena et al. (2013), refers to when focal companies have direct access to lower-tier suppliers. The direct model includes monitoring, governing, and collaborating with lower-tier suppliers through formal and/or informal mechanisms.

In the '*indirect*' approach, focal companies usually provide their requirements to first-tier suppliers to monitor lower-tier suppliers – for example, standards and information-sharing mechanisms. '*Work with third parties*' refers to working with members who are not from the on-chain level. For example, focal companies could work with NGOs, or even competitors, to assign delegate responsibilities to these external members for supervising low-tier suppliers. The final type is '*don't bother*', which means that there is no information about the lower-tier suppliers and the concern is limited to the first-tier suppliers only. This framework provides a more realistic governance model where the focal company can measure the choice or mix the optimal governance model under the influence of various contingency variables (Tachizawa & Wong, 2014).

Adopting the institutional theory and supply chain uncertainty views, Sauer and Seuring (2018) provided a three-dimensional framework for MT-SSCM. They believe that supply chain uncertainty is the core element to consider in MT-SSCM implementations. The first dimension represents the interplay of pressures among supply chain members from the supply chain and institutional environment. It may also be viewed as the institutional distance between focal companies and sub-suppliers. When the institutional distance is low, sub-suppliers are more willing to couple the sustainability goals of focal companies, and vice versa.

The second dimension is supply uncertainty which focal companies need to manage. Supply uncertainty depends on the sub-suppliers' impacts on the focal company's objectives. When focal companies face high management demands, they prefer to engage sub-suppliers in a direct management approach or monitor sub-suppliers when management demands are low.

The third dimension is demand uncertainty, that is, a focal company's ability to manage. These capabilities depend on the power of focal companies over sub-suppliers (Tachizawa & Wong, 2014). For example, when focal companies have limited power to influence the sustainable practices of sub-suppliers, those sub-suppliers will have limited incentives to share information and implement SSCM practices. In such cases, a collaborative approach with a third party may be more effective (Lechler et al., 2019).

Powerful focal companies can actively lead sub-suppliers and even gain competitive advantages, where the direct or indirect governance approaches are suitable. This model constructs the institutional field of MT-SSCM, taking into account the environment of sub-suppliers and the relationships between focal companies and (sub)suppliers. It considers supply chain members as a relational space, explaining the antecedent (institutional field) for managing sub-suppliers and the coupling reactions of sub-suppliers, thereby enriching the institutional theory embedded in MT-SSCM.

More recently, Jamalnia et al. (2023) turned the spotlight on sub-suppliers, proposing the contingency variable framework to manage sub-suppliers' sustainability approaches for MT-SSCM. In general, 37 contingency variables were mapped out via a comprehensive review, which are useful to explain how contingency variables affect the effectiveness of SSCM practices.

## 3 Practices in MT-SSCM

Focal companies can manage lower-tier suppliers through a variety of approaches. Following the governance mechanism proposed by Tachizawa and Wong (2014), some focal companies prefer a direct management approach to engage with lower tier suppliers (Wilhelm et al., 2016a, b), while others prefer to use the collaboration approach – such as working with third parties and alliances (Hannibal & Kauppi, 2019; Lechler et al., 2019). As the main proponents of MT-SSCM, the efforts of focal companies are essential. Using transaction cost economics (TCE), Meinlschmidt et al. (2018) explored how focal companies – buyer firms – manage their sub-suppliers under different contextual factors. These contextual pressures include environmental uncertainty, behavioural uncertainty, and asset specificity, which jointly affect perceived sustainability risk and TCE governance modes.

From a first-tier supplier's perceptive, Wilhelm et al. (2016a) believed that Tier-1 suppliers play an instrumental role, termed the 'double agency role'. On the one hand, first-tier suppliers need to fulfil the sustainability requirements of the buyer firm (the first agency role); on the other hand, they need to disseminate these requirements and ask their suppliers (i.e. sub-suppliers) to meet the compliance requirements (the second agency role). In addition to first-tier suppliers' resource availability, several factors may influence the agency role of first-tier suppliers, including buyer firm sustainability focus, use of power, internal alignment, and purchasing function. These agency and institutional factors impact the (de)coupling activities of first-tier suppliers. Wilhelm et al. (2016b) further echoed the governance mechanism proposed by Tachizawa and Wong (2014) regarding the four MT-SSCM types. Similar to the 'double agency' perspective, first-tier suppliers also can play the role of 'boundary-spanners' between sub-suppliers and focal companies. This concept is particularly influenced by social capital, where the cognitive capital and relational capital between first-tier 1 suppliers and brands (downstream relationship) significantly influence the SSCM practices of sub-suppliers (upstream relationship) (Jia et al., 2021).

From the supply chain perspective, Gong et al. (2021) explored multiple multi-tier linear supply chains. They perceived MT-SSCM as a social system where focal companies should leverage different governance mechanisms to reduce the inherent complexities among sub-suppliers at different vertical integration levels. Through an in-depth case study of *IKEA*'s cotton-textile supply chain, they found that internal complexity within the focal companies will impact the collaborative complexity with different tier suppliers, e.g. collaboration or assessment, and eventually reduce the environmental certainty in order to successfully implement MT-SSCM.

Villena and Gioia (2018) extended MT-SSCM to a supply network perspective via a grounded theory approach, which connects dynamic inter-organizational relationships between MT-SSCM stakeholders. They found that lower-tier suppliers are primary contributors to MT-SSCM risk and have different levels of responsiveness (passive, reactive, and proactive). To tackle these sustainability risks, they constructed four overarching dimensions, comprising (i) committing to a sustainable supply network, (ii) building sustainability capability, (iii) assessing sustainability practices, and (iv) managing sustainability risks and opportunities.

Therefore, focal companies need to commit to building a sustainable supply network, such as establishing a sustainable structure, setting goals, and encouraging suppliers to join. Then, focal companies need to build sustainable capabilities, whether through direct guidance or collaboration. As supply network members are actively engaged, sustainable practices need to be assessed and sustainable risks and opportunities need to be consistently identified.

Some studies further proposed critical success factors and barriers for MT-SSCM rollout (Grimm et al., 2014; Tachizawa & Wong, 2014; Chand & Tarei, 2021; Khan et al., 2021). For example, Dou et al. (2018) integrated the enablers into internal (intangible and tangible resource-related) and external (supplier-related and other) branches. They found that top manager support is the prominent enabler, which further explained the central role of focal companies to lead in the implantation of MT-SSCM. In practice, some barriers need to be addressed. For instance, Chand and Tarei (2021) argued that complex interrelationships can affect sustainable cascade benefits and that such barriers are intertwined with the cause–effect relationships. Furthermore, innovative technology solutions provide some insights into managing MT-SSCM, which is particularly beneficial for remedying information asymmetry in spite of the risk of privacy issues (Sternberg et al., 2022).

## 3.1 Implementation Processes in MT-SSCM

The implementation of MT-SSCM is a gradual process that may be initiated by internal commitment or driven by external pressures. Implementation needs to understand the learning and diffusion process. The learning process should involve all members collaborating while sharing and creating knowledge around MT-SSCM.

Three learning stages can make up the implementation process. ‘Setting up’ is the initial establishment of the supply chain learning environment. ‘Operating’ means that learning procedures will gradually be implemented in the daily routines within companies. ‘Sustaining refers to maintaining a continuous learning process to meet daily and subsequent management requirements (Gong et al., 2018).

To embed a supply chain learning perspective into MT-SSCM, orchestrating resources from both supply chain depth and breadth perspectives is needed. Specifically, larger global focal companies can create dedicated learning teams internally and coordinate externally through collaboration with third parties (Gong et al., 2018). Similarly, Mena and Schoenherr (2020) proposed a green contagion concept to illustrate the diffusion of sustainability practices. This diffusion process demonstrates the propagation behaviour among supply chains, which can be achieved by collaborative and coercive mechanisms.

In addition to recognizing the complex nature of MT-SSCM, implementation can be supported by collaborating with others from a horizontal approach (Najjar & Yasin, 2021). Focal companies should seek modest approaches to adapt to their sub-suppliers rather than deliberately controlling the process. These focal companies can also collaborate with assessment-sharing strategic alliances (ASSAs) to improve supplier compliance. Specifically, ASSAs can exchange sustainable knowledge and assessment methods, which is particularly effective for focal companies that do not have the ability to directly govern their sub-suppliers (Lechler et al., 2019).

During the MT-SSCM implementation process, dissemination can be initiated by supply chain leaders with higher leveraging power, which leads to the concept of supply chain leadership (Jia et al., 2019; Liu et al., 2022). Power alone may not be able to quantify the supply chain leader's role, while leadership can provide an alternative explanation (Jia et al., 2019). Supply chain leaders should have greater influence with creative joint visions, be readily identifiable by their behaviours, and establish relationships with other members who are willing to follow.

Focal companies are usually the leaders in MT-SSCM implementation, with stronger sustainability commitments and the capacity to take on more pressure and deploy more effort and resources. The leadership role of the focal company also shapes the learning behaviour of other MT-SSCM members and needs to be adapted to match different learning stages. More recently, Liu et al. (2022) proposed two interesting leadership strategies – delegation and control strategies – to implement MT-SSCM. Similar to the first agency role proposed by Wilhelm et al. (2016a), the delegation strategy refers to focal companies delegating Tier-1 suppliers to help manage sub-suppliers (provide funds to Tier-1 suppliers), while the control strategy refers to directly funded sub-suppliers. Using a game theory model, they found that focal firms usually weigh profits and the violation probability of suppliers and adopt the optimal leadership strategy. For example, when the funding factor is uniform, control strategies are usually more effective in deterring supplier violations; conversely, firms tend to adopt a delegation strategy when the information asymmetry is high (e.g. limited information of suppliers).

Some studies further identified member capabilities to empower MT-SSCM. Wilhelm and Villena (2021) believed that the cascading activities are dynamic and depend more on the first-tier suppliers' sustainability attributes. These suppliers' attributes include integrated management systems, engaging with stakeholder networks, and sustainability violations. Marttinen and Kähkönen (2022) further verified the important role of focal companies' power. They see the power source as an important catalyst in disseminating sustainability requirements to sub-suppliers, which will further shape cascading capabilities. Also, practices show that the roles of suppliers are crucial. Suppliers can mitigate customer pressure (cascading benefits conveyed by the focal company), which is largely determined by their capabilities, such as reliance on internal investment, and this mediation benefit is lower for low-tier suppliers (Kim et al., 2021).

The MT-SSCM implementations can be influenced by industry-specific characteristics such as facing more or fewer supply chain tiers, complex supply relationships, and elusive institutional pressures. For example, the mineral industry, in particular, suffers from serious social sustainability issues such as lack of regulatory requirements, human rights abuses, and unsafe working conditions, which calls for a holistic supply chain due diligence (Hofmann et al., 2018). Also, in the fashion industry, the diverse sourcing channels constitute a global value chain system, and the global spread of suppliers creates regulatory difficulties (Mejías et al., 2019).

The issue of sustainability in the apparel industry has attracted particular attention, especially after the *Rana Plaza* garment factory collapsed in Bangladesh (Nath et al., 2021). Focal companies need to be flexible in responding to dynamic supply chains among different industries, e.g. by coordinating internal and external resources and actively working with alliances and even competitors. Moreover, focal companies need to position their power over suppliers and measure the most appropriate path for cascading sustainable dissemination.

## 3.2 Multi- theoretical Dimensions in MT-SSCM

The existing research applied multidimensional theoretical perspectives that enriched theory construction and validation. Table 1 shows a summary of the use

**Table 1** Theories within MT-SSCM

| Theory | Exemplar references |
|---|---|
| Agency theory | Wilhelm et al. (2016); Lechler et al. (2019); Sternberg et al. (2022) |
| Attribution theory | Hartmann and Moeller (2014) |
| Boundary theory | Jia et al. (2022) |
| Complexity theory | Najjar and Yasin (2021) |
| Contingency theory | Jamalnia et al. (2023) |
| Cumulative prospects theory | Khan et al. (2021) |
| Information processing theory | Hannibal and Kauppi (2019) |
| Institutional theory | Wilhelm et al. (2016); Mena and Schoenherr (2020); Nath and Eweje (2020); Nath et al. (2021); Grimm et al. (2022). |
| Network theory | Parviziomran and Elliot (2023) |
| Paradoxical tensions theory | Zehendner et al. (2021) |
| Resource dependence theory | Kalaitzi et al. (2019); Chand and Tarei (2021); Kim et al. (2021); Marttinen and Kähkönen (2022) |
| Resource orchestration theory | Gong et al. (2018) |
| Resource-based view theory | Mena et al. (2014); Chand and Tarei (2021) |
| Social capital theory | Jia et al. (2021) |
| Social systems theory | Gong et al. (2021) |
| TOE theory | Feng et al. (2021) |
| Transaction cost economics | Meinlschmidt et al. (2018) |

of theories within MT-SSCM. Interestingly, institutional theory and the resource-based view-related theories were adopted most frequently. This can be explained by the fact that MT-SSCM needs to consider institutional factors, particularly institutional pressures, which include coercive, normative, and mimetic ones (Nath et al., 2021; Wilhelm et al., 2016a).

Grimm et al. (2022) further extended the institutional theory to the institutional entrepreneurial perspective; they argued that in addition to being driven by institutional pressures, the implementation of MT-SSCM can be driven by the institutional environment that is created by institutional entrepreneurs. In other words, institutional entrepreneurs (usually focal companies) can shape the institutional environment, and thereby, the focus was shifted from the traditional enforcement of supplier implementation (e.g. by pressure) to the evolving institutions shaped by institutional entrepreneurs.

Other commonly used theories are related to the resource-based view, including resource dependence theory and resource orchestration theory (Mena et al., 2014; Gong et al., 2018; Kalaitzi et al., 2019). These theories emphasize the importance of resources for focal companies to implement MT-SSCM in order to achieve competitiveness. Moreover, it is not sufficient to merely rely on the resources of focal companies but also to internally and externally coordinate upstream and downstream resources to achieve the orchestration effect (Gong et al., 2018).

In addition to these diverse theoretical perspectives, other studies also adopt an inductive reasoning approach to enrich the theoretical construction and extension of MT-SSCM, such as the grounded theory approach by Villena and Gioia (2018).

Studies from the perspective of theoretical validation and testing are emerging, particularly to validate enablers and barrier factors for implementations of MT-SSCM (Dou et al., 2018; Khan et al., 2021). More recent studies are exploring the optimal performance of MT-SSCM implementations, such as requirements for cascading sustainable benefit implementation (Wilhelm & Villena, 2021), and decision analysis undertaken by focal companies as supply chain leaders to manage sub-suppliers (Liu et al., 2022).

## 4 Blockchain Technology-Based MT-SSCM

The rise of innovative technological solutions creates more possibilities for the implementation of MT-SSCM. Particularly, the revolution of SSCM with Industry 4.0 technologies application is expected to be a game changer. For example, Big Data and artificial intelligence (AI) technology can provide real-time data analysis to optimize decision-making, and blockchain technology (BCT) can empower supply chain transparency and high visualization to solve information asymmetry issues (Saberi et al., 2019). The following sections illustrate the BCT-based approach to supplement MT-SSCM practices.

### 4.1 What Is Blockchain Technology?

Originating from cryptocurrency – such as Bitcoin – blockchain technology (BCT) is expected to disrupt existing industrial operations and new business models. Leading companies are embracing BCT in practice; however, more recently, companies are extending the view of BCT as a groundbreaking technology to internal organizational innovation (Deloitte, 2021).

Definitional constructs help us to understand the technical characteristics of BCT. For example, Dutta et al. (2020, p. 4) defined BCT as ‘an immutable, tamper-proof distributed ledger technology (DLT), which is utilized in a shared and synchronized environment where all the transactions are validated by users and are traceable’. Also, BCT can be viewed as a decentralized, distributed database system to record transaction data, where data are composed of connected data blocks to form a chain.

From the technical perspective, BCT is composed of connected blocks, each with corresponding packet contents. Specifically, each block includes a version number (e.g. Blocks 5, 6, 7), a hash value (to record the value of the previous block), a timestamp (when the data were entered), and a nonce and difficulty target (to measure the level of difficulty of the data-recording effort) (Lim et al., 2021). Each block records the data value of the previously linked blocks, which can prevent subsequent data tampering since any change will cause a chain reaction of data changes (Dutta et al., 2020). For MT-SSCM, ideally, each tier can record all information included in the previous tiers (e.g. material, information, and financial flows), thus ensuring the traceability of the MT-SSCM and supplementing supply chain due diligence (Hofmann et al., 2018).

Therefore, based on these technical attributes, some key features can be summarized: decentralization, consensus mechanisms, immutability cryptographic features, and smart contracts (Xie et al., 2022).

It is imperative to distinguish the BCT types, which further determine the BCT functions. The easiest way to differentiate among them is by the access rights of the transaction. Public BCT means that all nodes can access, read, and submit transactions, while private or permissioned BCT means that only verified nodes can access this set of transactions (Ziolkowski et al., 2020). ‘Permissionless’ means that any registered node can participate in the mining process, while ‘permissioned’ requires the need to obtain authentication before participation (Nandi et al., 2020). The difference in BCT types affects technical characteristics. For example, a public blockchain implies a highly centralized governance model ensuring immutability and no central entity controlling all nodes (e.g. a central bank), but such type suffers from inefficiencies and high-energy consumption (Babich & Hilary, 2020). Some argue that private blockchains may go against the essentially decentralized concept of BCT because access is usually determined by ‘coordinators’; however, this type is sufficiently flexible to be able to adapt to dynamic governance (Ziolkowski et al., 2020).

### 4.2 Blockchain Technology in SSCM

The application of BCT in SSCM can be seen as an extension of traditional SCM application, such as product quality, transportation, inventory optimization, and collaboration (Wang et al., 2018; Nandi et al., 2020). Following the trend of BCT for sustainability (Bai & Sarkis, 2020), some studies conceptualized the BCT potential for SSCM (Saberi et al., 2019; Kouhizadeh et al., 2021). Based on the seminal SSCM study by Seuring and Müller (2008), the BCT functions in SSCM can be categorized from the triple bottom line perspectives.

Economically, BCT is expected to bring additional economic performance to existing businesses. The most notable examples are decentralization or disintermediation. The ideal scenario is that BCT can reduce intermediary parties so that profits are increased by taking advantage of information asymmetries, such as reducing transaction costs and improving transaction efficiency (Lumineau et al., 2021). This application can be explained by the transaction cost theory, while BCT can limit opportunistic behaviour and form more transparent and valid transactions (Schmidt & Wagner, 2019).

Going further, this decentralized governance structure relies on the execution of smart contracts, which is more likely to disrupt the existing governance structure. One popular and ideal upcoming structure is called decentralized autonomous organization (DAO), which is a state-of-the-art structure managed entirely by protocols and smart contracts (Lumineau et al., 2021). Also, BCT empowers rich business opportunities and disrupts existing business models. BCT applications led by large companies are proving to deliver real economic benefits. For example, the industry transportation giant *Maersk*'s adoption of BCT in international logistics has proven to reduce the traditional cumbersome paperwork and lengthy validation process. The application demonstrates chain-of-custody, reducing the potential for fraud in the shipping process (Kshetri, 2018).

Blockchain technology provides new business models by disrupting traditional business incumbents. Morkunas et al. (2019) proposed that BCT can disrupt existing business elements in the contexts of four themes: customer, offer, structure, and financial visualization. Generally, these value creations are expected to bring additional economic performance, although there are many uncertainties that need to be addressed.

Environmentally, BCT brings various dimensional functions. The direct effect is transforming the traditional economy into the circular economy realization. Generally, BCT adds value to products and maximizes resource utilization via the integration of circular thinking into SSCM, with the core functions of reliable information and transparency, and greater automation (Bai & Sarkis, 2020). This transformation is verified through 10 case studies carried out by Kouhizadeh et al. (2020) incorporating regenerate, share, optimize, loop, virtualize, and exchange dimensions. It can also help BCT to transform from a linear (make–use–dispose) to a circular supply chain (Wang et al., 2022).

Another interesting environmental application is related to carbon. Many countries proposed national carbon-neutral strategy goals; however, the key issue is how to specify a standard for measuring and calculating carbon emissions. BCT provides a traceable solution for carbon emissions and can even help set the standard carbon footprint calculation. Also, secure real-time information can balance carbon emission reduction allowances, assist in carbon asset trading and development, and maintain the fairness of the carbon market (Saberi et al., 2019).

As a resource for achieving the circular economy, BCT demonstrates great potential in recycling. Similar to other traceability functions, BCT is able to track the life cycle of products and reduce waste going to the ocean or being disposed of in destructive ways such as incineration and landfills (Zhang et al., 2020; Gong et al., 2022; Xie et al., 2022).

Going further, BCT helps prove the origin (provenance) of green products. Many products claim to be sustainable, such as using recycled materials. Consumers need to trust the brands or certificates provided by third parties, but, unfortunately, these elements are still largely questionable. Full transparency of product traceability and accurate tracking of substandard products may enhance consumer confidence in reducing product recall and potential resource consumption (Saberi et al., 2019).

Socially, BCT is perceived to address potential social sustainability, such as human rights, equity, and safe employment situations (Saberi et al., 2019). Hofmann et al. (2018) listed the existing social sustainability issues, particularly in developing countries. In the complex context of the MT-SSCM, social sustainability is often difficult to trace, as in the case of the appalling scandals of child labour and blood diamonds. The main approach is to ensure socially sustainable stability and immutability. Also, several studies have proven that BCT can provide fair trading systems and environments, suppliers' support (e.g. provide funds for farmers via incentive mechanisms) (Chaudhuri et al., 2021; Upadhyay et al., 2021), and maintenance of supplier–customer relationships (Chaudhuri et al., 2021; Upadhyay et al., 2021).

Another characteristic is the incentive mechanism to encourage people to participate. Specifically, BCT could reward people who actively participate in recycling behaviours – such as waste sorting – with crypto tokens that could be exchanged for items and public services (Gong et al., 2022). This application benefits developing countries in particular, where informal recyclers such as street pickers play an important role in waste collection. However, they suffer from poverty, extreme working conditions, and social problems, and BCT offers a new way to integrate them into the formal recycling chain. There are some pioneer case companies that have implemented this innovative idea into practice (Xie et al., 2022).

## 4.3 Blockchain Technology Potential in MT-SSCM

The above discussion summarizes the application of BCT extended to SSCM and demonstrates excellent triple bottom line benefits. In the context of the MT-SSCM, the prominent decentralization, transparency, and traceability of BCT seem to be able to naturally combine with MT-SSCM. These potential functions include holistic supply chain transparency, innovative governance mechanism, and MT-SSCM standard integration.

### 4.4 Holistic Supply Chain Transparency

Increasingly, brand companies are being pressured by sustainability claims, such as their own CSR disclosures, as well as external pressures to disclose the source of their products (Sodhi & Tang, 2019; Xie et al., 2022). These sustainability disclosures are more often reflected in their internal sustainability reports. However, the pain point for focal companies is that it is difficult and costly to access and disclose these upper-level supplier data, which is once again reflected in ‘chain liability’. Therein, BCT provides a holistic, traceable, and visible solution (Saberi et al., 2019; Hastig & Sodhi, 2020).

Focal companies can link their Tier-1 suppliers as well as upstream suppliers by setting up a BCT-based information system. In the BCT-based information system, suppliers are required to upload specified data content, such as basic product information, time, status, and even other sustainability metrics such as resource consumption and working conditions. Once production information data are entered into the BCT system, focal companies can set the access right of data visualization (based on BCT categories). Specifically, supply chain members have priority for data entry and access, whether to disclose all production information or to disclose key production process information to customers (Lumineau et al., 2021). Based on the technical features of BCT, any data, once entered, cannot be tampered with, and any impact caused by malicious third parties or supplier malpractice will be recorded in the system (Najjar et al., 2022).

A common approach is to combine other technologies, such as QR codes and internet-of-things (IoT) technology, to create a digital twin to digitally upload information about the physical product to the system, where subsequent records are supported by scanning the codes (Agrawal et al., 2021). The realization of these functions must be based on the linking of all involved parties. For some brands that have already deployed information systems (e.g. enterprise resource planning (ERP) systems), applying BCT can further empower trust, as it disrupts the previous practice of self-verification by the brands. As Agrawal et al. (2021) demonstrated, BCT creates a holistic and connected tracking system among different tiers and stakeholders. It records information starting from the raw material supplier, product information (e.g. 100 units), and stakeholders (e.g. senders and recipients), and all the links and transactions are recorded in the information system. According to the basic principle of BCT, each block records the data packets of previously linked blocks, so that each link is able to check upstream production information, material, and information flow.

### 4.5 Innovative Governance Mechanisms

Effective governance mechanisms can help to enforce MT-SSCM practices. Traditional governance models face paradoxical thinking as multi-stakeholders have conflicting social and ecological goals, (Zehendner et al., 2021). Focal companies are counting on suppliers to be conscientious about sustainable practices or are relying on their first-tier suppliers (Wilhelm et al., 2016a), while suppliers would prefer focal companies to provide help, such as financial assistance and training. An eclectic paradigm is to partner with third parties, such as NGOs or competitors, to help enforce supplier compliance (Tachizawa & Wong, 2014). However, the extent to which this approach is effective and how it combines with direct or indirect approaches is subject to industry-specific contexts.

From a transaction cost perspective, BCT can reduce both ex-ante and ex-post opportunistic behaviour. Supply chain members are inclined towards profit maximization, which is the main pain point that makes governance difficult. The BCT can ensure that supplier evaluation metrics are objectively documented, which gives high credibility to performance measurement. The cost of suppliers deviating from their sustainable compliance would increase significantly, which directly corresponds to reputation and subsequent performance evaluation (Lumineau et al., 2021), ultimately jeopardizing supply relationships (e.g. brands looking for alternative suppliers). Similarly, any MT-SSCM link to tampering and information distortion can be easily traced; therefore, post hoc opportunism is more easily detected (Schmidt & Wagner, 2019). In short, the purpose of managing opportunistic behaviour is to maintain sustainable supplier compliance as the cost of non-compliance will otherwise be high.

These perspectives still commence with focal companies, who dominantly govern sustainability practices and push their suppliers to comply. However, in practice, there are some sub-suppliers with relatively higher power, who are not even controlled by the first-tier supplier (Wilhelm et al., 2016b).

Another innovative governance approach relies on smart contracts, which can coordinate the governance with other stakeholders. In other words, unlike traditional contract- and relational-based governance, BCT can facilitate collaboration and coordination via its on-chain protocols (Lumineau et al., 2021). Goldsby and Hanisch (2022) offered a matrix of four types of BCT governance model: Coordination includes alignment and interfaces, resource deployment and operations, and mutual adjustment, while control refers to the allocation of decision-making rights among BCT members (Goldsby & Hanisch, 2022).

Focal companies can use a dynamic approach by combining these modes. For example, the brand could initially adopt a custodian model (Goldsby & Hanisch, 2022), meaning that coordination takes place across organizations (brands and their suppliers), with control dominated by the key players. The brand needs to realize that the coordination is a chain perspective, rather than relying on internal coordination. Moreover, the brand can assign the governance to the key suppliers – which can be determined by their power and order volume. Generally, these BCT-based governance types provide innovative governance mechanisms, and the provisions of smart contracts can specify decision-making and access rights in terms of control and coordination.

## 4.6 MT-SSCM Standard Integration

Sustainability standards are imperative to achieve consistency for supplier compliance, e.g. through the implementation of a code of conduct or standards such as

ISO14001. However, the lack of supply chain standards or gaps in the regulatory framework are the main obstacles in this regard (Hofmann et al., 2018). This is particularly true for globally dispersed suppliers where environmental standards may vary, thereby largely hindering their evaluation and implementation.

Wang et al. (2022) proposed that BCT can address standard identification and coordination issues. BCT can unify MT-SSCM standards (e.g. standard operating procedure) and can trace and update the standard identification in real time. Also, it can help achieve standards' synchronization (production standard, environmental protection standard, and labour protection standard) in terms of operations and service. These implementations are built on the premise of BCT-specific technical features (e.g. smart contracts).

The BCT creates trustless systems capable of accomplishing information sharing and sustainable compliance dissemination (i.e. suppliers need to perform to specified compliance standards that can be easily disseminated to multiple tiers). BCT also has supporting regulatory functions such as avoiding the lag in manual inspection – any non-compliance will be detected. The integration of this set of standards can link multiple stakeholders to strengthen BCT network effects and reconcile mutual stakeholder benefits (Gong et al., 2022). Generally, BCT integrates members, processes, and information and governs MT-SSCM through a BCT-based ecosystem perspective, which can help solve the difficulties of standard identification and coordination.

## 5 A Case Study of a BCT-Based MT-SSCM

### 5.1 Company Background

This section provides a case study of a textile company which uses BCT to manage its SSCM practices. The case company is BETA (fictional name due to confidentiality), a textile company specializing in recycled fabrics, inaugurated in Shanghai, China. BETA is committed to using sustainable and environmentally friendly materials due to concerns of environmental pollution and waste issues in the textile industry.

BETA noticed the huge potential of used plastic bottles and collaborated with local scientific institutions and NGOs to develop an innovative polyester fibre production method that can be made from recycled plastic bottles (RPET). This sustainable path drives BETA's innovation journey and, in recent years, has led to the exploration of using BCT technology.

BETA applies a foundry format and is not directly involved in manufacturing; rather, it coordinates with textile chain members to complete the production and processing and then exports products to the European market. This combination of BCT verification and physical verification strengthens BETA's commitment to recycled products and attracts many European brands with high sustainability aspirations. Currently, BETA has grown into an international company, with several awards, and exports fabric products to over 20 countries.

## 5.2 Blockchain Technology Application

BCT applications are motivated by the pain points of recycled product validation that exist in the textile industry. The use of recycled products is becoming increasingly popular and can be driven by multiple considerations, such as regulatory pressures or brands' internal CSR promotion. However, verifying the authenticity of recycled products can be challenging, particularly with the multiple stages and stakeholders involved in the MT-SSCM context (Agrawal et al., 2021). The common practice is for brands to obtain (purchase) certificates, e.g. global recycling standard (GRS) certificate, or for regulators to conduct random testing. However, these traditional verification practices are inefficient. At the processing stage, some factories are still unable to prove that materials are made by using recycled products as claimed. Also, it is difficult to distinguish directly between virgin and recycled materials. BETA was concerned with the suspicion of counterfeiting, and in the face of increasingly stringent sustainable supplier screening pressure from brands, BETA germinated the idea of a BCT application.

BETA started pilots with its suppliers with whom it had long-term trading relationships and gradually expanded to the whole recycling chain. The BCT system was initiated by BETA, and it is more like a private BCT version: BETA set up strict supplier screening criteria (i.e. verified the participants that can join). For verification and joining, first, these suppliers need to obtain relevant certificates. BETA assigns quality control personnel to visit sites and conduct sampling inspections according to their internal physical testing (Beta's proprietary process [patent pending] to test the content of recycled plastic materials in products, which is currently applied to fibres, yarns, fabrics, and end products). Therefore, only members who meet sustainable supplier standards and have completed verification can join the BCT network.

Another key element in this case is how to engage participants on board (i.e. the willingness of suppliers to participate). Initially, BETA was just passing the requirement to upstream suppliers to upload information via its bargaining power and terminated orders with others who did not want to join the system. However, the level of supplier awareness of BCT was limited at this stage, and BETA made efforts to minimize the burden of using BCT systems on its suppliers. In practice, the requirements that suppliers need to meet are very simple: Suppliers only need to scan the QR code and upload data as required, and there is no additional cost or burden based on the original processes. BETA covered the cost of system development as well as staff training, and the BCT deployment model spreads quickly.

BETA created a BCT-based recycling chain, proving that its textile products are made from collected PET bottles and a cascade of multi-level stakeholders, as Fig. 1 shows. The process begins with the collection of PET bottles (from inland and marine sources), which are categorized (and sold) by waste pickers to waste sorting centres or recycling companies. The sorting centre compresses the collected PET bottles into standard bales, and this is where the BCT tracking process begins. Each standard bale is equipped with a QR code, and all tiers of the product flow need to be

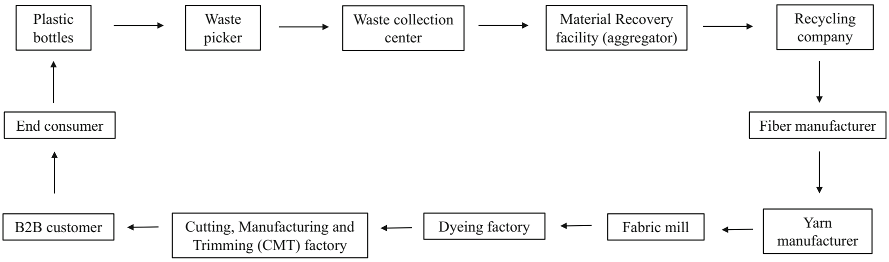


**Fig. 1** BCT-based recycling chain of BETA. (Source: created by the authors)

digitally uploaded. The aggregator then transports the standard bale to a recycling company to be cut, washed, shredded, and converted into the fibre format adapted to different garment production needs. The subsequent processes follow the original textile production process that includes yarn making, weaving, dyeing, and garment cutting. Ultimately, BETA exports the product to mainly European brands, which sell to end consumers.

Since BETA does not have a physical factory, all stages need to be coordinated, and this is where BCT plays a critical role. The original approach was adopting the back-to-front calculation – when BETA receives orders from brands, it needs to contact the garment factory, confirm the amount of needed raw materials, and cascade this information to the upstream suppliers (PET bottle providers). This process was complex and inefficient (e.g. traditional paper based), and more importantly, there was no guarantee that the material used was indeed made from recycled material.

BETA records the whole process of the recycling chain from the collection side and sets up specific data upload and verification requirements for suppliers. Each bale is attached with a QR code tag designed by BETA, which records the product name, quantity, and time, and requires photo confirmation. Using similar logic, all the remaining link stages need to scan the QR codes in and out to record real-time data, while all data are recorded in the BCT platform. After scanning the attached QR codes on the products, consumers can access the life cycle history of the textile products.

BETA links up multi-level members based on the original textile supply chain and invokes the feature of immutability to ensure the transparency and visualization of the whole recycling chain (see Fig. 2). In practice, the key is coordination, and BETA arranges staff training for recycling chain members, including system login, data entry, and quality confirmation. BETA also arranges irregular factory visits to assist BCT-enabled traceability through its own physical verification approach.

From the BCT governance perspective, BETA has a relatively high degree of *decision rights*. It designs the BCT system and creates innovative boarding procedures for suppliers. This private BCT version is reasonable because there are strict criteria for supplier selection (only validated suppliers can join) and BETA as the coordinator retains some degree of control.

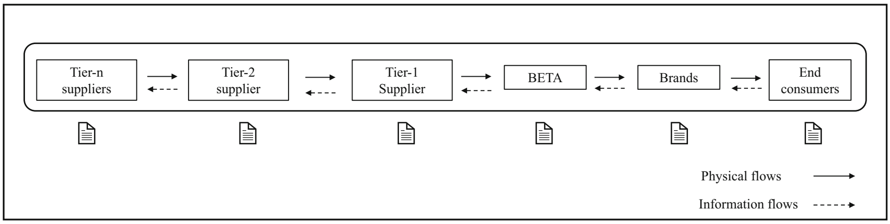


**Fig. 2** BCT-based system in MT-SSCM of BETA. (Source: created by the authors)

BETA adopts a relatively high degree of technically enacted approach to ensure *accountability*. It sets out the procedures that MT-SSCM members need to complete, including data validation and uploading. In other words, technical procedures are used to manage the material and information flow of the MT-SSCM process.

For *incentivizing* members to join, BETA adopts a nonpecuniary approach to align members. These suppliers are often carefully screened with good sustainability compliance. They are more willing to showcase their sustainable practices to attract larger orders or even partnerships with large brand owners. Since suppliers do not need to bear additional costs such as BCT system development, the incentives for BETA and the recycling chain members are consistent – i.e. the incentive to join the system is high.

## 5.3 Value Adding to MT-SSCM

The BCT brings added value to MT-SSCM and mutual benefits for multiple stakeholders. Focal companies (BETA) can meet brand requirements for sustainable supplier compliance and provide transparent visibility across the chain. BCT has proven to help BETA with supply chain optimization, specifically by greatly reducing communication and coordination costs. BCT provides trusted systems that may be able to assist with the validation difficulties in the industry.

This digital approach is an innovative means of traceability for the textile industry and may create brand marketing value for BETA. For (sub) suppliers, this is a breakthrough to help them with digital transformation, especially for some small- and medium-sized enterprises with limited information technology systems. Traditionally, these small factories may only have a dyadic supply relationship with buyers and sellers and only limited connections with other MT-SSCM members. Through a BCT-based platform, suppliers may be able to create network benefits, such as linking influential brand companies. For external regulation, such as NGOs or regulators, BCT can be combined with traditional verification methods to achieve a more convincing and trustworthy approach, which facilitates external regulation and helps brands to confirm their provenance.

## 6 Emergent Concerns, Outstanding Research, and Future Directions

There are some interesting topics worth exploring in the future. First, the use of BCT as a potential technology solution is still in its preliminary stages, with most studies only presenting conceptual frameworks, and even fewer from the MT-SSCM perspective. Therefore, more empirical studies are needed; for example, long-term performance, critical success factors and barriers, engaging participants, and practical challenges from real adoptions deserve future exploration.

Second, applying BCT to govern MT-SSCM deserves more in-depth exploration. Tachizawa and Wong (2014) proposed four basic MT-SSCM governance models. It will be interesting to see how far BCT can conform to or even disrupt the traditional governance models.

Some potential research questions include how to encourage (incentivize) participants to join the BCT system; how to achieve a pluralistic and co-governing BCT network; and how BCT governance can incorporate traditional governance models (of contractual and relational governance).

The BCT alone cannot be the panacea, and practical examples show that BCT requires the combination with other technologies, such as IoT. Therefore, coupling with other Industry 4.0 technologies is worth exploring. Furthermore, some emerging studies adopt theoretical elaboration to explain the phenomenon, such as network theory (Gong et al., 2022) and transaction cost theory (Schmidt & Wagner, 2019). More multidimensional theories may open new research perspectives for BCT-based MT-SSCM, as Table 1 shows.

## 7 Managerial Implications

Managers can systematically sort out the organizational structure and governance model of MT-SSCM and apply it to firms' daily operations. Various case studies presented in this chapter provide an overview of existing BCT-based MT-SSCM practices in the recycling industry, and this innovative approach may provide insights into other technological-driven MT-SSCM – for example, business model transformation. Moreover, for BCT technology initiators, the recycling perspective reported in the case study may become a new application scenario, extending the current wide range of applications in computer science, cryptocurrency finance, and logistics.

## 8 Summary and Conclusion

This chapter reviews the concept of MT-SSCM and the potential application of BCT, with a specific application case study (BETA). From the SSCM context, more research has recognized the importance of 'chain liability' and of extending the supply chain tiers to enforce supplier compliance. Similar to traditional SCM research, MT-SSCM studies started from initial conceptual framework construction, and gradually more empirical studies were conducted to explore its practices.

This chapter illustrates the conceptual framework construction, empirical exploration, and theoretical application of MT-SSCM. Also, this chapter proposes that technological innovation can drive MT-SSCM. Applying BCT as an example, this chapter introduces the underlying concept of BCT and the potential application to MT-SSCM. Finally, this chapter shows an application that has adopted BCT in the multi-tier textile supply chain.

In summary, MT-SSCM research is still in the initial stage and more empirical exploration is needed. There is a need to be aware of possible research difficulties, particularly with respect to data permissions. Multi-tier complexity and personnel are involved, and it may be difficult to obtain a comprehensive perspective. Furthermore, BCT is seen as a potential complementary technology to disrupt traditional MT-SSCM practices. However, the uncertainty of the technology itself and the lack of maturity is not only reflected in the current limited application but also in its long-term effectiveness, which still needs to be evaluated.

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# Sub-supplier Management

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## Contents



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**Abstract**

Sub-suppliers – the suppliers of a focal company's directly contracted suppliers with whom the focal company has no contractual relationship, also termed tier-n suppliers – have become of increasing concern to companies and their various stakeholders. Conventional supply chain management approaches consider direct suppliers being in charge of and responsible for sub-suppliers; however, it rarely occurs. Challenges in the upstream supply chain and new public policy require new approaches to realize targets and objectives also in the context of companies that are part of the supply chain but lack a direct contractual relationship with a focal company. This chapter covers the status quo of the body of knowledge in sub-supplier management and points to numerous streams of research to further progress this rather new field.

**Keywords**

Sub-supplier · Tier-n supplier · Supply chain transparency · Sustainable supply chain · Circular economy

## 1 Introduction

Sub-suppliers have become of increasing concern to companies and their various stakeholders (Choi et al., 2021; Tachizawa & Wong, 2014). Sub-suppliers are "suppliers' suppliers or tier-n suppliers, upstream in the supply chain with no contractual relationship to the focal firm" (Grimm et al., 2018, p. 240; a focal firm is defined as the firm (or company) whose management we look at). However, in business practice, the understanding of how to manage sub-suppliers has remained a challenge.

This definition puts attention on the intermediating role of the direct suppliers, with which the focal company has contractual relationships, and on the direct suppliers' dependence on input factors provided by sub-suppliers for their internal operations (Wilhelm et al., 2016a). This definition excludes subcontractors who do not provide input factors to direct suppliers' internal operations but perform a part of the direct suppliers' internal operations based on a contract with the direct supplier

(Gold et al., 2020). To give an example from the perspective of a retailer sourcing bread from contracted bakery A: If bakery A contracts bakery B to produce some of the breads it sells to the retailer, bakery B is a subcontractor. In contrast, mills selling flour to any of the two bakeries are considered sub-suppliers.

The conventional perspectives in management focus on the company: its competitive environment, the company's resources, or its direct relationships. Conversations addressing the context in which companies operate – ranging from a company's dependence on nature to a company's stakeholders – rarely pay attention to the consequences of the sharing of work upstream or downstream in supply chains. It is commonly assumed that a company's ability to interact freely with its direct suppliers and direct customers allows them to address the opportunities and threats in upstream or downstream supply chain levels (Read, 1958). There is evidence that such an assumption is incorrect (Villena & Gioia, 2020).

Challenges in the upstream supply chain and emergent public policy require new approaches to realize targets and objectives for companies that are part of the supply chain but lack a direct contractual relationship with a focal company. Major events of global supply chain disruptions (e.g., 9/11, Fukushima, and Covid-19), geopolitical issues, and sustainability issues have been major triggers for research in this growing field.

This chapter provides insights into influential articles and refers readers to recent reviews on the state-of-the-art for sub-supplier management. We summarize the body of knowledge in sub-supplier management and point to numerous streams of research to further progress this rather new growing field.

## 2 Background

There have been several examples of sub-supplier (or lower-tier) supplier scandals. In 2015, a study on Malaysian sub-suppliers of major electronics brands revealed low compliance with the Code of Conduct of the Electronics Industry Citizenship Coalition (EICC), dangerously compromising the global electronics brand's reputation (Nadvi & Raj-Reichert, 2015). In another study, Villena and Gioia (2018) found that most sub-suppliers in Mexico, China, Taiwan, and the United States lack both environmental management systems and procedures for handling red-flag social problems. These sub-suppliers rarely know the sustainability requirement that downstream focal companies have, and even when they are aware, these sub-suppliers are passive to address their main environmental and labor issues. During the Covid-19 pandemic, the media reported almost daily supply shortages caused by unknown sub-suppliers in the upstream supply chain, often located in distant parts of the world, and how these supply disruptions caused companies to struggle with keeping their operations running or meeting customer demand (e.g., for home electronics).

Sub-suppliers are difficult to manage for several reasons. First, there is no contractual relationship between them and the focal company, making it a challenge for the focal company to request their adherence to any type of economic, environmental, or social requirements – and eventually enforcing compliance with them. Second, most focal companies do not have much visibility to sub-suppliers – that is, focal companies do not know their identity. Deloitte's 2021 Chief Procurement Officer (CPO) survey found that only 15% CPOs have visibility beyond their first-tier suppliers. Third, sub-suppliers quite often are small and medium-sized companies that share little information publicly, especially regarding their environmental and labor endeavors – or they are so big or powerful in their respective markets that they ignore such requests for disclosure. Fourth, some sub-suppliers are traders (not the actual producers) of the supplied material, protecting their revenues with secrecy on their sources. These suppliers are thus reluctant to share their suppliers' names with customers, making difficulty for the focal firm to map their entire supply chain. Fifth, supply chains are highly dynamic complex adaptive systems with new actors joining, established actors leaving, or established actors changing their identity at any time (Carter et al., 2015). Sub-suppliers are not immune to this phenomenon. All these characteristics make sub-suppliers to a challenge for downstream companies that have to comply with an increasing number of regulations and that need to protect their reputation from scandals occurring in their extended supply chain.

There is an increasing number of studies on sub-suppliers. For instance, Grimm et al. (2014) identified 14 critical factors to manage them in the food sector. They found that trust between the focal company and (tier-one) supplier and between supplier and sub-supplier is essential. The perceived value for suppliers and sub-suppliers and the risk of disintermediation are other critical factors. Wilhelm et al. (2016a) propose that (tier-one) suppliers play a double agent role – they need to comply with their customer's (i.e., the focal company's) requirements and they also need to request their own suppliers (i.e., the sub-suppliers) to comply with such requirements. Villena and Gioia (2020) identified best practices that large firms use to manage suppliers and sub-suppliers considering economic, environmental, and social metrics. More recently, Senyo and Osabutey (2023) and Jamalnia et al. (2022) conducted literature reviews of multitier supply chains, the latter identifying 37 contingency variables that influence the effectiveness of sub-supplier's sustainability management approaches.

In contrast to direct supplier relationships, the way a focal company relates to its sub-suppliers via its suppliers is more nuanced (Yan et al., 2015). Hofstetter (2018) suggests a framework based on eight exemplary constellations among these three actors by differentiating their respective relationships as either close (collaboration) or distant (arm's length) – acknowledging that in reality, relationship qualities are somewhere between these two extremes. Each of these constellations describes a specific situation for the focal company about how it is linked with the direct supplier and the sub-supplier. Sub-supplier management needs to take the specific situation into consideration.

## 2.1 Share of Value-Added Moving Upstream to Sub-suppliers

The increasing relevance of the upstream supply chain seems to have taken many practitioners, but also academics, by surprise (Sarkis et al., 2021). Many companies have followed the strategy of focusing their activities on their core competencies and value generators, outsourcing all other activities to suppliers. In many industries, in particular in apparel and consumer electronics, this outsourcing resulted in extreme scenarios: companies giving up all internal production. This shift led to a “fine slicing” of the supply chain – an extension of the supply chain by adding many more actors that each contribute a smaller range of activities.

As a result, these companies benefited from using cheaper production conditions in developing and emerging countries – compared to their local options. However, the increased distance to the actors in these new locations reduced company understanding of their sourcing market (Davis et al., 2010; Alexander, 2022).

## 2.2 Sub-supplier Influences

The actual impact of sub-supplier performance on a company’s success has only recently received attention. The reasons include an increasing concentration in many upstream levels of supply chains, reducing the alternatives available to companies. On the *cost* side, conservative estimates state that two-thirds of a company’s cost of goods sold are caused by the upstream supply chain beyond the direct supplier (Hofstetter, 2018). Volatility in raw material prices and currency exchange rates have also substantially increased over the past few decades. Labor cost and environmental costs have further increased in many countries over this period of time, while buyers intensified price pressures (Li et al., 2021).

Practitioners mention that over 85% of *quality* problems were caused by problems related to the upstream supply chain beyond the direct supplier. Often, sub-suppliers comply with specifications but are unaware of the actual use of the material they supply (Tse & Tan, 2011).

Some research on *delivery reliability* identified numerous causes for shortages that are not caused by direct suppliers. In many industries, direct suppliers are successful in achieving higher supply reliability than what they experience themselves from their supply chains.

*Innovativeness* of companies relies increasingly on the innovativeness of suppliers and sub-suppliers. In particular, innovations in materials and electronic components far upstream the supply chain have been key enablers for breakthrough innovations in finished goods markets.

In terms of *sustainability and legal compliance*, most serious environmental and social issues occur in upstream levels of the supply chain (Wilhelm et al., 2016a; Villena & Gioia, 2018). It is estimated that on average, at least 70% of carbon emissions occur in scope 3, which involve suppliers and all kinds of sub-suppliers. Forced labor, excessive overtime, gender disparities, and alike often occur in suppliers further upstream. Clearly, sub-suppliers bring considerable economic, environmental, and social risks to firms. If not properly managed, firms will face push back from their stakeholders.

## 3 Current Concerns

Despite the increasingly acknowledged relevance of sub-suppliers, work on sub-suppliers and sub-supplier management remains a niche in the management field. Among this body of research, we highlight 16 themes we consider attracting major interest: *ensuring availability of economic input factors, ensuring quality of economic input factors*, *reducing cost of economic input factors, stakeholder pressures for sub-supplier management, liability for sub-supplier action, voluntary industry self-regulation, sub-supplier risk management, sub-supplier innovation, combining individual strategies and public policy to reach sub-suppliers, combining individual and collective industry action to influence sub-suppliers, developing sub-suppliers and safeguarding sub-supplier-specific investments, considering the specific context of sub-suppliers, influencing concentration on sub-supplier levels, transparency in upstream supply chains, structuring and organizing sub-supplier management, and governance of upstream supply chains.*

### 3.1 Ensuring Availability of Economic Input Factors

Limiting dependence on specific input factors has for long been a key concern to both companies individually and national economies collectively. Literature and practice mainly addressed the case of access to unprocessed raw materials as geological, climatic, biological, or cultural reasons restrict their availability to specific world regions. Control over unprocessed raw materials has been linked to ownership questions, countered by local government regulations that limit foreign ownership of agricultural land or natural resources.

Most companies source processed materials as input factors for their operations. Raw material exploiting companies (e.g., mining companies, farmers, and fisheries) are sub-suppliers for the majority of companies – often with trading steps in between. Sub-suppliers are vital for bringing goods to consumers. Let us consider, for instance, farmers who work on the land and with animals. They are likely the first node of most food supply chains (e.g., produce and processed products). However, SCM scholars rarely investigate how farmers and nature fit into industrial processes to foster resilience and sustainability of supply chains.

Major supply disruptions – such as 9/11, the Covid-19 pandemic, and the war in Ukraine – have made the relevance of supply chains more popular. In particular, the relevance of suppliers further upstream became even more pronounced. Resilience in supply chains became a predominant concept to improve material availability even in cases of severe external shocks, but this conversation hardly addresses sub-suppliers. A frequent reaction in business practice is to mitigate supply risks or increase resilience by adding more alternative suppliers – at the expenses of reducing sourcing volumes per supplier. The resulting decrease of sourcing volume per supplier may reduce the relevance of the focal company for the suppliers and with that their motivation to engage with sub-suppliers on requests by the focal company. How does this take into account situations of high market concentration on tier-n levels? Could be the same enablers for firm resilience be applied to sub-suppliers? Or perhaps, given their remote upstream position in the supply chain, are there some uniqueness that we should consider?

The literature on modeling inventory in multi-echelon supply chains (de Kok et al., 2018; Lee & Whang, 1999) acknowledges the need for coordination among multiple steps in a supply chain to ensure availability on inputs. Most of this literature investigates downstream distribution or corporation-internal scenarios. The special situation of upstream sub-suppliers still needs to be investigated in more detail by these analytical models.

## 3.2 Ensuring Quality of Economic Input Factors

The quality management literature is not ignorant of the role of upstream sub-suppliers to ensure that raw material or intermediate goods comply with the buyer's needs and requirements (Yoo et al., 2021). However, both literature and practice consider suppliers responsible to ensure quality of supplies. Several challenges are often mentioned to be important: (1) are sub-suppliers aware of the needs, requirements, and actual use, (2) are sub-suppliers able to produce the expected quality – both in terms of product and processing quality, (3) are systems in place that control and ensure the reliability of the quality level, and (4) are practices for remedy in place to quickly and efficiently respond to deviations. Companies are limited in their ability to control these factors and usually rely on information of either their suppliers or third-party certificates. It usually is only in case of major problems, and limited to remedy, that companies engage with sub-suppliers and suppliers – only until the problem is solved.

## 3.3 Reducing Cost of Economic Input Factors

High raw material price volatility has existed for many years. Reasons for volatility range from speculation by financial players over bad harvests to sudden demand increases of specific industries, or the rise of unexpected trade barriers. Supply chains are victims of drastic price increases and volatility, consuming either their margin or the margin of their suppliers.

Conventional procurement strategies to limit volatility costs require addressing various market strategies – weak ties with suppliers that allow immediate supplier switches to benefit from spot market deals. Financial strategies make use of hedging offers, transferring the major risk to a financial services company at a reasonable fee. To address volatility, some companies buy options and sell volumes to individual sub-suppliers, while others keep ownership of the material provided to sub-suppliers and have these sub-suppliers engage via the suppliers as service providers.

## 3.4 Stakeholder Pressures for Sub-supplier Management

In contrast to governments, the public has no means to enforce new business practices in companies. Yet, public scrutiny and societal conversations can become important pressures where many companies have taken the public requirements seriously and respond to these pressures (Wilhelm et al., 2016b). For instance, customers – a key external stakeholder – increasingly expect that companies are more responsible and more transparent about how their products have been manufactured. For these customers, there is no difference between the company itself, its direct suppliers, or its sub-suppliers acting inappropriately or violating its own claims. In fact, these pressures make the company responsible for enforcing and ensuring compliance (Hartmann & Moeller, 2014).

Employees, an important internal stakeholder, could also prompt their companies to assume more responsibility beyond direct suppliers. Some employees are genuinely concerned about the environmental and working conditions of suppliers and sub-suppliers. These employees are often catalysts for carrying out internal pressures but face some internal barriers such as the lack of resources and knowledge on how to manage lower-tier suppliers (Grimm et al., 2016).

## 3.5 Liability for Sub-supplier Action

Tightening global government regulations also link companies to practices of sub-suppliers, even if the company is not aware of a specific company being a member of its supply chain and violating laws. Traditionally, companies argued that it was impossible for them to identify all sub-suppliers, and without such transparency, they can neither be expected to control, to influence, nor to ensure legal compliance of sub-suppliers in their supply chains. But regulations have required them to rethink this common response.

The US Dodd-Frank Act, containing a section on conflict minerals, was one of the first laws holding US-based companies accountable to declare the sources of the materials they use. Kim and Davis' (2016) analysis of the reporting practice concluded that companies are mostly unable to report on their upstream supply chain, and that the willingness to do so is low – instead of supporting the regulator in realizing the law's intent, they looked for ways to get around it.

Hofmann et al. (2018) provided insights into key motivational factors, barriers, and enablers of those implementing conflict mineral reporting. There is a stream of new regulations in Europe, New Zealand, and Australia that focus on eradicating modern slavery and human right violations in upstream supply chains (Sarkis et al., 2021). These regulations prompt companies to take more responsible deep into their supply chains, including sub-suppliers.

### 3.6 Voluntary Industry Self-Regulation

Companies within an industry have been organizing to tackle recurrent environmental and labor problems, and as these increasingly go beyond company boundaries, these actions target direct and lower-tier suppliers. To a certain extent, member companies aim to self-regulate and create tools and systems that allow them to collectively address the problems that are critical to their sector. In a few cases, they are working directly with policymakers to influence regulations related to tier-one and lower-tier suppliers. For instance, the Responsible Business Alliance (RBA) has created a Code of Conduct that its members (mostly electronics brands and suppliers) are required to comply with and monitor compliance with the Code periodically. These suppliers belong to multiple tiers within the electronics supply chains.

### 3.7 Sub-supplier Risk Management

Increasing global span and dynamics in supply chains have caused greater disruptions in upstream stages of sub-suppliers. Lack of supply chain transparency and knowledge about sub-suppliers limits focal company's ability to detect relevant events and predict supply effects. Consequently, companies are limited in their ability to prepare for relevant scenarios and, thus, to react in a targeted manner (Pournader et al., 2020).

Even when sub-suppliers are known, the distance makes it difficult for a focal company to monitor – collecting and interpreting data – and to determine focal company effects of supply deviations (Munir et al., 2020). Insurance companies, often leading in evaluating risk, do not have meaningful approaches to evaluate sub-supplier risks and do not offer coverage of risks by sub-suppliers.

During the Covid-19 pandemic, when major supply shortages occurred, some companies reported that they experienced substantially fewer shortages or supply surprises in long-term, trust-based supplier relationships. Even though they were often not able to know their sub-supplier identities or problems, they could rely on their (first-tier) supplier ability to address the problem and find a solution that allowed them to continue their operations under reasonable adaptations to the new situation (Dewick et al., 2021). Beyond such anecdotal evidence, deeper knowledge is needed to prepare for the next set of disruptions in multitier supply chains (Flynn et al., 2021).

### 3.8 Sub-supplier Innovation

The decreasing share of internal value added across industries and the shift to sourcing functional systems instead of components has shifted key innovations from within the focal company to sub-suppliers. Examples of this shift include the development and production of new materials or electronic components.

To realize its product strategy in such a multitier value chain setup, focal companies rely on sub-suppliers to meet its innovation plans. It also requires (first-tier) suppliers to adopt these sub-supplier innovations for the products they supply to the focal company. For exceptional cases, a company may be able to engage with suppliers and selected sub-suppliers in joined trilateral R&D projects.

A more common approach is to inform suppliers about the product strategy and let them search for or engage with their suppliers (sub-suppliers) to find solutions. These efforts include cases of collaboration with one or two suppliers (Potter & Wilhelm, 2020). This approach requires that suppliers are motivated to form an offer. Sub-suppliers often face the challenge that their customers do not (fully) disclose their customer identities, their plans, needs, or use (Homburg et al., 2014). Consequently, sub-suppliers are not aware of the actual needs, plans, or ideas to focus their R&D.

These structural limitations caused by the supplier acting as a barrier between the focal company and the sub-supplier limits sub-suppliers' ability in finding use for their innovations. Since sub-suppliers lack access to their customer's customers, they fully depend on their customers to make their innovations a success. It is unclear how supportive or hindering this situation is for sub-supplier innovation. A common assumption is that suppliers only adopt such innovations from sub-suppliers that benefit them in their role as intermediaries but undermine innovations they interpret as threats (e.g., by substituting the supplier's own products). This situation implies that breakthrough innovations require overcoming such barriers set by suppliers in their current setup.

## 3.9 Combining Individual Strategies and Public Policy to Reach Sub-suppliers

The lack of a contractual relationship is a substantial barrier for any company to engage with or influence a sub-supplier. Companies not only lack power to ensure that sub-suppliers engage and ultimately comply with their requests; the lack of a contractual relationship causes high uncertainties – from the persistence of the requirements to the persistence of the relationship. Even if the mediated relationship between the sub-supplier and the buyer persists, the mediating supplier may change practices, strategies, and tactics – ultimately changing the decision context.

In the field of sustainability, public policy can create a legal context that requires companies to engage in initiatives of their customers' customers. However, this action requires that the policymakers in the country of the sub-supplier align with those of the customer – from objectives or intents over execution to enforcement. This idea is not without problems: Foreign buyers are not typically active in the official political process in sub-supplier countries. Their actions to get the national policymakers to agree with their intents are usually considered an illegitimate intervention and interpreted a neocolonial action. Even in the case when public policy takes up buyer objectives and policies, the motivation towards and the control of adherence depends also on the sub-suppliers' customers and on what these customers are asked for from their customers. Sub-supplier sustainability cannot be "outsourced" to governments and states.

### 3.10 Combining Individual and Collective Industry Action to Influence Sub-suppliers

Many companies appear reluctant to exert influence on sub-suppliers, pointing to cost, lack of transparency, lack of power, lack of access, or uncertainty of reward (Villena, 2019). Instead, collective action of many companies and other organizations that have common interests in the same group of sub-suppliers has been widely established, often in the form of voluntary industry initiatives (see above). In that way, member organizations collectively put pressure on sub-suppliers. This pressure could range from sub-supplier monitoring over sub-supplier development to certifications. A potential caveat for this collective action is that, despite the influence on sub-suppliers toward a desired end, the minimum standards do not allow differentiation among members. Additionally, direct interaction with sub-suppliers can generate exceptional outcomes and may lead to sub-suppliers adhering to the special interests of the focal company.

Some knowledge exists on how companies establish collective action (Peters et al., 2011; King & Lenox, 2000). Yet, knowledge is scarce about how companies can anchor collective action in their own organization and behavior. This anchoring helps avoid misalignment of requirements from sub-suppliers and maximizes the overall supply chain benefit from collective action (Tan et al., forthcoming).

The business case for complying with customer sustainability requirements is often unclear for suppliers – for the sub-supplier level we know even less. Also, knowledge is limited about what activities or objectives are better realized by companies individually, or by the collective, or by a combination – and how such a combination should look like. Analyzing a sample of Chinese suppliers, Wilhelm and Villena (2021) found that suppliers are more willing to request sub-suppliers when these suppliers have adopted an industry-wide sustainability code. More research analyzing how collective industry action is certainly needed.

### 3.11 Developing Sub-suppliers and Safeguarding Sub-supplier-Specific Investments

Economic actors evaluate and decide upon relation-specific investments into the development of a legally separate organization based on their expected economic return (Wagner & Bode, 2014). In the relationship with a sub-supplier, the critical element in this equation is the allocation of the return – who benefits from the investment. The literature on safeguarding relation-specific investments draws on the investor's ability to control how the organization receiving these investments allocates the generated returns. Remember: The peculiarity of the relationship to a sub-supplier is by definition the absence of a contract linking the company – in its role of investor – with the sub-supplier – in its role as receiver of the investment – and thus the existence of a supplier in between, connecting both – in its role as mediator. When the supplier is a trader and the producer requiring development is a sub-supplier, it becomes particularly difficult for the focal company to safeguard sub-supplier-specific investments.

### 3.12 Considering the Specific Context of Sub-suppliers

The practices, outlined above, of focal companies to define, implement, and enforce solutions as they face increasing pressure to eliminate upstream supply chain social or environmental issues have received critique (for sourcing from the Global South, see Ponte, 2022; Baumann-Pauly & Jastram, 2018; Serdijn et al., 2020). Many of these efforts seem to miss their objectives at the sub-supplier level. Sub-suppliers complain that implementing the required changes do not necessarily solve the causes of sustainability issues but instead only increase their cost, lower their competitiveness, or further limit their wealth. These solutions are interpreted as to serve focal companies to demonstrate engagement and to mitigate their risks in their supply chain but to ignore the context and the objectives and needs of sub-suppliers. Without understanding the specific (local) context, it is difficult to develop a plan to resolve the actual environmental or social problems. However, understanding the context, especially in developing countries, brings enormous challenges for researches who often have to do filed work and face language, cultural, and economical barriers (see e.g., Hofstetter et al., 2022; Nath et al., 2019, 2020; Sancha et al., 2019). It is not surprising why there is a scarcity of research on sub-suppliers in these regions.

### 3.13 Influencing Concentration on Sub-supplier Levels

Recent decades have been dominated by strong cost competition in supply chains. This situation causes companies to source as a commodity and seeking the lowest cost. This mindset towards procurement has caused a high concentration of production capacity, its location, and its ownership.

More recently, the Covid pandemic made companies experience the dangers of high concentration and discuss strategies to establish additional alternatives (Sarkis et al., 2020). As one goes upstream in supply chains to the sub-supplier level, the limited transparency hinders such strategies. An interesting approach in this context is a supply chain based on very short lead times, where speculation in procurement is replaced by production and ordering based on actual demand (De Treville et al., 2014). Short lead times are only possible when geographical distances remain within limits, which influences the rules upon which location decisions are taken. While intellectual property protection may protect the concentration in terms of ownership, concentration in terms of location and site capacity are under pressure.

## 3.14 Transparency in Upstream Supply Chains

The need for transparency in supply chains has become more evident nowadays. Different perspectives and details will be influenced by the supply chain context. For example, does a packaged food manufacturer need to know the name of each olive farm that supplied olives for the olive oil that eventually is used in the product? Some may say "yes." Others may say that they want to be sure about compliance with organic farming and production principles for this olive oil, while others may be more focused on the olives' origin. Different stakeholders with their differing interests and differing perspectives ask different questions. Expecting companies to have all answers readily available may neither be possible nor required – but these expectations show the current level of confusion and disagreement with the current situation by various stakeholders.

The conversation about supply chain transparency requires advancement and higher focus. The dynamics and scale of supply chains as well as competition and confidentiality considerations in business relationships make it difficult for any actor to gather information on the composition of a supply chain. It is also difficult to keep this information reliable and current.

Supply chain transparency may result in high costs. Methods and services do exist, with commensurate costs, to map supply chains by asking for the names of suppliers, some data already exists that may be used as a proxy. Stakeholders may know more about a company's supply chain than the company itself (Busse et al., 2017). Life cycle assessments, for example, provide insight into supply chain production processes (Lake et al., 2015). Transportation data shows links for material flows between actors (Bansal et al., 2020). Trade data gives insights on an aggregated level (Schmidt et al., 2022). Additional research is needed on how these data sources can be combined for a better understanding to minimize costs and without the need for much extra data collection.

## 3.15 Structuring and Organizing Sub-supplier Management

Efficient interaction between a company and its sub-suppliers requires organizational structures. These structures are even more needed in a setting that is as informal and opaque due to lack of contracts and the unknowns about sub-supplier identities (Villena, 2019; Sauer & Seuring, 2019).

The limited literature suggests that engagement with sub-suppliers is often limited to realize a specific objective (usually to resolve an acute problem). Such a project organization aims at the resolution of a specific matter instead of the sub-supplier and the company's relationship with this company. In many procurement units, the mandate is to maintain the relationships with suppliers with a focus on optimizing procurement cost (Villena, 2019). Mandating engagement with sub-suppliers is largely overlooked. A significant worry about engaging with sub-suppliers is in determining the efforts needed and estimating the potential benefits of this engagement.

It appears that many companies' supplier management capacities are insufficient to tackle the supply chain issues the face beyond direct suppliers. A series of questions arise. How can capacity be developed for interacting with sub-suppliers when no contractual relationship exists? What sub-supplier management practices need to exist, and how should the sub-supplier management performance be measured? What power should this unit (compared to other units) be granted from top management? What power can top management actually have to achieve its objectives? What are core business processes to engage with sub-suppliers – from improving the current situation with sub-suppliers, to excluding specific sub-suppliers from the upstream supply chain, to identifying and onboarding companies as new sub-suppliers?

### 3.16 Governance of Upstream Supply Chains

Upstream supply chains require high coordination efforts, with both practitioners and academics aiming to reduce inefficiencies. A solid body of knowledge exists on buyer-supplier relationships. Different interests and criteria compete in this environment. Recommended approaches depend on the specific situation – for example, during the pandemic with its high unknowns, relationships based on mutual trust and benevolence yielded better results. Extrapolating this situation to upstream supply chains and their global, cross-industry reach, we assume the interests and criteria to be heterogeneous. In other words: Every buyer-supplier relationship across a supply chain is different. We also know that high performance requires a minimum level of alignment – but how can such alignment be realized with so many companies involved that all follow their own objectives, interests, strategies, or tactics?

There are efforts to agree on common sustainability standards within an industry (Grimm et al., 2023). For instance, industry initiatives, such as the Roundtable on Sustainable Palm Oil and Responsible Business Alliance, have developed a common sustainability standard for industry. There are several advantages of having this type of standards. One, the industry gains efficiency. Companies, first-tier suppliers, and lower-tier suppliers have to comply with these requirements, eliminating the needs of complying with multiple standards. Two, suppliers have to show compliance with the industry standard once, avoiding audit fatigue. Third, industry members share expertise and collectively address their long-lasting sustainability issues.

## 4 Emergent Concerns, Outstanding Research, and Future Directions

This chapter introduces some early conversations for future research. Emergent and future areas include *alignment of customer requirements with supplier requirements*, *sub-supplier management and a transformation into a circular economy*, *sub-supplier management and ecological and social concerns*, *resilience of* *sub-suppliers, and regionalization (onshoring) of globally concentrated industries at the sub-supplier level.*

### 4.1 Alignment of Customer Requirements with Supplier Requirements

The conventional practice in managing sub-suppliers is to consider suppliers to be responsible for managing their suppliers and to assure that they meet the requirements defined in the contract. The basic understanding for this practice assumes suppliers to be a coherent entity with similar institutions and practices throughout the organization, and it assumes that they also require and enforce these institutions and practices on their suppliers.

The assumption of suppliers adopting and snowballing customer requirements appears to be a severe and misleading simplification that misses reality for several major reasons. On the demand side, suppliers struggle with heterogeneous patterns of requirements from many different customers. These requirements are often conflicting – unclear or unstable in priority. In particular, when customer requirements concern social or environmental dimensions, patterns are difficult to find. This situation causes suppliers to segment customer claims and to either take up or ignore some of these requirements.

On the supply side, suppliers struggle with similar conflicts. For example, buyers balance objectives such as price, quality, availability, innovation, or responsibility and respond to market offers or shortages. To actually comply with customer requirements, brand claims, or commitments made to customers, suppliers need to integrate these aspects in their own procurement principles and practices. This integration can occur through supplier codes of conduct. This translation is influenced by many considerations, interests, and limitations – from within the company and from external stakeholders.

### 4.2 Sub-supplier Management and a Transformation into a Circular Economy

The circular economy concept has seen increasing global attention across many industries (Hofstetter et al., 2021). In a circular economy, all material remains in use in a closed system. Connecting material output of activities as an input for another activity – with no material being lost or disposed – is a logistical challenge.

While market mechanisms allow matchmaking between demand and supply, active mapping of demand and supply within a value chain offers opportunities for efficiency and resilience. Because of today's limited transparency in value chains, we know little about how to best make these connections. The hope seems to be once more on the free market's ability to connect buyers with suppliers and allow them to realize their business. The shortcoming of this approach is that it does not take into account the needs associated with circular innovations.

For example, many focal companies that have shifted to using recycled packaging material reported that ensuring access to waste, investing into recycling technology, and other circular activities require their own active participation in activities with sub-suppliers at different supply chain steps. Considering that a major share of the "last producers" are sub-suppliers, engaging in technological changes requires active collaboration among those who manage materials in each stage of the supply chain.

The literature on global value chains is based on the linear economy reality and considers the powerful multinational companies (MNCs) as being the key actors that, because of their power, define the "rules of the game." Many suppliers and sub-suppliers have lower power compared to MNCs and, thus, have no other option than to adhere to those rules if they want to be part of global value chains.

Given the major changes ahead from the circular economy vision, it is unclear what resources or capabilities will in future be scarce or available in abundance. Those who control the scarce but important resources or capabilities will have a power advantage, and these might well be companies that are more distant to final goods or positioned after final goods sales – leading some of these sub-suppliers to become global value chain *makers*.

### 4.3 Sub-supplier Management and Ecological and Social Concerns

There is an opportunity for scholars to study sub-suppliers in key raw-material sectors such as forestry, agriculture, mining, and fishing. For instance, agriculture contributes between 13% and 18% of the world's greenhouse gas emissions. Reports about poor working and living conditions concern to a large extend farming, fishing, or mining.

The Netflix documentary "Seaspiracy" shows some evidence of the environmental impact of commercial fishing as well as how migrant workers are exploited inhumanely. Thus, there is a need to learn more about the challenges that sub-suppliers in these sectors face and, more importantly, explore how our research can support them. However, we warn that there are many challenges. Firms in these sectors are located in specific regions and most hire migrant workers. Thus, scholars will need to be cognizant of the associated language barriers, budget, cultural differences, and risks. Despite these challenges, conducting this type of research could be impactful.

### 4.4 Resilience of Sub-suppliers

Little research exists about (a) the drivers that prompt sub-suppliers to be resilient and (b) how sub-suppliers manage (or tradeoff) resilience and sustainability simultaneously. The Covid-19 pandemic showed the fragility of supply chains, especially sub-suppliers that are distantly located. For instance, the dairy farming sector in the United States suffered significantly at the Covid-19's onset – due to changes in market demands, dairy farmers were asked to dump their milk production affecting their income and increasing risks of leaving the market (Villena et al., 2021).

The question arose on how to build more resilient supply chains, but perhaps the right question is how to make them more resilient and sustainable – especially those sub-suppliers located farther upstream (Flynn et al., 2021). The concept of resilience further needs clarification – in particular for farming. Today's industrial approach, working on an ecosystem to produce a planned outcome by adding material (e.g., fertilizers) or changing production equipment (e.g., genetic modification of organisms), faces widespread concerns from quality to environmental. Some agricultural industries engage with alternative approaches such as biodynamic in wine making (Sharma et al., 2021).

### 4.5 Regionalization (Onshoring) of Globally Concentrated Industries at the Sub-supplier Level

The supply shortages experienced during the peak of the Covid-19 pandemic resulted in public debates on solutions. Some politicians promoted local production – often without any further consideration of the respective upstream supply chain. In fact, with some companies having started to move business away from China when the US-China tariff war started in 2019, the Covid-19 pandemic only accelerated this process. Some companies moved to other Asian countries whereas others moved to Mexico and India. However, many of them realized that the risks still remain high because many of their sub-suppliers still remain in China.

Many focal companies are still trying to move key sub-suppliers, but this process has been really difficult. Given this scenario, researchers and practitioners need to explore how companies are trying to move their entire supply chain rather than just the first-tier level (Dou et al., 2018). The research on eliminating planning mismatch costs through ultrashort lead times (De Treville et al., 2014) offers financial arguments for close proximity sourcing.

## 5 Managerial Implications

Many companies have difficulties and face trepidation when managing multiple tiers of the upstream supply chain. Their trepidation is due to the potentially millions of sub-suppliers that exist. Managers might miss out on the opportunities and the strategic dimension of developing the company in its ecosystem with too deep a focus. Lack of supplier willingness to disclose sub-supplier identity, lack of power to influence sub-suppliers, lack of capacity to deal with this "extra work," and lack of capability to understand and influence sub-suppliers are just a few among many deep concerns.

In times of cost pressures in management, adding another level of responsibility is a concern that companies wish to ignore. The current practices of holding direct suppliers responsible for the upstream supply chain are just too comfortable.

A comfortable route with maintaining the status quo can cause stagnation and make organizations and their supply chains less competitive. We suggest three areas that need adjustment from the current rather narrow supplier management practices of business leaders: *making the case for sub-supplier management, revising corporate governance, and reimagining value creation*.

## 5.1 Making the Case for Sub-supplier Management

Why should a company engage with sub-suppliers when success so far was achieved consistently without this deep focus? Skepticism about sub-supplier management is deeply rooted in the DNA of today's economic and management thinking. While the risks and threats for a company originating from upstream levels in the supply chain get more commonly accepted, this does not necessarily translate into motivation to increase action, unfortunately.

The conversation and concerns associated with sub-suppliers has reached a level of agreement that action must be taken. Yet, in line with the risk perspective of this conversation, action shall be taken by suppliers who are considered responsible for these risks. Imagining sub-supplier relationships as a source for competitive advantage is far from most management conversations where procurement is more about reducing costs short-term than about increasing differentiation in the mid-term (e.g., with a value co-creation approach). More proactive organizations and focal companies engaging their sub-suppliers can gain more opportunities that will serve them in the short and long term (albeit we also recognize the challenges in doing so).

## 5.2 Revising Corporate Governance

Current corporate governance practices may have missed opportunities offered by the upstream supply chain. Although the role of governance structures (supervisory structures) is not to be involved in operations management matters, they play a key role by defining the mandates of senior management and controlling the agenda of board meetings. Many companies have reduced their share of internal value added through a history of outsourcing and sourcing of systems. However, many companies have not defined roles and mandates to closely observe these major value adding steps in the upstream supply chain.

Supply shortages during and material cost rises after the Covid-19 pandemic may illustrate this thought: Companies who did not pay attention to these developments in their upstream supply chain appeared caught by surprise, requesting national governments to ensure the continuation of supply and respective conditions. They ignore the opportunity of such situations to establish unique solutions with sub-suppliers that would provide them sustained competitive advantage – and in particular during future crises a potential increase in market share. From this perspective, the current corporate governance practices appear misaligned to today's threats and opportunities of which many relate to the upstream levels of multitier supply chains.

### 5.3 Reimagining Value Creation

The intensifying transition into a more circular economy and the fast progress in digitalization require companies to understand their real value contribution to those using their goods or services (Vargo, 2021). While many incumbents understand these developments as necessity to add new goods or services to their portfolio, new entrants emerge with radically different offerings. No matter what the new goods or services are, they will require a complex network of suppliers and sub-suppliers. It is hard to imagine that such supply chain designs can be crafted by finding suppliers through requests for quotes. Rather, it seems that profound understanding of value creation in the various steps of the supply chain is required to develop, together with partner suppliers and partner sub-suppliers, new approaches to value creation.

## 6 Summary and Conclusion

Sub-supplier management is a fast-growing concern in supply chain management. Sub-suppliers can be highly risky and are difficult to manage. However, some leading companies have made progress on working with them directly and/or via tier-one suppliers or collectively with industry groups. The increasing number of regulations have also created pressure on companies to be more accountable on their supply chains, including those who are deeper upstream. Customers are increasingly more interested in learning how, where, and under which conditions their products are manufactured. All these forces make it necessary to study sub-supplier management. Yet, many challenges remain. We invite researchers and practitioners to join forces to explore the research gaps we outlined above and learn more about these critical actors in multitier supply chains.

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# Part V

# Downstream Relationships

# Supply Chain Management and Customer Relationship Management

## How Technovation Empower Their Integration

Yiru Wang

## Contents



**Abstract**

Supply chain management (SCM) and customer relationship management (CRM) have existed as separate developments. Even mainstream CRM system suppliers do not provide functionality for all supply chain sectors. However, lean business operations call for the integration of these two systems to achieve customer satisfaction while using fewer resources. Industry has been working toward the effective integration of the SCM and CRM to improve overall operational performance by lowering cost by improving operational efficiency, as well as improving stakeholder and customer experience and satisfaction. This book chapter provides some supply chain operations evolution. Supply chain

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networks have evolved from regional networks to global value chains (GVC). Platform-based e-commerce has enriched the traditional business context, as have technological innovations. These changes call for advancements in the SCM-CRM integration to achieve the lean operational goals. The book chapter further proposes a shift in identification of "customers" in CRM to "stakeholders" to better adapt to the SCM-CRM integration. Reidentifying all participants in the supply chain network as customers fits the best interest of the supply chain operation as a whole and can ease SCM-CRM integration. Various industrial practices and SCM-CRM integration across the supply chain network in this context are overviewed. Some future directions of SCM-CRM integration development are also introduced.

**Keywords**

SCM · CRM · Customers · Stakeholders · Integration

## 1 Introduction

Business ecosystems and supply chains offer a supply chain network that includes upstream suppliers and downstream end customers. Successful management of the supply chain system includes addressing effectiveness and efficiency of the business ecosystem, resulting in a thriving and sustainable business environment. Supply chains are critical linkages and elements of the business ecosystem.

Supply chain management (SCM) is dynamic and complex. Being heavily dependent on physical and informational infrastructure, supply chains can easily be disrupted. Natural disasters, such as earthquakes and floods, worker strikes, high employee turnover, pandemics, and policy changes, may interrupt the system from running smoothly – greatly affecting the business ecosystem. Knotted upstream supply chain systems hinder downstream customer interest and satisfaction; once disruptions occur, it is beyond single organizations alone to turn supply chain performance around. To mitigate the risk of supply chain failure, effective customer relationship management (CRM) may be of help in maintaining downstream customer satisfaction.

CRM includes business management of customer relationships across sales, marketing, customer service, and e-commerce activities. Businesses adopt CRM systems to professionally manage customer information from a range of different customer interfaces and activities, including organizational websites, phone lines, email, live chat, marketing campaigns, and social media. Businesses typically use large amounts of data collected via the CRM platform to learn about and predict customer behavior, perceptions, and performance. This data allows businesses to learn more about their target customers and to effectively cater their services to customer needs in future business interactions; this system further allows businesses to retain customers and drive sales growth (Bain, 2018). An optimal CRM system is embedded with tools for customer analytics, personalization, social media, and collaboration, among other features, to allow for efficient CRM in the SCM context. However, in SCM, CRM systems typically operate on their own with specialized expertise and focus.

In this chapter, we elaborate on how various parties in the supply chain system utilize CRM information, strategies, and systems to understand and predict customer behavior. With information-oriented CRM strategies, supply chain managers can gather real-life, up-to-date customer information and feedback, which provide better support for supply chain decisions that respond directly to customer needs and demands. We also discuss possible venues for enhancing CRM performance in supply chain operations and organizational operations at large.

## 2 A New SCM Environment

As shown in Fig. 1, the supply chain system is embedded in a larger environment. Advances in globalization and technology have changed today's supply chain system in tremendous ways. For instance, today, production takes place along the global value chain (GVC), and transactions emerge both online and offline, imposing heavier needs for the supply chain ecosystem to parallel this dynamic environment.

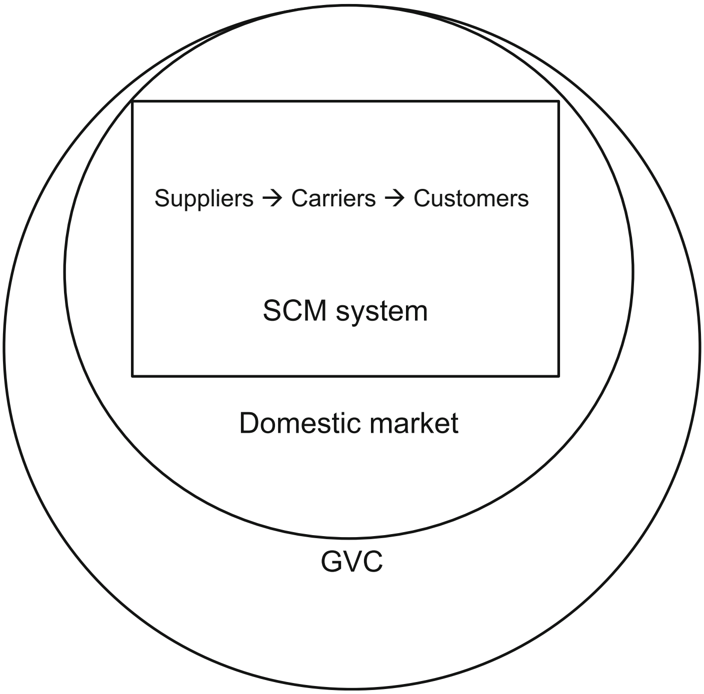


**Fig. 1** SCM actors and the environment

The GVC refers to international production sharing. This means that production is broken into fragmented activities and tasks to be conducted in different countries (Horvath, 2001). A full range of activities, including design, production, distribution, and after-sales service, are divided among multiple firms and workers across geographic spaces to bring a product from its conception to its end use and beyond at lower manufacturing cost (Seric & Tong, 2019). While the GVC may generate lower production costs, it relies more on a successful supply chain system with transportation and delivery cost trade-offs (Horvath, 2001). With fragmented production in different countries, the supply chain system has become more complex and fragile.

Simultaneously, the booming platform economy has reshaped the supply chain system even further. Technovation-technological innovation, globalization, and decentralization, for both individual and business customers, tend to purchase more via online venues. This shift in markets creates two supply chain venues: offline supply chain venues and online supply chain venues. Although the core operation of the supply chain system remains the same, the online supply chain venue provides more access for customers for tracking their purchases and providing supply chain services feedback. It allows for businesses to react to the information collected and provide enhanced customer services.

Technovation simultaneously arose with other technological innovations such as the Internet of things (IoT), blockchain, artificial intelligence (AI), machine learning, analytics, robotics, and automation (Stackpole, 2020). Supply chain participants may adopt different types of new technologies in their operations to improve operational performance and gain customer satisfaction. Studies also confirm that technology adoption is a significant indicator for investment decisions and operational performance. Practitioners with domain-focused expertise can help facilitate the technovation-enabled integration across disciplines (Subramani, 2004; Rai et al., 2006; Ma & Agarwal, 2007).

## 2.1 GVC Emergence

Globalization has fragmented supply chain systems. Take face masks – from the COVID crisis – as an example. SCM of masks is sophisticated and complex. This occurs across three primary stages: offshore manufacturing and inspection, inventory maintenance and international shipping of the masks, and delivery to individual, business, or institutional customers. Each stage has dozens of procedures and interactions with different parties, including material suppliers, manufacturers, quality control, carriers, border customs, customers, and frontline employees. To maneuver within these supply chain participants and processes requires managing the supply chain system complexity.

The environment, language, and policy differences, as well as the culture-induced organizational differences, call for smoother collaboration between different stakeholders. Effective CRM could be a solution to support this complex task.

## 2.2 Digitalization of SCM and CRM

The booming platform economy has imposed significant changes on the supply chain system, adding more fragments to the supply chain systems. With more and more individual customers ordering products online, both domestically and internationally, smaller deliveries have also become a part of traditional bulk shipping systems.

From a supply chain perspective, customers shop online due to the accessibility of products. Such accessibility can be viewed in two ways. On the one hand, customers have a need for products not available in local brick-and-mortar stores, and the online platform inventory addresses these needs for such products. Alternatively, customers are seeking convenience. Rather than procure products on-site, they prefer to get products shipped to their doorsteps.

CRM is moving online as well (Holmström et al., 2019). Customers, including individual, business, and institutional customers, gain access to an "order tracking" platform so that they can monitor the whereabouts of their packages in real time. By doing so, customers evaluate the business's supply chain performance, which will assist in their future purchase choices. Intuitively, customers may be likelier to purchase from a "fast-shipping" business compared with a "slower-shipping" one. Moreover, there are a growing number of online services for customers to gain a greater understanding of the shipping process. For example, if there is a weather-caused delivery restriction in the area, an AI-embedded CRM system will generate an automatic message for customers in the affected area in case they have event-relevant questions such as delivery status and the delay.

Customer online shopping needs add more to the workload in the existing supply chain system. At the same time, an advanced digital SCM-CRM system helps facilitate efficient and effective SCM practices.

Technovations reduce human error during the supply chain process to ensure better customer satisfaction. In the area of CRM, they facilitate efficient communication with customers using automatic notifications, tracking, and user information collection. The effective adoption of technovation and the ability to follow the fast-moving technovation current is the key to gaining competitive advantage and facilitating future success (Stackpole, 2020).

For example, the cloud- and AI-embedded IoT technology can be adopted with AI- and machine learning-embedded analytics to not only show the whereabouts of an item but also the traffic flow and weather conditions. Supply chain participants can make decisions based on the leverage analytic results to determine the route of such shipment should be redirected or maintain as is – especially for high-value, high-maintenance, fragile items with an accurate delivery time commitment, such decisions can help facilitate on-time delivery and the product quality upon delivery. Effective SCM-CRM can do more than that, by engaging customers in the decision-making process. Customers may opt to get delivery status change notifications via cellphone texts to monitor delivery status. Upon rerouting delivery, customers can get informed and then opt in to approve the status change or refuse the status change. Such practices increase customer engagement and, in turn, improve customer satisfaction and commitment (Bowden, 2009).

## 3 Current Concerns: SCM and CRM

On the supply side, SCM focuses on optimizing the business operation flow by linking materials, information, services, and financial flows through a supply network (Mason & Roth, 2009). SCM systems are widely adopted by businesses together with enterprise resource planning (ERP) software to "boost enterprise efficiency, improve decision-making by providing greater visibility into operations, and promote collaboration via information sharing" (Mason & Roth, 2009, p. 134).

On the demand side, CRM focuses on maximizing the values of customer relationships, CRM links marketing, sales, customer service to customers to maintain and cultivate long-term business-customer relationships. CRM systems are also widely adopted in various business sectors, including sales, marketing, service, and e-commerce. They are used around the world to maintain successful, long-term business relationships between a company and its customers (SAP, 2021). On average, the return on CRM investments is about \$5.60–\$8.71/\$1 spent on CRM (Nucleus Research, 2014). In this chapter, we focus specifically on CRM and SCM-CRM integrations.

Over the years, CRM practices have become more advanced, but the core of the practice is always to ensure that the business is "highly customer involved." Traditional CRM practices involve tasks generated from periodically updated customer data and standard company-designated communication materials. They are typically performed during regular business hours with the overall aim of ensuring successful transactions.

More recently, many companies have moved to social CRM, a new mode of CRM practice (Choudhury & Harrigan, 2014). When practicing social CRM, customer records are updated in real time according to customer activities on various platforms including emails, customer services, and social media. These updates could generate various customer nudges such as business feedback to a customer's negative word-of-mouth or customized activities such as an online introduction session of a new product. Via social CRM, nudges can happen via dynamic media channels to connect and engage customers. Effective CRM nudges can lead to customer-relevant and worthwhile interactions before or after the transaction to ensure sustainable and loyal customer relationships. Up-to-date CRM software supports CRM practices that utilize databases and unified processes to connect all customer-facing activities, including customers' social media activities (Trujay, 2021).

In sales, well-maintained CRM systems help sales representatives make successful connections and effectively maintain relationships with customers (Nguyen et al., 2007). An AI-based CRM system (AI-CRM) automates lead generation, personalized communication, customer emotion detection, quote generation, customer service, and sales forecasts efficiently in the short term. AI-CRM improves a business's ability to predict customer lifetime value, generate adapted treatments for customers, and design customized plans for customer prioritization and service discrimination to build sustainable long-term customer relationships (Libai et al., 2020).

In marketing and e-commerce, effective CRM facilitates accurate predictions of customer responses. It helps the company learn about the customer's preferences and needs by studying customer inputs, activities, and purchase records. Automation is an advanced CRM function that is widely used in the field of marketing. The CRM system can answer customer questions 24/7, and it can send automated emails and service messages/calls to customers to keep everything up to date, so customers will not miss anything due to field service errors. Specifically, CRM in e-commerce provides customers with omnichannel commerce experiences across different platforms, including mobile devices, online, and brick-and-mortar locations.

Successful CRM provides benefits to a business. First, efficient processes can be established with effective CRM. With transparent information and automatic scheduling, firm operations and collaborations between management, operations, marketing, sales, and service teams can be conducted more smoothly and with less effort. CRM also facilitates a smart work experience among field workers. Information shared across sectors and with all project-relevant personnel across teams and departments makes internal and external stakeholders part of this network and keeps information syncing real-time between all parties. Therefore, those involved in interdisciplinary collaboration can always be on the same page, meetings are operated more smoothly, and the team as a whole can serve customers at all possible points so that customers and customer service personnel do not have to repeat their previous communication every time when making a service phone call.

Given this background, what is the current SCM-CRM integration status? Many examples have been found. Most examples have SCM and CRM as separate systems but serve the business together. One example is Dell's industry pioneer "made-to-order" personal computers (Klinker et al., 2006). First, Dell developed the concept of engaging customers to build customized personal computers. This CRM procedure was first via phone calls, moving online to a "Premier Pages," which is a custom-built computer platform to obtain customer needs for their personal computer. To address growing customer needs, Dell then created their i2 SCM system to ensure all necessary parts were ready for assembly. Nowadays, many computer manufacturers are doing similar things, but it is a concern that two independent systems may lead to poor operational efficiency and waste of operational resources in the business daily operations, which is unsuitable for optimizing profitability.

The field of supply chain is not a traditionally CRM-heavy field for several reasons. First, the common CRM practices mostly lie in the B2C (business-to-customer) context, while a supply chain is a complex system with a mix of B2C and B2B (business-to-business) elements, which means that the "customers" in this case may include both upstream raw material suppliers and downstream individual customers and corporate buyer. The core aspect of CRM, communication, differs greatly between B2B and B2C practices (Zeng et al., 2003). Unlike B2C firms, B2B entities are less likely to adopt social media as a marketing tool and have struggled to implement successful social media strategies (Swani et al., 2014).

In addition, supply chain networks are diverse. In GVC, the end customer may purchase a car that is designed in the United States but assembled in South Korea, with windshield glass made in China and an engine manufactured in Germany. The complex nature of the supply chain network makes it quite difficult to integrate all parties together in the same system and communication with the same language and at the same time may prove challenging.

Since the beginning of SCM becoming an independent field of study, transparent and timely information about customers, supply chain participants, and the environment has always been valued for better decision-making. With transparent and up-to-date information, SCM participants can make scientific and legitimate SCM decisions. Through time, the need for transparent and timely information has not been changed, but one difference in SCM could be that its focal orientation has been moving from "increasing efficiency and reducing costs" to "facilitating customer satisfaction and cultivating customer loyalty." The world's second-largest software company by revenue and market capitalization, Oracle, states that "the customers now play a front-and-center role in setting SCM priorities" (Oracle, 2021).

This shift leads to the demand for SCM-CRM integration by not only in operation systems but also in practitioner requirements and is further an issue under investigation by researchers. Integrated SCM-CRM system capabilities go beyond basic functions, such as contacting and delivering standard messages from the company to the customers, as well as maintaining and tracking inventories and shipments. Now, companies can streamline all customer-facing processes, collect real-time data, and strengthen relationships with customers at the center of business activities. Effective SCM-CRM includes initiating, leading, and facilitating customer interactions about supply chain operations, as well as recording customer information, communication, and transaction records on supply chain operations. In this new era, we expect effective analytics of customer data, more automatic supply chain operations, and the prevention of supply chain service failure.

Ultimately effective SCM-CRM helps improve customer experience and customer retention (Rigby & Ledingham, 2004). With the complete tracking of all relevant customer activities, including purchases, services, phone calls, and so forth, all customers have a personalized SCM-CRM account that helps the company design and deliver personalized strategies or tactics to fulfill customer needs, improve customer experiences, and resolve issues quickly. Real-time analytics of customer data also help to identify the best tactics and the right timing for customer interactions and the optimal omnichannel combination designs to serve the customers' supply chain needs. Additionally, after-sales customer services can help companies achieve higher customer satisfaction and boost customer loyalty.

## 3.1 A Shift from Customer Orientation to Stakeholder Orientation

Supply chain operation is a service provided to customers, and successful services are always desired by downstream customers. However, to understand CRM from a service perspective, we first need to define the role of customers in the supply chain process.

An overview of the supply chain process is shown in Fig. 2. On the microlevel, only downstream individual or business customers can be seen as end customers. However, all parties in the supply chain process, including raw material suppliers, producers, warehouse staff, retailers, and customers, are receiving products at some point. Therefore, from a macro perspective, all supply chain participants can be seen as customers or stakeholders. Accordingly, one upstream supply chain stakeholder's performance can impact the downstream supply chain stakeholder's perception and performance. Therefore, optimal supply chain performance needs to incorporate all members of the supply chain process (Park-Poaps & Rees, 2010; Bhattacharya & Fayezi, 2021), and effective CRM needs to account for all supply chain network participants.

To obtain optimal service quality, supply chain practitioners need to switch from a customer-based view, which takes only the end customer into account, to a stakeholder-oriented (SO) view that considers all supply chain network members (Ferrell et al., 2010). The SO mindset does not designate anyone stakeholder as more important than the others, nor are certain stakeholders prioritized depending on the situation of concern. SO imposes importance on cultivating long-term sustainable business relationships between stakeholders. In the following parts of this chapter, we elaborate on how supply chain suppliers, customers, and carriers practice CRM to facilitate satisfactory service performance via SCM and, specifically, SCM-CRM.

## 4 Outstanding Concerns of CRM Practices by SCM Participants

### 4.1 CRM by Upstream Customers: The Suppliers

On the supply end, there are a variety of suppliers who create an order and ship it to downstream receivers. As indicated in Fig. 2, the upstream suppliers usually initiate the production of orders with raw materials – orders which are then delivered to the downstream stakeholders. Other than the end customers, all supply chain stakeholders have the opportunity to act as suppliers in the supply chain system – and in


**Fig. 2** Overview of the supply chain process

some cases the end customers can return their products and materials for recycling when closing the loop of supply chains.

Among the different types of suppliers, there are two major categories: corporate suppliers and entrepreneurial suppliers. The major distinctions between these two types of suppliers are their experience in business practice and their financial capital. Such distinctions, in turn, impact their CRM practices.

### Corporate Suppliers

Many accomplished companies act as suppliers in the supply chain. In the Gartner supply chain list, Colgate-Palmolive, Johnson & Johnson, and Nestle are listed among the top five supply chain stakeholders based on scores on key attributes, such as environmental, social, and governance (ESG), 3-year weighted return on physical assets (ROPA), and revenue growth and inventory turns (2020 cost of goods sold/2020 quarterly average inventory) (Griswold, 2021).

Corporate suppliers devote significant effort and expenditure on SCM, CRM, and associated operation management programs. Recent SCM revamps have been closely linked with CRM; the annual costs on such improvement could be tens of millions of dollars for a corporation (Simchi-Levi & Timmermans, 2021). As the time for changes comes, the revamps of SCM and CRM systems are massive. Looking at the 3- to 5-year transformational effort and corresponding large investments in cloud technology, RFID (radio frequency identification) tags and readers installation on every container and facility, automation and robotics technologies, and the corresponding monitoring systems to identify supply chain participants performance and monitor ongoing environmental conditions including weather, policies, and those that might impose risks on supply chain practices. All those improvements shed light on CRM explicitly to ensure real-time communication, easier and cost-effective customer data storage and retrieval, and faster corporate response or decision-making per SCM-related events, which in turn improves the efficiency of the corporation SCM and benefits corporation operation at large.

Corporations are willing to spend time, money, and effort to revamp operation systems such as SCM or CRM due to their overall goal to gain more profit by ensuring efficient operation and maintaining customer satisfaction concerning social responsibility at large. At the same time, corporate operational budgets are relatively large compared with small and medium enterprises, so they have more capital on operation refinement.

Taking Johnson & Johnson as an example, Johnson & Johnson's recent innovation has been the main focus of their supply chain practice. Other than adopting the aforementioned digital advances in the development of their focal medical product line, they have also engaged in broader CRM practices to further benefit the corporation and its customers. The Johnson & Johnson supply chain sector generates massive amounts of data from their CRM, ERP, inventory management, distribution management, and logistics management systems to analyze operational performance and make the appropriate improvements to self-improve and better serve their customers.

Specifically, the SCM team displays a visual canvas with the ideal supply chain scorecard to its upstream and downstream stakeholders for corporate decision-making. By doing this, the management team in the upstream manufacturing facilities can collaborate with others working toward the same SCM goal more efficiently and cohesively with the use of data and facts during their continuous improvement activities.

Furthermore, advanced collaboration features are facilitated by the CRM platform to ensure that no meeting insight is lost. The advanced system quickly saves shared digital content and/or physical whiteboard content. It also records meeting information in real time and distributes meeting notes to relevant parties. This allows SCM participants to access, use, and visit the relevant meeting workspace more efficiently and effectively in future meetings.

Boosted by the COVID pandemic, customers intend to avoid in-person interactions. Johnson & Johnson responds to such needs by implementing a superior real-time collaboration system across distances to improve the coordination of different supply chain participants via contactless interactions. It was recently awarded two new Lighthouse designations, (The World Economic Forum and McKinsey & Co. co-established the *Global Lighthouse Network* in 2018 to accelerate a more comprehensive and inclusive adoption of technologies in manufacturing (Shapiro, 2021), which is "a marker of excellence in manufacturing innovation" (Shapiro, 2021). The system facilitates a customer connectivity system in orthopedics and a vision care order-fulfillment system. The contactless technology allows end customers with different preferences to have their demands fulfilled with satisfaction.

## Entrepreneurial Suppliers

Entrepreneurial suppliers, which refer to newly established start-ups or smaller scaled suppliers, regardless of their position in the supply chain process, share similarities in economic valuation, scope, and operational characteristics with large corporations. But their operational budget could be significantly smaller due to the scale of business. Therefore, larger-scale SCM revamps are harder for entrepreneurial suppliers to achieve. For businesses that rely on the GVC, 2021 and the COVID crisis has become a particularly stressful year. However, for manufacturers that procure raw materials locally, SCM has been easier. For example, Nanotronics, a science technology company in Brooklyn, NY, sources most of its components locally and has had a smooth year (Krueger, 2021).

For small businesses, Fulfillment by Amazon (FBA) and drop-shipping have been new solutions. Fulfillment by Amazon (FBA) is a service that helps businesses grow by providing small business owners access to Amazon's logistics network. Small business owners have products sent directly to Amazon Fulfillment Centers from the manufacturers. Amazon Fulfillment Centers handle the order, receiving, and maintenance of inventory for the products in the order. When a customer makes a purchase, Amazon Fulfillment Centers handle the packing, shipping, customer service, and returns for those orders. With a commission fee, FBA lifts the SCM and CRM obligations from business owners with effective, sophisticated, and experienced e-commerce SCM solutions.

Such practices have been widely adopted around the world. In China, Alibaba CaiNiao delivery has a stronger focus on CRM (Falcone et al., 2019). Centered in Hangzhou, CaiNiao delivery utilizes driverless vehicles to deliver packages within a short distance from the delivery center. Upon the packages' arrival, with the help of IoT, the built-in system in the delivery car automatically sends a notification to the delivery person that the packages have arrived so that they can get ready to collect them and complete the last mile of delivery to customers' doorsteps. The messages can also be sent to individual customers if the system senses that the customer lives really close by. Then, the customer can choose whether to stop by the car and pick the packages up or have the delivery personnel store the package in nearby lockers for pick-up afterward.

Although such practices have largely been implemented by larger corporations, such as Amazon and Alibaba, many small business owners may choose to work with FBA or CaiNiao Delivery to share the benefits of such technovations with an operating cost. However, if small business owners choose to work with a conventional SCM carrier, then the CRM quality is undetermined, and the business could be heavily dependent on the carrier themselves. Then the operating cost will be on the collaboration expenditure with the carriers, and the tracking and customer service cost toward all steps in the logistic process from getting inventories from the supplier, inventory storage and management, last-mile shipping to customers' doorsteps, and the after-sales service.

## 4.2 CRM by Downstream Customers: The Buyers

Individuals, corporations, institutions, and entrepreneurial firms can act as buyers in supply chain systems. To obtain the buyer position, individuals, corporations, institutions, and entrepreneurial firms have to be at the downstream side of the supply chain process. While all buyers at different positions in the supply chain process share the same interest in receiving deliveries at the planned time and maintaining good communication with the upper stream suppliers, they may have different interests because of their various positions in the supply chain process as well as their own distinctive characteristics.

Individual customers are all individuals who make transactions from a retailer to obtain the end product for their usage. They are typically at the end of the traditional supply chain process; while considering sustainability, circular economy, and closed-loop supply chains, the customers become a "middleware" in the closed-loop supply chains. Individual customer expectations of the supply chains are relatively simple to understand: they want to get their orders at the promised time. Some of the orders are time sensitive if they include fresh products or emergency items. In other cases, some of the customers are relaxed with respect to the delivery time if their purchase is from a long-term supplier, or they can easily find alternatives elsewhere.

Corporate, institutional, and entrepreneurial customers are likely to be secondary customers at the second-furthest end of the tier continuum, before individual consumers and end customers. After acquiring the products, they will most likely store them for further retailing or distribution. Therefore, delivery timing is crucial for these customers, because late deliveries of certain emergency items (e.g., food, water, or toilet paper), medical supplies (e.g., cleaning, medical, preventative, or school supplies), and seasonal goods (e.g., holiday or graduation items) will hinder the regular operation of the business, as well as the comfort and enjoyment of the customers and society at large.

When shoppers purchase from online retailers, they gain an understanding of whether the product is available by reviewing product information on the retailer's website. In most cases, they can easily track product availability by setting up email or text notifications on the website. The receiving customers can track package delivery information on the retailer's website or the associated carrier's website as needed. Customers typically perceive online delivery that is efficient, secure, friendly, and sustainable as satisfactory. However, when a delivery fails, a customer's communication with the retailer platforms is crucial to recovering from service failure. Typically, customers will communicate with the retailer's customer service department with the hope of securing a redelivery or refund. With synced and shared information from the carrier, customer service usually does not have newer information on the delivery process. Therefore, the typical solution for failed supply chain service is for the retailer to redeliver or refund the customers.

Such solutions will lead to financial losses for the retailer, but they help ensure improved customer service to individual customers. This might conflict with the responsibility of the SCM or operations managers, who are expected to provide satisfactory delivery service at a minimum cost to the retailer. This responsibility should be reflected in the retailer's operations plan; the contracted parties, including retailers, warehouses, logistics carriers, delivery personnel, and customer service personnel, should be involved in the operations plan to facilitate effective and satisfactory delivery at a lower cost, as indicated in Fig. 3.

In this context, the operations manager's responsibility is to ensure good supply chain performance all along the retailing operation supply chain process. Accidents like human errors, missing packages, natural disasters, and delivery problems are unlikely to be eliminated (Su, 2009). However, the operations manager should be able to optimize the CRM process and monitor all retailing operation supply chain processes by maintaining an ideal level of communication and information transparency with not only the individual customers but also with the retailing operation supply chain stakeholders.

Synching collaborative information and feedback system could be utilized by the retailing operation supply chain stakeholders. Specifically, fluent CRM could be established by creating a unique QR code or RFID for all products or packages. Once a process is completed at one supply chain step, a status update can be generated by scanning the code. Such on-time updates will generate a mutual understanding of the timeline and whereabouts of the product to be delivered. After practicing for a while, reliable SCM standards, such as the rate of output of a warehouse in terms of orders per day, rate of on-time delivery, and optimal changeover times, can be created and

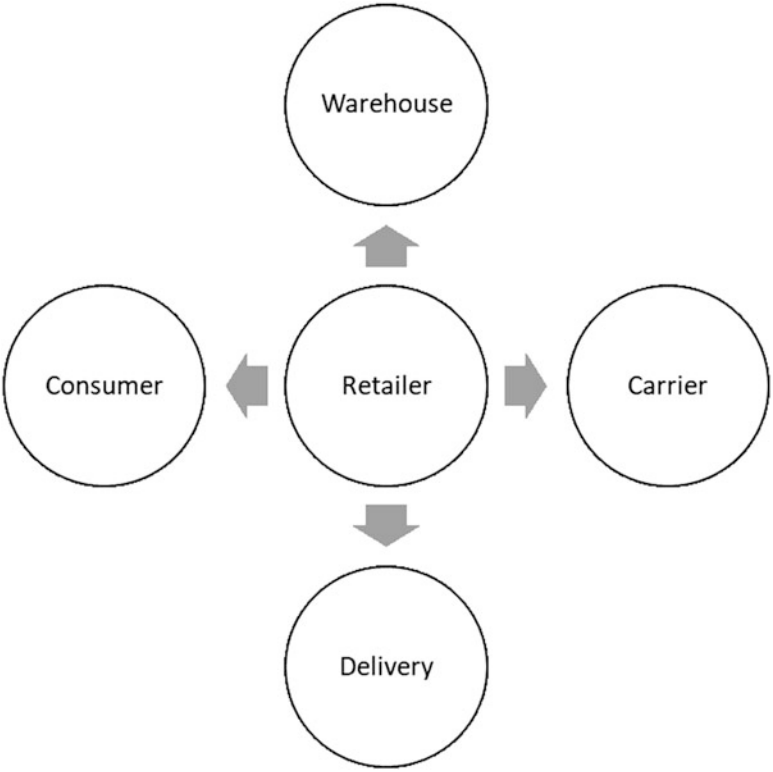


**Fig. 3** Overview of the retailing operation supply chain process

adhered to, and the contract agreed upon by all parties involved in the operations plan can be updated as needed.

Information from daily operation processes facilitates effective operation planning and forecasting. Accordingly, this information is the backbone of all supply chains. With the available data, even if a difficult situation approaches, operations managers can create a simulation model of how fast service recovery can be established and update the information for downstream customers in the supply chain process. Such up-to-date information facilitates effective and efficient CRM within the supply chain network.

Another type of CRM can be facilitated by gathering customer reviews. While supply chain participants want to service their customers better, there is not much information on supply chain performance gathered from customers. Especially for some time-sensitive deliveries, supply chain performance is equally as important as product performance. Take Amazon Fresh as an example; most of the helpful negative feedback (Fig. 4) expressed complaints about the supply chain performance. In both reviews, the customers complained that the strawberries delivered are "molded." These reviews pointed to a logistics and product failure to either failed

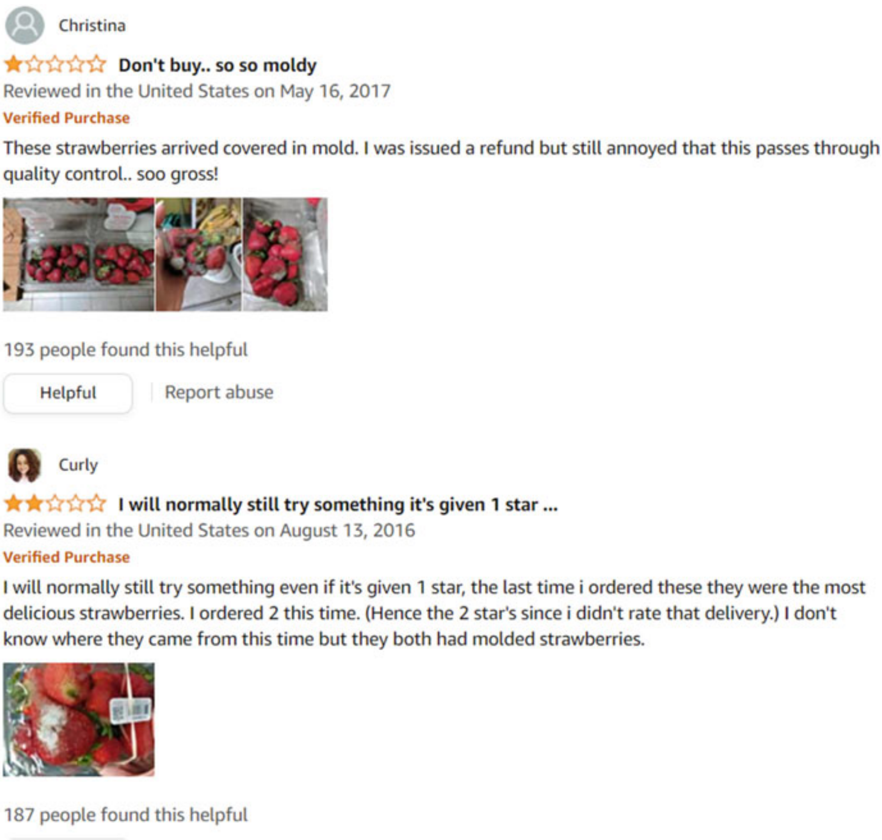


**Fig. 4** An example of Amazon Fresh reviews

inventories or slow deliveries using moldy strawberries in this specific scenario. These issues lead to customer dissatisfaction, negative word-of-mouth, redacted customer flow, and poor sales performance for Amazon Fresh. For a new business model of cold-chain-based fresh e-commerce, businesses gain their credibility and reliability value with regard to business models based on the accumulation of day-to-day operations and logistics. Having negative word-of-mouth may hinder the sustainability of such a business model.

Among various retail operations supply chain stakeholders, customers will only be able to comment on the supply chain performance associated with the most adjacent stakeholder in the process, which is typically the retailer, regardless of whether the retailer is a corporation, an institution, or an entrepreneur. Therefore, retailers need to manage customer reviews effectively. First, retailers may collect customer feedback specifically on supply chain performance. For instance, Amazon Fresh has not only an overall rating for product purchases but also features ratings for features such as product freshness, flavor, and value for money to capture customer feedback on the supply chain, product quality, and product value. Such feature rating systems can help platforms gain a better understanding of the overall supply chain operation.

When customers write reviews, they tend to write one review that covers everything. Unless the supply chain performance is especially unacceptable (as shown in Fig. 4), customers may not touch on the supply chain part of the business at all. If the review is based on features, it will gauge more supply chain details and perceptions from the customers, which can be highly beneficial for the platforms' future operations management. For example, when such reviews are collected, the platform can provide specific feedback to customers. If there is a critic, the platform can contact the customer further for rectification and secure more detailed feedback.

Documenting feedback effectively in the back-end system, analyzing it with keywords, and delivering it to relevant stakeholders may help supply chain participants improve their future practices. For instance, "packaging"-focused statements could be referred to the warehouses, "shipping"-focused statements could be referred to the carrier, and "delivery"-focused statements could be referred to the delivery contractors or individuals. Via such "customer-to-platform" communication, CRM can be further improved by providing updated customer supply chain feedback to different stakeholders and by coming up with suitable resolutions for the problems raised.

## 4.3 CRM by Middle Stream Customers: The Carriers

In the supply chain network, ocean shipping is relatively common for upstream supply chain participants, whereas last-mile delivery is more important for downstream participants. Both types of logistics services are equally important links in supply chain network operations.

Last-mile deliveries carry more customer goods. Corporate carriers, such as the US Postal Service (USPS), UPS, FedEx, and DHL, are the main carriers in the US supply chain network. They deliver daily purchases to customer doorsteps and form deep relationships with customers. Corporate carriers often partner and subcontract with mainstream retailers and e-commerce platforms. The corporate carriers handle the last-mile delivery from the business warehouse to the customers' doorsteps.

With rowing e-commerce, gig – individual proprietor – carrier services have been booming in recent years and have begun to carry more weight in last-mile delivery services. In Amazon's FLEX program, individuals with suitable vehicles are recruited to deliver Amazon packages in population-dense areas to lift the heavy load off corporate shipping partners. As online grocery procurement becomes more popular, Instacart and local supermarkets hire in-store procurement personnel to fulfill customer orders. These innovative shipping solutions have allowed more "nonexpert" individuals to enter the supply chain and have decentralized the operations of the field.

More cargo movements occur with upstream logistics. With GVC, more upstream commodity-trading activities occur across borders. This means that cargo ships

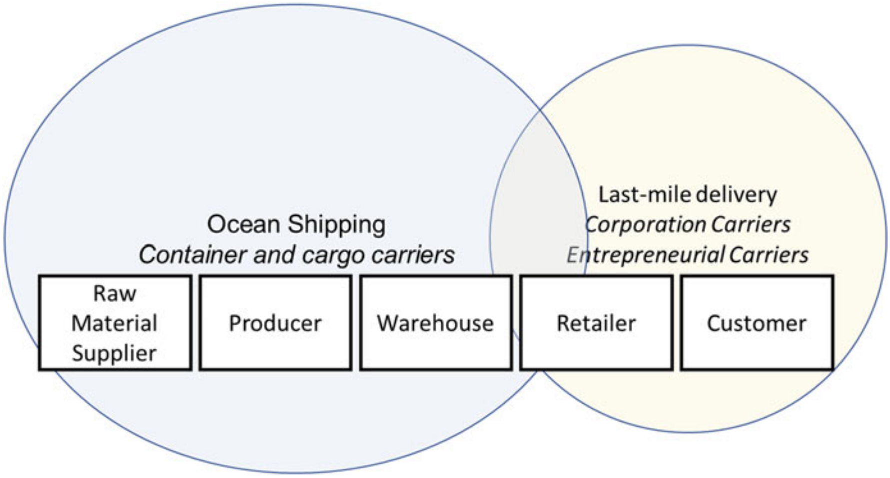


**Fig. 5** Shipping and delivery modes along the supply chain network

carrying bulk items, such as commercial goods and products in containers (e.g., grain, sugar, fertilizers, minerals, and oil), travel around the world in dry or liquid bulk formats. As indicated by Fig. 5, the cargo ships load supplies from raw material supplied or producers and unload them to middle stream customers, usually the producers or manufacturers and warehouses. Carriers such as Kirby Corporation (liquid bulk, US-based) and Star Bulk Carriers (dry bulk, Singapore-based) are publicly traded companies. Then, the corporation carriers and entrepreneurial gig carriers will take over from the warehouses, performing late-mile delivery to end customers' doorsteps. But the public or the downstream customers have relatively limited knowledge of cargo carriers' operations, but cargo carriers' performance significantly impacts individual customers at large.

## Corporate Carriers in Last-Minute Delivery

With respect to CRM, the end customers come to know the corporate carriers who deliver to their doorsteps all the time, such as UPS, USPS, and FedEx, very well from their daily encounters. As they focus on the "last-mile delivery" services, including sending and receiving packages and handling new appliance deliveries, the end customers, including individuals and business owners, deal with these corporations all the time. At the same time, delivery performance impacts customers' retention intentions. One study found that 56% of shoppers would not buy from a brand again if they were not satisfied with the shipping service (Ross, 2021).

Most retailers, including supermarkets and department stores, have a collection of brands from different merchants. As Fig. 6 shows, while the supply chain systems deliver the products from the merchants to the customers, they also supply logistic status information to gain customer awareness. While the downstream customers can also supply information to the upstream merchants through different paths, especially when they face a logistics service failure. The customers can facilitate the

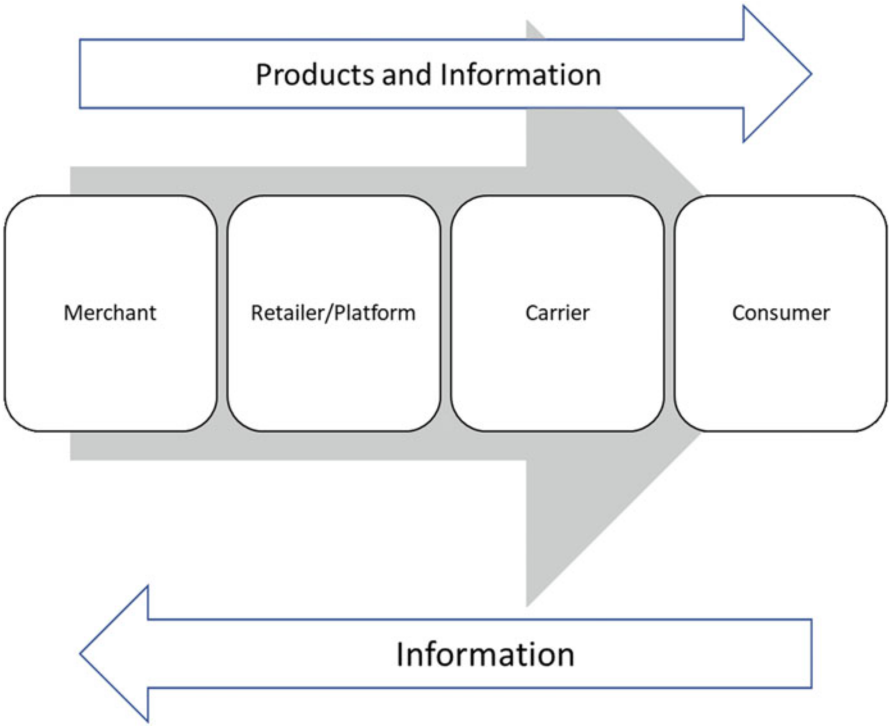


**Fig. 6** Flow via the logistics process

appropriate attribution of complaints about merchants, platforms, or carriers, and this process is associated with the self-influential effect of customer complaints. However, problems with service failure also spill over into word-of-mouth and retention intention issues. By spreading online word-of-mouth using online reviews, customers attribute logistic service failures to not only platforms but also merchants and consequently complain about them both.

In terms of logistics service quality, successful delivery is made at the promised speed in a safe, high-quality, and sustainable way. Nevertheless, logistics service failures still happen; delayed delivery and package damage are among the major service failure incidents (Ross, 2021). Although unpredictable issues, including traffic, bad weather, or vehicle problems, are among the elements that are out of the carriers' control, maintaining effective and efficient CRM can mitigate such problems.

Customers often complain about a lack of visibility during the last-mile delivery process. In an ideal situation, customers want to know where their packages are and when they will be delivered. Today, most domestic retailers offer tracking numbers to their customers so that they can track their packages as they see necessary to gain a complete understanding of the delivery process. This provides transparency in the logistics process. However, in recent years, missing packages have become a common incident in certain areas. Accordingly, customer needs for up-to-date product location information have increased, and a line of text indicating the expected time and most recent location has become insufficient. Therefore, for better CRM, carriers have started to provide more discrete tracking information, including a digital signature or a real-time photo taken by the delivery personnel, to provide another level of insurance on package whereabouts.

Customers are also offered different B2C delivery management software services when making purchases. General logistic management programs, such as ShipStation and Amazon FBA, provide transparency in real-time status for both merchants and end customers, and shipping discounts for frequent merchants are also available. It has been reported that 55% of customers back out of their purchases due to concerns including delivery speed, high delivery costs, and a lack of transparency (Jacobs et al., 2019). Such programs help reduce shipping costs and increase retention intentions.

CRM functions embed many B2B delivery management systems. B2B delivery management systems, such as KeepTruckin and Route4Me, help manage the overall operation of all supply parities, from carriers and delivery personnel in the field to warehouses and workers. Other than basic functions, such as GPS tracking, cost control, safety, and compliance, CRM features, such as IoT-based driver tracking and WIFI-enabled streamlined driver communication, two-way messaging, and workflows, have been added to facilitate smooth connections between different supply chain links.

The utilization of integrated B2C and B2B delivery management systems and software ensures high delivery efficiency, even during uncontrollable accidents. Streamlining communications processes from the warehouse to the customer's doorstep allows for flexible changes in the delivery plan, such as last-minute rerouting, customer unavailability on-site, or shipping requirement changes. Therefore, with the adequate deployment of delivery management systems, transparent communication among the workforce and between workforces and customers leads to smooth deliveries, increased customer certainty, lower costs, increased customer satisfaction, and better retention rates.

### Entrepreneurial Gig Carriers as Supplements in Last-Minute Delivery

To resolve service failures in last-minute delivery services, merchants and platforms have been working hard to come up with new solutions to help achieve last-mile delivery speed, timely delivery, and accuracy. Crowdsourcing, or what has otherwise been referred to as the gig economy, has become a trendy solution to this particular issue. The gig economy is a labor market characterized by the prevalence of short-term contracts or freelance work, as opposed to permanent jobs. Among all competitors, Amazon and Uber have been the pilot innovators in the gig economy, even the entire field of supply chain at large.

Taking Amazon as an example, almost anyone can sign up as an Amazon FLEX driver. Upon approval and Amazon FLEX assignment, the driver can pick up the assigned packages at a delivery station, and they will be expected to deliver the packages to customers within a time slot of 3–6 h. Time-sensitive orders, such as

Prime orders and Amazon Fresh groceries, are usually covered by Amazon FLEX programs, but the delivery time slot is 2–4 h for these services. Some drivers are assigned to take store orders, while others are assigned instant offers that are only available in limited areas. Other platforms practicing similar gig economy-based practices, such as Instacart, Uber, and TaskRabbit, are operationalized in similar ways.

From a CRM perspective, there are pros and cons to gig-based delivery practices. In terms of the pros, such a system allows more individuals to work on last-mile deliveries. This means, proportionally speaking, that the orders can be delivered more efficiently within the serviced areas. However, delivery quality may be mitigated. Due to inexperienced one-timer trials with a short-term contract at 2–5 h and an almost 100% turnover rate every day, there is virtually no chance of creating a consistent delivery experience for customers. Without professional training and practices, customers may obtain unsatisfied delivery experiences. Indeed, the delivery experience is entirely left up to "chance." Careless delivery personnel may drop the package without concern for the safety of the contents. In a worst-case scenario, a delivery person may have to use a regular car to transport items that need refrigeration.

Compared with the relationships built between customers and corporate carriers, the complete lack of a relationship between end customers and crowdsourced delivery personnel hinders customer loyalty. Before the rise of such services, customers generally received packages from the same delivery person every day through the simplest but most effective CRM strategy of all time: as random small talk accumulates over time, customer loyalty will be built. However, with gig delivery, such a relationship is missing from the company's operations. The merchants or platforms should therefore come up with supplementary CRM tactics to fulfill customers' social needs.

### Container and Cargo Carriers in Ocean Shipping

With growth in international trade, container and cargo companies are typically global shipping companies that aim to provide high-quality transportation services to upstream customers. The business scale for container and cargo carriers is usually sizable. For example, a fully delivered basis for a Star Bulk fleet comprises 128 modern vessels with an average age of approximately 9.6 years and a total capacity of more than 14 million DWT (Star Bulk, 2021).

Over 90% of the world's trade is carried by sea (Guerrero et al., 2015). Compared with shipping via airplanes and trains, the cost is lower, a larger volume of products are transportable, fewer restrictions are imposed, and more items are allowed. Ocean shipping via ocean freight is a major way of shipping in this sector. Such entities specialize in large loads of goods, with typical shipments weighing more than 100 kg. End products and raw materials are put into cargo freight and loaded onto vessels, while the vessels follow predetermined and planned sea routes to transport these goods and commodities. The successful delivery of end products and commodities impacts the manufacturers' and retailers' planned operations, as well as the end customers' purchases and consumption rates.

However, due to the nature of sea travel and the long distance between destinations, the duration of transportation is much longer than that of other transportation formats, which eases CRM among ocean shipping parties in terms of providing update shipping status changes to customers or continuously monitoring shipment status.

Trusted and long-lasting relationships are at the heart of the container and cargo carrier business. Due to their size, these businesses focus on building and maintaining relationships with all counterparties, from charterers and brokers to shipyards and financial institutions, for the sake of operational sustainability. Maintaining a healthy balance sheet throughout each shipping cycle, with reasonable levels of indebtedness and the strong support of many prominent international banks and leasing companies, is a necessary condition for sustaining credibility and relationships with supply chain network participants.

Technology, innovation, and data analytics comprise strategic advances that allow for better CRM to be built. Advanced resource planning systems help optimize resource allocation in daily operations and collect real-time data at high volumes and volatility. Then, business intelligence analyzes the data collected to monitor cargo performance, optimize strategic decision-making, and predict future operational movements.

## 5 Future Directions: The Venues Toward SCM-CRM Success

As technology advances, the technological infrastructure of CRM has been evolving. Three main changes to CRM applications have facilitated improvements in supply chain practices.

One of the ongoing changes is the further integration of SCM, CRM, and ERP systems, which is currently progressing at a slow-moving pace. However, once established, the integrated system will facilitate effective and efficient CRM and, in turn, make collaboration between different SCM stakeholders more effective and efficient. Second, outsourcing is a traditional solution for dealing with stakeholder diversity in supply chain networks. The implementation of outsourcing is a double-edged sword, however, although it may reduce business operational costs and mitigate problems in international trade. Finally, additional automation functions embedded in the current CRM systems can mitigate most of the concerns derived from the adoption of third-party outsourcing partners. Each is now presented.

### 5.1 Seamless Integration of SCM, CRM, and ERP Systems

Many companies have successfully adopted technovation-oriented CRM systems for their own benefit. Large platforms and retailers, such as Starbucks, are now able to integrate customer order information collected by the transaction processing system (TPS) developed by IBM. The TPS is not a traditional form of CRM software, but for the high-traffic customized beverage industry, the TPS can be seen as a subsidiary CRM system. The TPS is used in every order at Starbucks. It collects, modifies, retrieves, and stores all customer transaction data. Then, with electronic data interchange (EDI),

TPS information is integrated into data points in the Starbucks dataset, which is then embedded in its HighJump Software Supply Chain Execution (SCE) solution system to automate Starbucks product distribution networks (LeBlanc, 2019). This means using customer order data collected from TPS, Starbuck customizes ingredient needs by store locations and then allocates different ingredients at different quantities to different store locations to avoid food waste. As a result, the SCM-CRM integration helps Starbucks reduce operational costs, allocate resources scientifically, and establish a positive brand image for Starbucks as a socially responsible company to gain customers' trust and preference and achieve competitive advantage (Saeidi et al., 2015). In this case, the TPS corresponds with the SCE to create effective SCM-CRM integration in this high-traffic industry. It could be a good example for the restaurant industry and even the general retailing industry where customers' needs are prioritized.

With integration businesses can collect rich customer data from customers' ordering activities. This information may include customer product preferences, store references, time to purchase, and transaction details, which can be translated into valuable insights for the supply chain operations. Rich customer data can guide company decisions about when, where, and how often to send what supplies, what most in-demand products or services could be for advertising at different locations, and what expectations the company should have about its products and service performance. Such integration makes a powerful tool for businesses to understand customers' needs and facilitate effective decision-making on resource allocation.

CRM and ERP systems have also been integrated via smooth data transfer, exchange, and consistent information sharing between both systems. An example of ERP and CRM integration is how SAP (ERP) and Salesforce (CRM) are able to seamlessly pass data between each other. The integration facilitates the transparent end-to-end visibility of business processes. Business logistics, sales, customer support, and customer feedback allow the business to have all the aggregate information it needs to improve operational efficiency, eliminate data duplication, help promote employee collaboration, and facilitate sustainable business relationships.

Although we have seen CRM systems integrated with SCM and ERP systems via EDI, integration via EDI may need encoding and decoding or human coders to translate document information. Companies, especially those with complex supply chain networks and business activities, are struggling with materializing more seamless integration of SCM and CRM systems. The seamless SCM-CRM system collects comprehensive, detailed, and up-to-date data to facilitate better decision-making with faster analysis and automated predictions. With better decision-making, businesses are able to gain competitive advantages. The market need for such integration has been evident; customers, suppliers, and even employees are expecting easier-to-use, transparent operation platforms to use at work (Chorafas, 2001).

There is a need for the seamless integration of front-office (CRM) and back-office (SCM) databases through Internet-based technologies. Although companies may be willing to implement such integration, it can be time-consuming and costly in terms of initial financial investment and technological expenditure.

## 5.2 CRM Outsourcing

One major restriction on CRM practices in the supply chain concerns the diversity of the supply network participants. The diversity among these participants is both physical and psychological. First, with the GVC, suppliers, manufacturers, wholesalers, retailers, and customers are located in different countries. While geographical and time differences can be resolved by virtual meetings and flexible working arrangements, the language and cultural barriers may lead to difficulties in the supply chain process, especially when there is a problem to solve.

Current solutions require all supply chain participants to either know one unified language such as English, and all parties should be able to meet at a unified time. Or, the supply chain participants can outsource their CRM tasks to a middleman who has a good understanding of the business and know the language well enough to handle the communication.

There are pros and cons in terms of outsourcing CRM work to a third party. The pros are capable outsource partners should be able to improve the CRM efficiency and quality of customer relations among supply chain participants. These improvements should then lead to the reduction of expenditures, improved efficiency of the supply chain process, enhancement of customer satisfaction and loyalty, and increased sales.

There are also “trust” concerns about outsourcing. For example, a third-party outsourcing partner may not be able to understand the business as thoroughly as the company wants (Gray, 2021). Therefore, the outsourcing partner may not be willing or able to perform the detailed requirements or follow the organizational hierarchy and policy. This may ruin the overall CRM performance from the beginning. Also, in the field of CRM, a variety of efficient and useful CRM tools are available for selection. But not all tools are compatible with the current supply chain of the hiring company. Typically, third-party outsourcing partners would like to select a minimum number of CRM tools to lower their own operating costs, but the CRM tools of their choice may not be ideal for the specific company that requires their service.

Finally, CRM tasks involve a high volume of communications with customers and financials, which could induce threats to a company’s information confidentiality and privacy due to concerns about outsourcing employee moral standards (Cai et al., 2021). The trust issues may hinder the performance and collaboration with the third-party outsourcing partner and, in turn, hurt business performance. Introducing blockchain-based SCM-CRM systems could help with a high level of transparency, traceability, and trust in supply chain operations (Cai et al., 2021).

## 5.3 Automation

SCM participants may choose automated CRM software for more effective and efficient CRM practices (Kim et al., 2003). Automation may be a solution to problems caused by outsourcing while simultaneously providing benefits.

Automated CRM systems should be able to automatically enter relevant data to reduce employee data entry times. It has been said that a salesperson spends 17% of their working hours a day on data entry and cleaning (IRC Sales Solutions, 2020). Automated CRM systems are a huge time-saver in this respect. At the same time, automatically captured data from customer-end profiles, customer transaction histories, order statuses, and customer feedback are more accurate, thereby avoiding human data entry mistakes.

Automated CRM systems can also set up personalized email sequences for business communications. AI-based CRM systems are able to form personal email sequences based on their learning of data stored in the system; such data could be customer profile information, transaction records, or communication histories. The system may be connected to a translation platform to help translate the content automatically. A simplified example is Gmail's automatic nudge and reply functions. In this way, a personalized and customized email conversation sequence can be generated with minimum input from the employee's end.

Automated CRM systems can also sync customer interactions across departments and business partners automatically to allow for smooth inter-supply chain process collaborations. After the CRM system automatically logs phone calls and email interactions each time a customer is engaged, employees across different relevant departments and supply chain participants should get up-to-date information on their end. Moreover, CRM systems can learn to assign tasks to different parties according to a series of preset rules and priorities.

Automated CRM systems, such as chatbot software, should also facilitate customer service. Well-trained chatbots can engage with customers about service-related issues. Questions about operation hours, location, and shipping status can be automatically answered by the chatbot, and human customer service agents can intervene when there is an open-ended question without a fixed answer. Of course, the information obtained and provided should be automatically logged into the CRM system for greater visibility into service-related inquiries.

The adoption of automated CRM systems relaxes the restraints imposed on CRM applications within the supply chain network by reducing the business-customer time-lapse, language barriers, and risks associated with hiring outsourcing partners.

# 6 Summary and Conclusion

With changing environmental factors including the expansion of GVC, the emergence of e-commerce, and the rapid advancement of technovation, the field of SCM calls for more consumer-oriented practices, especially for business-to-CRM. To develop a successful CRM under GVC, the supply chain participants need to pay attention to customer needs and demands and employ integrated SCM-CRM strategies to facilitate customer satisfaction and cultivate customer loyalty.

The supply chain field has been focusing on efficiency and cost-effectiveness, and the customer-centered orientation has been relatively new to the field. In this chapter, we reconceptualize the definition of "customers" as all supply chain participants in the whole supply chain process regardless of their relative positions. In turn, following the marketing literature, we redefine the customer-centered view to the supply chain stakeholders' view, which means all supply chain participants along the supply chain network should be equally valued. Therefore, the SCM-CRM strategy should be providing transparent and timely information to all relevant supply chain participants.

We further expanded the discussion of SCM-CRM strategies adopted among different supply chain participants, including upstream customers, which are the suppliers; downstream customers, which are the customers; and the carriers. Among those participants, we recognize and identify different types of participants according to business scale and SCM practice patterns. Via such categorization, we were able to present different SCM-CRM practices. Last but not least, we proposed three future directions on SCM-CRM strategy in terms of seamless integration, blockchain-based outsourcing, and automation for firms and researchers to explore for future SCM practices.

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# Managing Customer Order Decoupling Points in Supply Chains

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## Contents




**Abstract**

The concept of a customer order decoupling point (CODP) has been discussed since 1984. The CODP refers to the point in the supply chain at which a product is linked to a specific customer. Consequently, make to stock (MTS), assemble to order (ATO), make to order (MTO), purchase and make to order (PMTO), and



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engineer to order (ETO) all refer to different positions of the CODP. The CODP separates the operations downstream of the CODP that are based on actual customer orders from those upstream that are forecast driven. We discuss the strategic importance of the CODP and the characteristics of upstream versus downstream operations. The CODP concept is applicable to all industries, and we illustrate it with examples from the food processing and service industries. We discuss how the CODP relates to bottlenecks, the product life cycle, leagility, mass customization, modular product designs, and postponement. With respect to the differentiating features of upstream versus downstream, the CODP is an important contingency variable for many operations and supply chain management areas, including performance measurement. We conclude this chapter with a discussion on theoretical perspectives.

**Keywords**

Contingency · Customer order · Decoupling · Leagility · Mass customization · Modular design · Postponement

## 1 Introduction

The positioning of the customer order decoupling point (CODP) in the supply chain is a strategic decision. The CODP refers to the point in the supply chain at which a product becomes earmarked for a particular customer. It should be addressed when developing and introducing new products and is strongly related to the product offering – in particular, decisions on product volume and variety, such as the level of product standardization or customization. In addition, the CODP decision strategically dictates how products are delivered to the market or to specific customers and strongly influences delivery lead times and reliability. A CODP at the finished goods inventory is typically linked to offering standardized products in high volumes, while a CODP further upstream the supply chain allows for larger product variety and more customization – typically in small volumes or even unique products. The concepts of competitive priorities, order winners, and qualifiers also relate to the CODP. Cost competition generally implies a late, more downstream CODP, while competing on product design and flexibility implies an early, more upstream CODP. Given this strategic role of the CODP as well as the implication for cost and efficiency, the concept of the CODP can and should be addressed explicitly in operations strategy decision-making.

The characteristics of the manufacturing process may constrain the positioning of the CODP by limiting the position of the CODP to particular stages along the supply chain. The fewer stages along the supply chain, the fewer options there are when deciding on where to position the CODP. This is often the case in process industries, while industries with many intermittent stages have more degrees of freedom to decide on the specific position of the CODP. If a new product is not constrained by existing manufacturing processes, the choice of an appropriate manufacturing process and supply chain can be discussed via the product–process matrix by Hayes and Wheelwright (1979) and the product–supply chain matrix by Fisher (1997), respectively.

A late CODP offering few standardized products in large volumes would typically require a line or continuous process and a physically efficient or lean supply chain. An early CODP offering a broad product range with many opportunities for customization tends to lead to a job shop or flow shop with a market-responsive or agile supply chain. Thus, the CODP has strong implications for the choices in designing manufacturing processes and supply chains.

## 1.1 Defining CODP

There are five basic options for positioning the CODP: make to stock (MTS), assemble to order (ATO), make to order (MTO), purchase and make to order (PMTO), and engineer to order (ETO). The differences depend on which types of operations activities remain after the receipt of the customer order.

Figure 1 illustrates the position of the CODP for these five basic operation types and the fact that the operations downstream of the CODP are customer order driven by definition, and the operations upstream of the CODP are forecast driven. The figure also shows that the CODP coincides with a stock point and, by definition, the last stock point along the supply chain. Consequently, the CODP is the most important stock point in the entire supply chain that is controlled by the firm since the customer service depends heavily on the availability of the correct set and number of items there.

If the products are MTS, the only activity that remains after the receipt of the order is the delivery to the customer from the finished goods inventory. Such inventory can be held at the plant or in a distribution center in the distribution system. All operations activities upstream of the CODP – that is, engineering, purchasing, parts manufacturing, and assembly – are carried out based on a forecast. This fact emphasizes the importance of having only those products in stock for

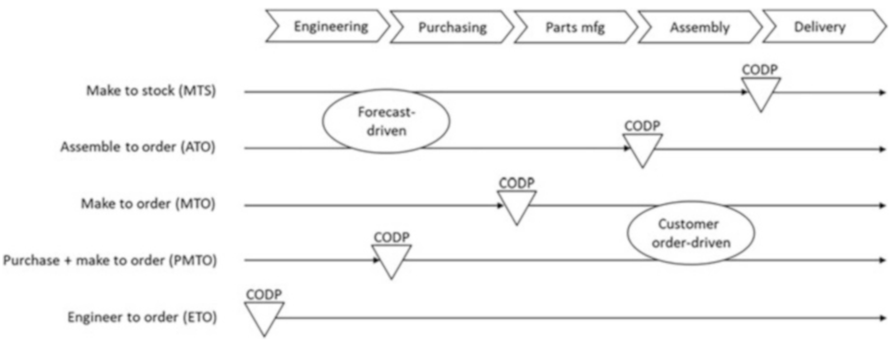


**Fig. 1** Illustration of the five basic CODP types

which forecasting is manageable. The forecasting of products with high levels of demand uncertainty usually leads to the insight that (too) large safety stocks are required and that the CODP for such products should be positioned further upstream.

The second category, ATO, includes approaches that resemble ATO, such as "configure to order" and "finish to order." The core idea is that all parts needed for the final assembly operations are available in stock and that the remaining operations can be carried out within a reasonably stable lead time. Typically, ATO also includes internal parts manufacturing upstream the CODP such that semifinished goods are made to stock. When the customer order is received, the corresponding parts are picked from the CODP stock point to the assembly operations. The number of parts held in the CODP stock point is typically much fewer than the number of potential finished goods. In terms of forecasting, it is easier to forecast the demand for a few parts than for many potential finished goods. Still, a large variety of products can be delivered.

In an MTO situation, all internal manufacturing is carried out after the receipt of the customer order, and the stock consists only of basic, common raw materials and purchase components. This situation implies that the product specification decided by the customer affects the very first operation, for example, by selecting specific materials and product dimensions or requesting specific product customization. However, in pure MTO, the customer is limited to the materials and components that are available in the raw materials inventory. The upside of such a limitation is that the firm has experience working with these materials and components and should be able to have a good grasp of the cumulative lead time that is required for a particular customer order.

The next position, PMTO, includes purchasing. Even if the basic product design is given (as in MTO), the customer may have a choice of selecting specific options, such as fabrics or colors, that are not available in the raw materials inventory (opposite to MTO) as essentially demand for a specific type is impossible to forecast and usually very rare. In comparison to pure MTO, lead times will be longer since some materials are bought from suppliers directly for the customer order. The comparative advantage is that a larger variety of options can be offered to the customer. An example is high-end furniture, where the cover fabric is purchased for an individual customer order.

Finally, ETO implies that the customer can influence the entire product design. Typically, a number of items are purchased to order. In addition, parts manufacturing and assembly operations remain. Often, the larger part of the lead time will be the (joint) specification and subsequent engineering of the product. Overall, all operations are carried out while the customer is waiting, which makes the agreed-upon delivery date a key goal. To remain competitive, it is of the utmost importance to monitor the cumulative lead time, which could be part of the order-winning criteria along with the ability to translate the customer requirements into a design.

The following key observations can be made:

- Delivery speed and reliability are dependent upon two key aspects: having the right mix and number of items at the CODP stock point when the customer order is received and having sufficient capacity to maintain stable lead times in all remaining activities. Usually, this situation requires some overcapacity on average in the stages downstream of the CODP to be able to deal with fluctuating levels of customer orders as well as the ability to schedule these customer-driven activities properly.

- The role of the operations upstream of the CODP is primarily to replenish the CODP stock point to maintain the right mix and number of items – at all times. For this part of the process, capacity can be planned and aligned well with forecasting so that capacity can, in general, be closely fitted to the average demand with very limited levels of overcapacity.
- The two aspects above do not depend on where the CODP is positioned; they are equally important for all CODP types. Still, it is important to realize that the scheduling complexity is generally much greater for ETO and MTO than for MTS because uncertainty increases, and more stages have to be scheduled for a longer period of time. For MTS, the complexity relates mainly to distribution activities, while ETO and MTO include some or many engineering and operations stages.
- These observations reinforce the fact that the CODP is the most important stock point controlled by the firm in the entire supply chain and hence is of strategic concern for the business.

## 2 Background

### 2.1 CODP History

The origin of the concept of CODPs dates back to 1984. The first article on the topic appeared in the *Harvard Business Review* in 1984, authored by Graham Sharman, a management consultant at McKinsey. He referred to the CODP as the "order penetration point" and highlighted its importance: "Although the possible combinations of ways to manage the flow of materials are virtually infinite, the one key variable in every logistics configuration is the point at which a product becomes earmarked for a particular customer. Downstream of this order penetration (OP) point, customer orders drive the systems that control materials flow; upstream, forecast and plans do the driving" (Sharman, 1984, p. 75).

In 1985, a book in Dutch appeared, co-edited by Sjoerd Hoekstra and Jac Romme. At the time, they were internal consultants in the Organization and Efficiency Department at Philips in Eindhoven, the Netherlands. The book was later published in the English language (see Hoekstra & Romme, 1992). They defined the "decoupling point" (DP) and argued that it "is one of the most important of business decisions; it forms the basis for the whole logistic organization and for the planning and control of the goods flow" (Hoekstra & Romme, 1992, p. 8). The book includes three case studies, on medical systems, paging systems, and computer systems, discussing various types of improvement initiatives focusing on DPs.

Also in 1985, a Swedish book coauthored by Jan Olhager and Birger Rapp included discussions on CODP. The topic of the book was computer-based systems for manufacturing planning and control (MPC), emphasizing the need to first improve manufacturing operations before designing and implementing an MPC system. They discussed the differences between MTO and MTS operations and introduced the concept of a "customer order point" (COP) as a stock point in the material flow when the delivery lead-time requirements exceed the manufacturing lead time: "The manufacturing is divided into two stages. In the first stage, pure make to stock can be used. The operations lead-time in the second stage must be shorter than the required delivery lead time, in order to enable make-to-order operations" (Olhager & Rapp, 1985, p. 35; translation by the authors).

## 2.2 Characteristics of Upstream Versus Downstream Operations

Following the introduction of the concept of CODP in 1984–1985, research has successively added perspectives that relate to the differences between upstream MTS-type activities and downstream MTO-type activities. Examples include supply chain information system (Giesberts & Van der Tang, 1992; Olhager, 2010), operations strategy (Olhager, 2003), manufacturing focus (Hallgren & Olhager, 2006), capacity planning and scheduling (Soman et al., 2007), multiple CODPs (Sun et al., 2008; Verdouw et al., 2008), and stock-keeping unit classification (Van Kampen & Van Donk, 2014). Moreover, specific elements have also been further explored; for example, more detailed work has been done related to engineer-to-order systems (e.g., Dekkers, 2006; Gosling & Naim, 2009; Cannas & Gosling, 2021), stressing the different options and problems within organizations with that type of CODP. Table 1 summarizes some key characteristics of upstream versus downstream operations, illustrating that these two areas of the supply chain are distinctly different.

**Table 1** Some key distinguishing characteristics for upstream and downstream operations

| Characteristic | Upstream of the CODP | Downstream of the CODP |
|---|---|---|
| Demand per individual item | High | Low |
| Product range | Narrow | Broad |
| Demand uncertainty | Sufficiently low to allow for holding inventory at the CODP stock point | High |
| Typical order winners | Price | Flexibility, delivery speed |
| Typical order qualifiers | Quality, delivery reliability | Quality, delivery reliability |
| Typical process | Dedicated equipment | General equipment |
| Manufacturing task | Provide low-cost manufacturing<br>Replenish the CODP stock point to maintain high fill rate | Manufacture to customer specification<br>Achieve short and reliable lead times |
| Improvement initiatives | Cost reduction | Lead time reduction |

## 2.3 DPs in the Supply Chain

From a supply chain perspective, two interesting observations can be made. First, the supply chain operations reference (SCOR) model (APICS, 2017) takes the CODP explicitly into account. The three basic processes – source, make, and deliver – in the SCOR model are differentiated for MTS, MTO, and ETO products. Thus, the SCOR model acknowledges that the position of the CODP has an impact on the design of operations processes for sourcing, manufacturing, and distribution.

Second, a distinction can be made between "customer order decoupling point" and the general concept of a "decoupling point" (Olhager, 2019). The purpose of a DP in general is to decouple two successive stages along a supply chain to allow the two stages to operate independently of each other. Such decoupling is typically done by holding inventory between the two stages that can absorb differences between downstream demand and upstream supply.

There may be multiple DPs along the supply chain, but only one CODP exists in a given supply chain from the perspective of the focal plant. For example, in an MTS situation, the focal plant has the CODP positioned at the finished goods inventory. There may be additional DPs in the internal supply chain upstream of the CODP, such as raw materials inventory and semifinished goods inventory. These may serve to reduce the replenishment lead time for a downstream stock point to maintain manufacturing efficiencies and to allow for economic purchasing quantities. The role of such a DP can be related to the basic inventory types, such as cycle stock (due to order quantities), safety stock (uncertainties in demand and replenishment lead times), smoothing stock (due to process stage imbalances), and seasonal stock (building up inventory before high season); see, for example, standard textbooks on operations and supply chain management. Taking a multi-actor supply chain perspective, most actors tend to have at least one internal stock point that can serve to decouple their operations from those of suppliers and/or customers (Olhager, 2019).

Figure 2 illustrates the total product structure (bill-of-material) for end products, from the extrusion of raw material to the completion of an industrial or consumable good, with the lead time along the x-axis. Such a product structure illustrates the cumulative lead time along the various branches in the product tree and subsequently looks more like a network than a chain. The total product structure may well involve multiple actors along the different branches. All branches must be analyzed in terms of lead times to determine where the CODP should be positioned to align to the delivery lead-time requirements from the market. Olhager (2002) discuss some key differences between having multiple actors involved in the total product structure versus the case where a single firm governs the entire product structure.

Figure 2 illustrates four different CODP positions: pure MTS, pure MTO, and two alternative ATO options. The market requirements dictate where the plausible positions are. If the market demands immediate deliveries, the MTS option is required, and the CODP is at the finished goods inventory of item A1. At the other end, if the market accepts a delivery lead time that extends beyond the cumulative lead time, then the MTO option is possible, and the CODP can be set at the extrusion of raw materials. The two ATO options refer to market requirements of a delivery

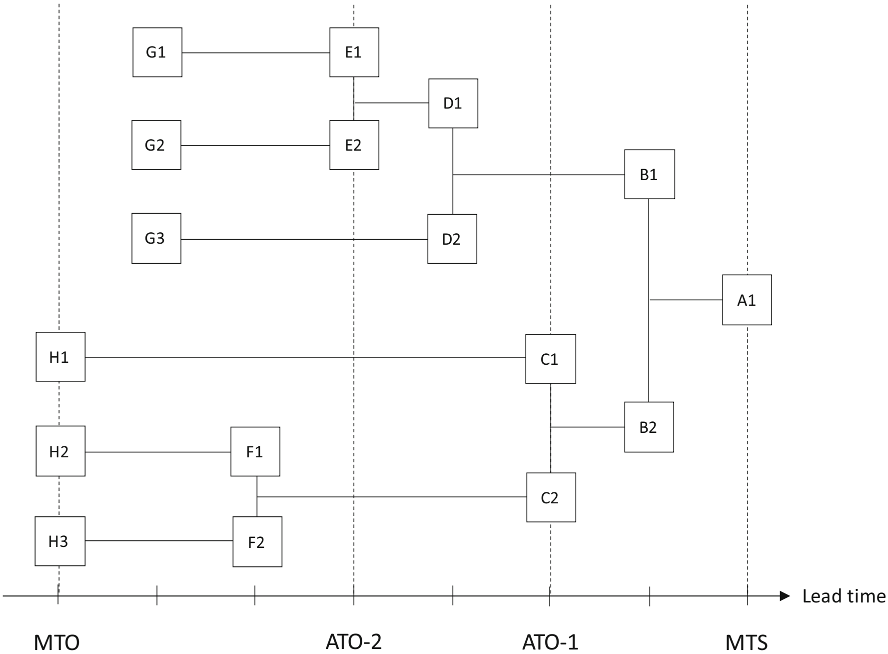


**Fig. 2** Alternative CODP positions along the cumulative lead time

lead time of two and four periods, respectively. In order to maintain a two-period delivery lead time in the ATO-1 situation, it is necessary to keep B1, C1, and C2 in inventory to have them available when the customer order arrives. Then, B2 is first assembled from C1 and C2, and then A1 is assembled from B1 and B2. If some slack time is needed to maintain short and reliable delivery lead times, the option to keep B1 and B2 in inventory may be preferable. In the ATO-2 situation, a few more items are needed in stock to be able to deliver within four periods: E1, E2, and D2, besides C1 and C2, assuming that the plant would want to perform as many operations as possible after the receipt of the customer order.

## 3 CODP in Different Industries

The field of operations and supply chain management has developed many generic insights that can be applied to different situations. Often, such insights implicitly refer to manufacturing industries that produce discrete products. Over the years, research has started to acknowledge that it might be important to highlight differences between different industries and acknowledge the importance of understanding the effects of industry- or sector-specific characteristics. In general, Sousa and Voss (2008) have shown that context is important when implementing specific operations management tools and practices, such as lean or quality management.

Building on that general comment, below we investigate two specific important industries – food processing (being an important part of process industries; see, e.g., Dennis & Meredith, 2000) and service industries, which both form important parts of most modern economies.

## 3.1 Food Processing Industries

The food processing industry is typically seen as a specific part of the process industry that can be characterized as processing natural raw materials that will be used to feed humans (similar to the processing of animal feed). Van Donk (2001), building on Van Wezel and Van Donk (1996), compiled a number of characteristics for food processing companies, which are listed in Table 2.

These characteristics can be used to adequately analyze specific situations and describe them, acknowledging that in most real-life situations, a selection will be more visibly present or be present at a high level. Based on these characteristics, Van Donk (2001) derived a number of general consequences for the food processing industry regarding the location of the CODP, as depicted in Table 3. Table 3 considers market and process characteristics and the downstream or upstream effect they have on the location of the CODP. For example, the high risk of obsolete end products in many food processing companies might lead to stockkeeping of raw materials rather than of final products, which is depicted as an upstream effect (further away from the customer). Oppositely, the lack of production control in terms of yield and quality will force food companies in general to produce more to

**Table 2** Characteristics of food processing companies. (Based on Van Donk, 2001, p. 300)

| Aspect | Characteristics |
|---|---|
| Plant | Expensive and single-purpose capacity coupled with small product variety and high volumes<br>The factory typically has a flow shop-oriented design<br>There are long (and potentially sequence dependent) set-up times between different product types |
| Product | The nature and source of raw materials in the food processing industry often implies variable supply, quality, and price due to unstable yields at farmers<br>The products are measured in units of volume or weight (as opposed to discrete manufacturing)<br>Raw materials, semi-manufactured products, and end products are perishable |
| Production process | Processes have variable yields and processing times<br>At least one of the processes deals with homogeneous products<br>The processing stages are not labor intensive<br>Production rate is mainly determined by capacity<br>Food industries have a divergent product structure, especially in the packaging stage<br>Factories that produce consumer goods can have an extensive, labor-intensive packaging phase<br>Due to uncertainty in the pricing, quality, and supply of raw material, several recipes are available for a product |

**Table 3** Process and market characteristics in the food processing industry and their influence on the CODP. (Based on Van Donk, 2001)

| Process and market characteristics | Presence/value in food processing | Effect on CODP position |
|---|---|---|
| Lead times and costs | Relevant set-up times | More downstream |
| Controllability | Low (sometimes) | More downstream |
| Value added and costs of stock holding | Unclear (in general) | – |
| Risk of obsolescence | High | More upstream |
| Delivery reliability | High | More downstream |
| Delivery time | Short | More downstream |
| Predictability of demand | Unpredictable | More upstream through information sharing |
| Specificity of demand | Large variety of end products (with common recipes) | More upstream possibilities |

stock, which is a downstream effect on the CODP. Van Donk (2001) applied the above general understanding of the food processing industry in a case study to illustrate how managers can use these insights in making CODP location decisions in the food processing industry.

Food processing also faces the increasing demands of their customers (often large retail chains), which influence the above characteristics, and even more, these characteristics might differ across products. For example, food processing companies produce their own regular brands MTS, while tenders of irregular orders (e.g., for export or specific seasonal products) tend to use an MTO approach. MTO is often seen as untypical for food processing companies, and they may have difficulty in deciding to accept such orders. Moreover, it is far from trivial to combine both MTS and MTO products in one production system. Soman, Van Donk, and Gaalman (2004) developed a hierarchical model that provides a framework for all decisions to be made in deciding on MTO or MTS and the joint decisions needed when producing both in the same system.

Figure 3 shows that based on the general characteristics as discussed above, initial decisions need to be made at the strategic level to decide on either MTO or MTS for each product. Based on aggregate-level information, an initial partitioning can be made into MTO and MTS along with service levels and lead times. This partitioning will set the stage for the coordination of capacity that determines order acceptance, production volumes, and lot sizing, which are in turn the input for the scheduling level where sequencing takes place, based on actual orders and demand. For each stage in the framework, actual realization as well as changes in parameters and plans at lower planning levels will be fed back to the higher stages. Such feedback enables that plans remain feasible and are adapted to what is possible at lower levels.

The specificities of the food processing industry are also highlighted in Akkerman, Van Der Meer, and Van Donk (2010), who showed that some food processing industries might even have a fundamentally different type of CODP: *mix to order*. While this type resembles ATO, it is different because for many food processing

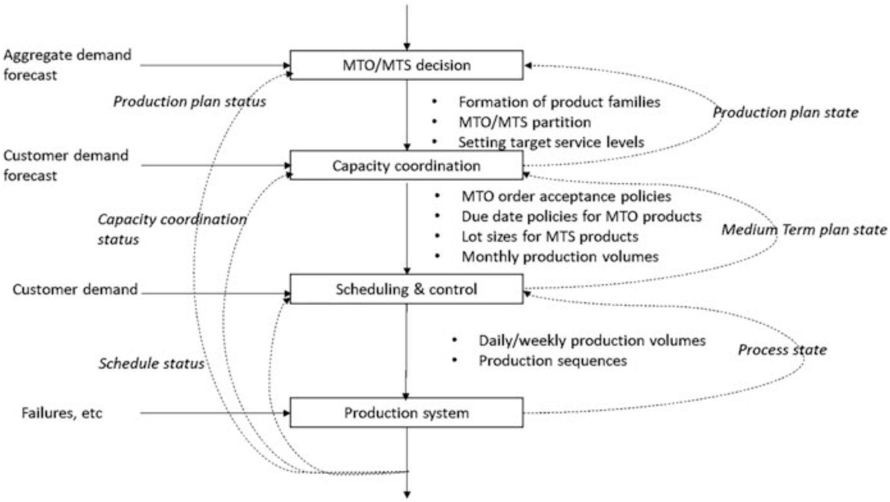


**Fig. 3** Combined MTO–MTS production planning framework. (Based on Soman et al., 2004)

companies, there are options to use different recipes to arrive at specific end products. So, rather than having known parts or subsystems, determining the different recipes and mixing them into final products provides different CODP decisions in some food processing industries, such as a flour mill. The work of Akkerman et al. (2010) provides quantitative models that support managerial decision-making to balance the costs and capacities of different stages. Another option – not uncommon in the food processing industries – is to combine different CODPs in one production system (cf. Fig. 3). Such hybrid systems have typically been treated by mathematical modelling and/or simulation tools; see Peeters and Van Ooijen (2020) for a taxonomic review.

## 3.2 Service Industries

Generally, service industries are characterized as different from manufacturing since some of the production and delivery of the services takes place simultaneously (Chase & Apte, 2007; Johnston & Clark, 2008). This simultaneity implies that, in general, services cannot be stored in anticipation of customer orders since there is direct customer involvement in some part of the process.

Similar to what was discussed above, the direct involvement of the customer might have both benefits and disadvantages. On one hand, direct involvement might increase customization, selling additional or complementary services, and flexibility in the offering of the service; but, as a disadvantage, it might incur higher costs, increase uncertainty and variation, and make planning and the capacity utilization of people and equipment more difficult. Not all activities need to be executed in the direct presence of the customer for most services, and consequently, companies can decouple *front-office* activities from *back-office* activities. Front-office activities are executed in direct contact with the customer, while back-office activities do not require direct contact and can thus be executed more efficiently and at lower costs. Companies can make different choices to trade-off costs against increased customization and offering a larger variety. Ongoing developments in information technology have altered these trade-offs and will do so in the future. We describe a three-step process, based on three concerns that require a decision for the design of front-office versus back-office operations, building on the ideas in Zomerdijk and De Vries (2007).

A first concern is the decision on how much customer contact is required. Following Chase and Tansik (1983), high levels of customer contact come with less efficiency, while the low-contact parts of a service enable efficiency, the allocation of dedicated resources, and the improvement of specific skills. To be more efficient, organizations should aim to increase the amount of noncontact activities, as this will also, in line with the activities upstream of the CODP, enable the better planning of activities and a high utilization of resources. Customer-driven or high-contact activities are less controllable for an organization.

It may be competitively advantageous to locate service core activities in the back office without customer involvement or contact. The CODP between back-office and front-office activities can include information or materials, depending upon the type of operations. For example, in fast-food restaurants, the “modules” of the “menus” typically are kept as semifinished goods inventory between the cooking area and the customer service area to facilitate short delivery lead times. Similarly, requests or filled out forms – such as information necessary to request a passport – are “stored” to be further processed in the back office such as actually producing the passport.

A second concern is the presence or lack of a connection between the front office and back office, also referred to as the decoupling decision. While the distinction between high- and low-contact activities might be used to decouple these activities organizationally and have distinct groups of people performing them, Metters and Vargas (2000) argue that more options are present. Decoupling might enable the separation of activities and locate them at different places, which might relate to lower costs but also might improve quality or speed. However, the coupling of the two types of activities is necessary if employees perform both contact and non-contact activities, combining flexibility and utilization.

A third concern is the grouping of personnel. Zomerdijk and De Vries (2007) argue that organizations need to decide on how front-office and back-office employees are grouped together. Often, it is assumed that the two previous decisions will result in separate departments. However, the back office and front office can be organized in one organizational unit.

Table 4 provides a summary of the three main issues in service organizations regarding coupling and decoupling activities in the service delivery process. While the essence of the CODP is similar in the service industry, that is, to separate the directly customer order-driven activities from the activities that can be planned, we also see that the two stages, depending on the choices that can be made regarding coupling and grouping, are less strictly separated as there is no physical inventory.

**Table 4** Decoupling in the service industry: alternative options, trade-offs, concerns, and consequences for three important decision dimensions. (Based on Zomerdijk & De Vries, 2007, p. 111)

| Decision | Alternatives, trade-offs, concerns, and consequences | |
|---|---|---|
| Customer contact | *Front office*<br>Cross-selling<br>Customizing or personalizing services | *Back office*<br>Efficiency |
| (De-)coupling | *Coupled*<br>Flexibility and responsiveness<br>Front-office utilization<br>Broad tasks | *Decoupled*<br>Employing experts<br>Planned back-office activities<br>Specialization |
| Grouping | *Market grouping logic*<br>Workflow coordination | *Functional grouping logic*<br>Economies of scale<br>Cross fertilization<br>Specialization and uniformity |

This is specifically true if the service contains more intangible rather than tangible parts. Table 4 provides a summary of the options for each area and some of their consequences. Following Zomerdijk and De Vries (2007), organizations can use the table to decide on each of the three areas, as there is no direct logical coherent choice or alignment.

## 4 Current Concerns

Some aspects provide interesting perspectives on CODP, such as bottlenecks, the product life cycle, and other concepts that can be related to CODP – leagility, mass customization, modular design, and postponement.

### 4.1 CODP and Bottlenecks

Should the bottleneck be positioned upstream or downstream of the CODP? The theory of constraints (Goldratt, 1990; Blackstone, 2001) fundamentally proposes that the bottleneck should be downstream to ascertain that it only works on actual customer orders and produces nothing to forecast. However, since the bottleneck should be fully utilized, it also determines the capacity for the finishing stages of production. By definition, non-bottleneck resources have overcapacity. Hence, the bottleneck dictates the production volumes for all operations downstream of the CODP and thus the production output of the entire production system.

Having the bottleneck upstream of the CODP instead allows the plant to control the utilization of the bottleneck at nearly 100% at all times. If the capacity of the bottleneck is aligned with the rate of the replenishment process of the CODP stock point, this process should be under control. The CODP stock point can be replenished at the same rate that the bottleneck resource is capable of. All processing stages downstream of the CODP have excess capacity, that is, higher capacity levels than the upstream bottleneck, which should imply that the lead time for the operations downstream of the CODP is stable.

Our experience is that the vast majority of practitioners prefer to have the bottleneck upstream of the CODP, arguing that control over the utilization of the bottleneck is key and that they do not want to have a constraining resource in the last part of the internal supply chain. Only a few practitioners prefer the bottleneck downstream of the CODP, such that the bottleneck only processes real customer orders, which they feel is better aligned with the core ideas of utilizing a bottleneck. The decisive question is whether the CODP or the bottleneck is the most important concept in this relationship.

The relationship between the CODP and bottleneck positions has implications for master planning (Olhager & Wikner, 1998). Since the CODP is related to the material flow and the bottleneck to capacity, the combination of the material and capacity perspectives provides interesting perspectives on how to conduct master planning. The fundamental approach to master planning is to focus on the items exhibiting independent demand, that is, finished goods for MTS, semifinished goods for ATO, and raw materials for MTO, PMTO, and ETO. In addition, tight bottleneck control may require an additional master planning level for the bottleneck to be able to control capacity utilization.

### 4.2 CODP Across the Product Life Cycle

Product demand volumes change along the four stages of the product life cycle – introduction, growth, maturity, and decline. In the introduction phase, demand volumes are low and demand uncertainty is high, which suggests that products should be MTO or even ETO. As demand volumes increase, demand uncertainty is typically reduced, leading to a successively lower relative demand variability (measured in terms of the coefficient of variation [CoV], calculated as the standard deviation divided by average demand). At the maturity stage, the product demand volumes are typically high, and the demand variability is low, which may allow for an MTS approach. The CoV is a measure that can be used for deciding on whether the relative demand variability is sufficiently small for holding the product in finished goods inventory. The specialty chemicals firm Rohm and Haas selected a value of CoV equal to 0.52 as the cut-off point between MTO and MTS policies (D'Alessandro & Baveja, 2000) using weekly data (i.e., the standard deviation of weekly demand divided by average weekly demand).

In the final decline stage, the CODP may well differ between situations, such as depending upon market requirements and the level of control of the end-of-life treatment by the focal firm. As with all CODP decisions, one should also realize that other factors play a role, such as the required delivery reliability and the costs of holding inventories and for lost sales. Companies might also be able to reduce forecast uncertainty by learning from earlier product introductions and gain a competitive advantage through shorter delivery times than others by using an MTS policy.

### 4.3 Relationship with Other Concepts

Leagility, mass customization, modular design, and postponement are concepts that are relevant to operations and supply chain management and that can be related to CODP, such as in terms of similarities and differences. In practice, a firm may well use one or more of these perspectives to guide operations and supply chain development as a complement to the CODP concept.

#### CODP and Leagility

The concept of leagility distinguishes between lean and agile supply chains and uses the CODP explicitly as the divider between lean and agile operations in manufacturing or supply chains (Naylor et al., 1999). Naylor et al. (1999) considered leanness and agility to be paradigmatically different and contrasted the two concepts: (i) lean requires the elimination of all forms of waste, including time, and it requires the implementation of a level schedule, while (ii) agile requires the use of market knowledge and a virtual corporation to exploit profitable opportunities in a volatile marketplace.

The distinction between lean and agile has been tested empirically concerning drivers, operational characteristics, and performance outcomes (Narasimhan et al., 2006; Hallgren & Olhager, 2009). Hallgren and Olhager (2009) found that leanness is associated with a cost leadership strategy and cost performance, while agility is associated with a differentiation strategy and flexibility performance. In a leagile system, a lean supply chain should be applied upstream of the CODP, while an agile supply chain would be more suitable for downstream operations (Naylor et al., 1999).

#### CODP and Mass Customization

Mass customization is concerned with catering to individual customer needs by producing customized products to a price as if the products were mass-produced (Pine, 1993). A key aspect is to be able to mix a variety of products in the same flow-oriented production system, such as an assembly line, to achieve economies of scale (Squire et al., 2006). There has to be some kind of similarity between the products that are produced in the same system, such as the platform concept in the car industry. As long as different car types share the same platform, they can be assembled one after the other on the same assembly line, even though the models and configurations may differ, specifically in the view of the customer.

Mass customization combines the customer focus of offering relevant customer-led variety and choice with the producer focus of operating a system at high utilization and high production volumes with economic efficiency. Jiao, Ma, and Tseng (2003) emphasize the reusability of both design and process capabilities, such as maximizing commonality in design, reusable tools, equipment, and expertise in manufacturing while providing diverse end products that can be enjoyed by different customers. Rudberg and Wikner (2004) added engineering resources to the CODP typology to take the features of mass customization environments into account and develop an order promising functionality for mass customizers. Referring to the

CODP concept, mass customization is applicable to MTO operations by adding the perspective of cost efficiency to the perspective of flexibility typically associated with MTO. Both perspectives are required in the associated assembly system to be able to mix customized products in a cost-efficient manner.

### CODP and Modular Design

In a modular product architecture, the finished good can be decomposed into separate modules. The customer can configure end products based on a selection of module combinations. Ulrich (1995) describes the modular approach in terms of a one-to-one mapping from functional elements to physical components, specific decoupled interfaces between components, and high independence between components. The principle of manufacturing a few different types of modules to stock and then combining a specific set of these for a particular customer order is fundamentally the same logic as the ATO approach.

Rather than forecasting a potentially infinite number of specific end product configurations, forecasts are made for the modules. In a well-designed modular system, the number of different types of modules is low, and the demand volume for individual modules is high. Thus, it is the module level that experiences independent demand, which also has implications for master planning, with a strong focus on the availability of modules, such that any potential end product can be built for the next customer order.

Combining economies of scale for the manufacturing of modules to the CODP stock point with offering the customer a broad range of customization opportunities creates an overall economic delivery of variety. Modular product architecture involves standard interfaces that allow for the outsourcing of significant portions of product design and manufacturing (Howard & Squire, 2007). If all modules are outsourced, that is, manufactured to forecast by strategic suppliers or contract manufacturers and not internally at the focal plant, the CODP changes from ATO to MTO (for the focal plant) since all internal operations – such as assembly – are carried out after the receipt of the customer order.

### CODP and Postponement

The concept of postponement has largely the same perspective as CODP (see Van Hoek, 2001, for a general introduction to and discussion of postponement). The main reason to postpone some operations is the absence of customer order information; in other words, to avoid speculation, the plant should wait for the customer order and then start manufacturing.

Pure (or full) postponement coincides with ETO, while pure speculation coincides with MTS, potentially to a stock point in the distribution system (Yang et al., 2004). Thus, the core idea with postponement is to delay the differentiation of products until a customer order is received (Wong et al., 2011). Product redesigns and the re-sequencing of operations activities have been proposed to maintain a generic product as long as possible and to shift the point of product differentiation to a late stage in the supply chain. Late product differentiation is generally considered better than early since it can increase the efficiency upstream of the CODP and the responsiveness downstream of the CODP. Postponement can also relate to timing or location (Pagh & Cooper, 1998), which might imply taking specific decisions later and/or to wait with shipments from a central location to a specific market. Such postponement of location can also be combined with postponing a final production step (e.g., specific packaging for a local market). While the concept of postponement acknowledges the need to partition the supply chain, this stream of literature does not focus on the characterizing features of upstream versus downstream.

## 5 Emergent Concerns and Future Directions

There are emergent concerns for which the CODP can possibly play a role in shedding new light and providing new perspectives and insights.

### 5.1 CODP as an Important Contingency Variable

Even though experienced supply chain managers understand that there is a fundamental difference between MTS and MTO operations, there is very little research that has identified such differences. Two notable exceptions are Olhager and Prajogo (2012) and Van Donk and Van Doorne (2016). Within supply chain management, supply chain integration has been seen as the most important aspect that both links internal functions and connects a firm with its supplier and customers (Van der Vaart & Van Donk, 2008). Hence, supply chain integration is usually defined as “the degree to which a manufacturer strategically collaborates with its SC partners and collaboratively manages intra- and inter-organizational processes, in order to achieve effective and efficient flows of products and services, information, money and decisions, to provide maximum value to the customer” (Flynn et al., 2010, p. 58). Following that description, it is mostly considered normal to look at internal integration (with a focus on the different functional areas such as purchasing, production, and sales) along with forward integration (with customers) and backward integration (with suppliers); see, for example, Frohlich and Westbrook (2001).

Olhager and Prajogo (2012) compare MTO and MTS companies employing a survey methodology. They found considerable differences in the effectiveness of different supply chain integration practices. For both types, the effect of upstream integration and lean-oriented practices (with more focus on internal and supply-related activities) is investigated. They found that companies that employ MTO benefit if they increase upstream integration efforts, while for MTS manufacturing companies, such efforts toward suppliers do not pay off. In contrast, lean-oriented practices increase performance for MTS companies but do not show effects for MTO companies. Van Donk and Van Doorne (2016) aimed to bring these insights one step further by conducting case studies that investigate the relation between the position of the CODP and the levels of the three types of integration. Their findings suggest that upstream integration is stressed the most for MTO. For ATO, internal integration gets the most attention, while downstream integration is the most important for MTS. This study, however, does not provide details on effectiveness.

Although these studies do not completely align, they hold an important message for researchers and managers as they show that the positioning of the CODP affects where and how efforts need to be taken – internally, with suppliers, and with customers. The logic is the same as indicated above, that is, the CODP separates the company into two parts that have different logics and uncertainties. The differentiating features need to be taken into account in order to run a business effectively and beneficially. For example, for an MTO company to deliver on time, much tuning with suppliers is needed once the order is confirmed, making downstream integration (from the CODP) very important while upstream is also monitored closely. Furthermore, a higher level of complexity (associated with MTO) requires higher levels of integration to improve supply chain performance, while higher levels of supply chain integration have been shown to not increase performance in less complex environments, such as MTS (Giménez et al., 2012). The CODP position also affects the approach to and effectiveness of resilience. Dittfeld, Van Donk and Van Huet (2022) show that MTO and MTS companies apply different strategies in dealing with disruptive events, specifically related to collaboration and redundancy.

## 5.2 Performance Measurement in the Presence of Multiple CODPs

Manufacturing firms tend to design one type of performance measurement system (PMS) that is applied to all types of operations and all types of plants, irrespective of their individual characteristics. This may work fine if all products share the same position in the CODP. The simplest form is when all operations along the internal supply chain are either MTS or made to customer order. Then, a single PMS is sufficient for all products and plant operations, tailored to the product characteristics, such as emphasizing the order winners and qualifiers; please see Table 1. However, designing a PMS for ATO operations is not straightforward. The issue here is to separate the upstream and downstream parts since these two parts require different systems. The upstream part should have an "MTS"-type PMS, while the downstream part should have an "MTO"-type PMS. Our experience is that even though practitioners acknowledge that this would be a valid approach (since they truly understand the difference between MTO and MTS), they feel that they do not have the resources or research support to implement such a PMS solution.

However, most plants tend to produce a mix of products with different demand volumes, variety characteristics, and consequently different CODPs. The challenge here lies in separating material flows – such as dividing the products into different plants-within-a plant or accepting that some parts of the internal supply chain will have a mix of products with different characteristics. However, the latter situation poses huge challenges.

If MTO products, competing on flexibility, are mixed with MTS products, competing on price, designing an appropriate PMS is far from trivial. First, mixing such products in one operations system will lead to deteriorating performance since none of the two product types will have an operations system that is tailored to its need. Second, should the PMS contain all types of performance indicators for MTO as well as MTS products, or a select subset of these? Irrespective of PMS design, the performance outcomes as identified by the PMS will be mediocre for both types of products. Thus, it is strongly advocated to first separate products with different CODPs into different physical entities and then tailor a PMS to each entity.

### 5.3 Is There a "Theory of Customer Order Decoupling Points"?

The above has provided different angles and approaches related to understanding CODP and the implications and linkages with many other important operations management and supply chain management concepts. The insights show the importance for any organization of understanding the location of the CODP and the reasons for locating it where it is, while also understanding the implications it has for strategic, tactical, and operational decisions. Important limitations for the application of specific approaches have also been highlighted. At the same time, the current state of knowledge around CODP is somewhat descriptive. Given a specific location, we can understand how the different elements have been working together to arrive at a specific organization's current CODP location. In other words, our current knowledge enables us to describe and understand situations and derive implications. However, the decisions leading to that location require trade-offs on a number of factors that are partly rather situational or specific.

To develop a "theory of CODP," it is necessary to be able to not only understand and describe but also to be able to predict what would be the appropriate location for the CODP given the specific mix of factors encountered in a situation. This situation would, among others, require more detailed and refined models and concepts that help to deal with the many trade-offs in deciding on the strategic position of the CODP as well as in helping to better understand the main characteristics of the specific situation. Related to such a development would mean developing tools and insights that can guide organizations when repositioning the CODP due to changes in demand, volume, capacity, or other issues (Van Kampen & Van Donk, 2014). Van Kampen and Van Donk (2014) showed that such changes require appropriate tuning with sales and marketing departments to be able to communicate the implications for customers. While shorter lead times will be welcomed, extending those will be harder. This result shows once again the strategic importance as well as the cross-functional importance of CODP decisions. Once researchers are able to come up with tools that can provide predictive analytics and aid in decision-making, and based on the firm foundations that are discussed in this chapter, a "theory of CODP" can potentially be developed.

## 6 Summary and Conclusion

The concept of the CODP has two main implications. First, it distinguishes between different positions of the CODP along the internal and external supply chains. The CODP position – ETO, PMTO, MTO, ATO, or MTS – is a strategic decision that must be made for all products or product groups. Second, it emphasizes that the operations upstream and downstream of CODP should be designed and managed in distinctly different ways. The operations upstream are fundamentally MTS in nature, while the operations downstream are correspondingly of an MTO character. The characterization of the segments along the supply chain as either MTS or MTO reflects the difference between forecast-driven and customer-order-driven operations, as illustrated in Fig. 1.

The CODP is acknowledged by experienced supply chain managers as an important and strategic concept and tool for designing and managing supply chains so as to align the operations and supply chain to the type of product. For example, a major UK lighting manufacturer developed four different strategies: MTO, ETO ("design and build-to-order"), ATO, and MTS (Childerhouse et al., 2002). In addition, Dell Corporation created four supply chains, each dedicated to a different customer segment: "build-to-stock" for online popular configurations, "build-to-order" for online low-volume configurations, "build-to-plan" for retail customers, and "build-to-specification" for corporate clients (Simchi-Levi et al., 2013). Both companies started with one strategy – MTO and build-to-order, respectively – before differentiating the supply chain concepts with respect to the characteristics of different products or customer segments. These examples verify that the CODP can be used as the core concept for differentiating operations and supply chains.

However, the CODP concept has not received as much attention in research even though there is strong agreement on some key characteristics of the upstream versus downstream parts (cf. Table 1). Still, there are opportunities for more research on the CODP. In conclusion, the aspects of the CODP as a contingency variable, PMSs, and a CODP theory deserve further research attention.

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# Product Innovation and Organization of the Supply Chain: Present Knowledge and Future Concerns

Paulo J. Gomes

## Contents



**Abstract**

Researchers and practitioners face an extraordinary challenge when integrating product innovation and supply chain configuration decisions. The purpose of this chapter is to deepen the understanding of issues related to the connection between product innovation and the organization of the supply chain. The chapter provides a reflection on the evolution of research on the topic, identifies key research gaps, and presents different research and practical concerns in the product innovation and supply chain management literature. Finally, the chapter discusses potential

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research directions at the intersection of product innovation and supply chain design and provides insights for managerial action.

**Keywords**

Product innovation · Product design · Supply chain management · System architecture · Modularity

## 1 Introduction

Product innovation has become the battlefield for global competition. Novel products or services are introduced in the market to meet user needs, linking competences relating to technologies and customers. Academic research has long been interested in the inquiry of innovation-to-organization problems: how organizations can sustain or thwart innovation through their ability to connect new products with organizational processes (Dougherty & Hardy, 1996). As organizations became more interconnected and work became decentralized, the importance of supply chain insight for successful product innovation gained more centrality in this inquiry.

Supply chain design drives the investment of capital into production and distribution capabilities. A product's supply chain decisions determine its success, since the costs of a new product's supply chain can potentially exceed its revenue. These supply chain costs are largely determined in the design stage of product innovation, hence can be evaluated across design alternatives. Supply chain decisions also impact product development (PD) performance such as speed to market and product quality, as they determine the critical path for launch dates and selection of suppliers, which influence the market share and revenue generation of new products.

Firms also introduce product innovations to improve supply chain performance as part of their supply chain innovations activities. Design for logistics practices and design for recycling, among other design principles, determine to a great extent supply chain performance across the entire product life cycle. These incremental product innovations can sustain product competitiveness, responding to market demands for lower prices or environmental-friendly products.

Other interdependences between product innovation and supply chain decisions are less obvious, for instance, poor management of product innovation portfolios can lead to product complexity, which will hurt supply chain performance. Changes in product architecture associated with product innovation can determine shifts in firm boundaries and the structure of supply chain networks. Thus, understanding the relationship between product innovation and supply chain management is critical.

Product innovation and supply chain management are research domains widely explored in the management literature. Early studies aimed at optimizing the supply chain after product design and development was completed. Recent studies recognize the mutual dependence between product and supply chain decision-making and have highlighted the importance of integrating these domains.

There has been increasing attention paid to the relationship between product characteristics and supply chain design (Fixson, 2005). Studies recognize the need for an approach that links product and supply chain design. Product design choices such as the number and type of components impact the number and location of suppliers, service level and delivery frequency (Fixson, 2005), turning product architecture into a vital aspect of supply chain management.

Several theoretical perspectives have been brought to bear on the connection between product innovation and supply chain organization, including information processing theory (Koufteros et al., 2007), knowledge-based view (Marion & Fixson, 2021), dependence theory (Silva et al., 2019a), resource dependency theory (Zacharia & Mentzer, 2007), transaction cost economics (Novak & Eppinger, 2001; Jacobides, 2005), complex adaptive systems (Baldwin & Clark, 2000), among others. In addition, there is a rich stream of research in operations research (OR) that focuses on the development of analytical models to investigate the connection between product design and supply chain decisions (Yao & Askin, 2019).

This chapter examines existing research on product innovation and supply chain organization in an effort to facilitate a more integrated approach to product design and supply chain management. Product innovation is considered as a firm capability to develop and adapt products to meet market needs and focus on the processes of opportunity recognition and product design and development.

The analysis of historical literature and managerial practices identified several interesting topics related to the impact of product innovation on supply chain design.

The chapter focuses on five topics: supplier involvement in product innovation, product modularization and architecture of supply chain systems, design for supply chain effectiveness, product innovation and supply chain agility, and product innovation and sustainable supply chains. A review of current concerns under each topic is provided. Furthermore, the chapter discusses potential research directions and provides insights for managers of innovation processes and supply chains.

The remainder of the chapter is organized as follows. The background section provides an analysis of the historical literature. Section 3 identifies concerns related to five major research themes at the intersection of product innovation and supply chain management: supplier involvement in product innovation, product modularization and architecture of supply chain systems, design for supply chain effectiveness, product innovation and supply chain agility, and product innovation and sustainable supply chains. Following that, in Sect. 4, emerging concerns and opportunities for further research are examined. Section 5 discusses management and practical issues related to the topic, highlighting future concerns and directions. The last section presents concluding remarks highlighting emerging concerns detailed in the previous sections.

## 2 Background: Supply Chain Configuration and Product Design

The key elements of supply chains are product (goods, services, information), supply chain operations, and agents. Upstream supply chains usually involve sourcing and inbound logistics. Downstream supply chains involve post-manufacturing activities such as distribution, retail, and service. Closed-loop supply chains incorporate reverse logistics, collection of products at end-of life cycle, remanufacturing, re-use, and recycling (Sarkis, 2019). Within operations, the design or development supply chain can be further distinguished (Simchi Levi et al., 2008). The development chain includes processes and interfaces that support product innovation, including technology development. Primus (2017) provides a detailed analysis of such process connections and contextual variables that affect those connections, such as industry clock-speed, the rate of product introductions in the industry category, and product characteristics (Zacharia & Mentzer, 2007).

Another constituting element of supply chains are agents. A supply chain structure consists of organizations and inter-organizational relationships. Supply chain design entails the design of organization, design of physical flows, information, and monetary flows between these multiple organizations (Sarkis, 2019). Supply chain design has been "referred to as the process of devising the supply chain infrastructure and logistics elements which includes determining the location and capacity of plants, distribution centers, transportation modes, fleet and lanes, production processes, and logistics information exchange pattern" (Sharifi et al., 2006; p. 1083).

A supply chain management system aims to effectuate and coordinate the connections between key processes that provide products to the end user. Product and supply chain operations decisions are highly interrelated across many dimensions. If these interdependencies are not recognized during supply chain design and management, the success of the supply chain may be compromised.

Recent literature reviews analyze research work that investigates supply chain configuration decisions during product design (Yao & Askin, 2019; Reitsma et al., 2021). Although the number of published articles in the last three decades has not increased dramatically, the breadth of topics is astounding. Reitsma et al. (2021) provide an interesting synthesis of supply chains considerations during product design at both the strategic and planning level.

From a strategic perspective, product design influences sourcing decisions, crafting of collaboration arrangements in the supply network, and postponement. First, the choice between internal work and outsourcing depends on product characteristics (Primus, 2017). It is accepted that modularity favors outsourcing, but integral product design can also be outsourced if there is not an excessive collaboration penalty and the supplier has superior technical capabilities (Ülkü & Schmidt, 2011). Product design can also influence geographical dispersion of supply chains and consequently the new product's environmental impact (Hong et al., 2018). For modular products, a geographic centralized supply chain minimizes product variety's negative impact on operational performance (Salvador et al., 2002).

Second, product design choices influence modes of collaboration with supply chain partners for product development, sourcing production, or logistics. Supplier collaboration in the product development process can be critical to the success of product innovation. The timing of supplier involvement may depend on the level of predictability surrounding product innovation (Gomes, 2013). Outsourcing highly modular products may require limited collaboration (Fine et al., 2005).

Postponement, or delayed differentiation, refers to delaying the commitment to a product in its final configuration or a location. Ideally, the location of product differentiation is aligned with the customer order decoupling point (CODP), where products are assigned to specific customer orders. The location where customization is performed in the supply chain affects how the manufacturer balances the levels of inventory and service (Lee et al., 1993). With proper product modularization, CODP positioning can be achieved by placing inventory in the supply chain at the product module level (Lee & Sasser, 1995).

At the planning level, key considerations include demand planning, inventory management, and capacity planning. Products may be designed to utilize available inventory in the supply chain to the maximum extent possible. Inventory levels across the supply chain can be reduced by minimizing product variety (Sharifi et al., 2006) or through product modularization. The transportation capacity across the supply network can also be planned based on a desired service level determined early in the product development process (Fixson, 2005).

Yao and Askin (2019) review operations research (OR) models that integrate product and supply chain design, or joint product and supply chain configuration design (JPSCCD). They note how supply chain studies revealed that there is significant waste resulting from poor coordination among supply chain partners (Fisher, 1997), which led industry to focus on aligning and coordinating production within a supply chain and eventually to collaborate with suppliers in product design. Graves and Willems (2000) offer one of the first models seeking to optimize supply chain configuration for new products, looking at the optimal placement of safety stock in a multistage supply chain. Yao and Askin (2019) trace the origins of JPSCCD to the ideas of concurrent engineering and product architecture. The traditional sequential product development paradigm, with designs being "thrown over the wall" to manufacturing, was under criticism for its low efficiency. Design-for-manufacturing was proposed to reduce manufacturing costs during the design phase (Bralia, 1986), leading to the emergence of the related concept of design for assembly. Design for supply chain management (Lee, 1993) expands the meaning of product design to incorporate supply chain configuration. Product architecture (Ulrich, 1995) plays a major role in linking the design of a product with its process and supply chain.

JPSCCD models grew in complexity to include multicriteria, supplier characteristics, uncertainty in operations of the supply chain (lead time and replenishment), and market dynamics. These models seek joint optimization of product and supply chain design (Fine et al., 2005). Product architecture information is typically captured by the product bill of material (BOM), which informs simultaneous design of product, process, and supply chain – three-dimension concurrent engineering

(3D-CE). Model resolution addresses trade-offs between competing priorities such as product cost, development lead-time, and supplier dependency.

The next section provides a more detailed analysis of key topics in the literature.

## 3 Current Concerns in the Literature

This section provides an analysis of literature on five topics where decisions regarding product innovation and supply chain design become intertwined. First, supplier involvement in product innovation. Secondly, the relation between product modularization and architecture of supply chain systems. Then, an overview of research in design for supply chain effectiveness and product innovation and supply chain agility is provided. Finally, studies that link product innovation and sustainable supply chains are reviewed. The section provides an overview of research in these domains and identifies gaps in investigation.

### 3.1 Supplier Involvement in Product Innovation

Aware of the impact product design has on supply chain performance, companies have begun integrating suppliers into the design process. This industrial practice triggered research on supplier involvement in design. Clark and Fujimoto (1991) seminal work on the automotive industry showed that Japanese firms were less vertically integrated than US firms and relied more heavily on suppliers for product development. Product development projects in Japanese companies had more new components and a vast majority of the projects in Japanese companies were fully developed by suppliers, as compared with 16% of USA. The high supplier involvement contributed to a Japanese advantage in product development lead time and cost.

Clark and Fujimoto's work influenced a stream of research on co-development with supply chain partners, both upstream with suppliers and downstream with industrial customers (Lenfle & Baldwin, 2007). PD best practices called for early supplier involvement (ESI) in product design, as a mechanism to ensure product integrity and mutual adaptation of product and process design along the supply chain. Through the involvement of suppliers, firms were able to improve product quality, cost, and lead time (Petersen et al., 2005). Supplier participation in PD also contributes to the success of new ventures seeking to develop a radical innovation (Song & Di Benedetto, 2008). There are potential drawbacks to early supplier involvement. A major concern is loss of flexibility. Supplier collaboration is typically built upon long-term, cooperative relationships. The focal development firm needs to sacrifice flexibility to achieve stability of that supply relationship.

Empirical work has also shown that the involvement of customers in product development in business-to-business markets has a positive effect on product innovation performance (for instance: Silva et al., 2019a). Several models have been proposed to enable collaborative design process with suppliers and customers, for example, the design chain operations reference model proposed in the mold industry (Lyu & Chang, 2010).

The successful integration of suppliers in product development intersects with other topics discussed below, namely, product modularization and supply chain sustainability. Integration of suppliers benefits from a modular design competence from the focal development firm (Salvador & Villena, 2013). The literature on product modularity and its impact on supply chain management is explored below. In addition, several studies find that supplier involvement enhances the ability of firms to deliver product innovations that improve environmental performance (Chistov et al., 2021). The relationship between organizing for product innovation and sustainable supply chains is addressed below.

### 3.2 Product Modularization and Architecture of Supply Chain Systems

The work on product modularity and systems architecture leveraged theories of design, complex adaptive systems, and transaction costs economics (Baldwin & Clark, 2000). The work of design theorists (Simon, 1962; Alexander, 1964) was particularly important in shaping product innovation literature. Two important ideas emerged. First, that the objective of design work is to ensure "fitness" between the object designed and its context of use. Hence, producers need to develop insights into the sequence of problems imposed by the emerging context. Second, that design choices form problem-solving hierarchies, a hierarchy of customer choice and a technical agenda for the producer (Clark, 1985). Products evolve through a sequence of design decisions framed by the interactions of problem-solving hierarchies. For instance, design for logistics may emerge within the technical agenda as a requirement for supply chain efficiency.

Research on product modularity has greatly advanced our understanding of how product innovation influences the architecture of supply chains. Simon (1962) proposed that systems can be decomposed into parts or components to reduce complexity, which became the genesis of modularity. Modularization in product development is the process of decomposing products into components, modules, or platforms while reducing their interdependencies (Ulrich, 1995; Baldwin & Clark, 2000). The shift toward modularity means products need to be modularized in its design through product innovation, with far reaching consequences to supply chain organizations.

Modularity results from decisions regarding product architecture. Karl Ulrich (1995) defined product architecture as "*the scheme by which the function of a product is allocated to physical components*" (Ulrich, 1995, p. 419). Previously, Ulrich and Tung (1991) had proposed a classification of types of modularity based on interfaces and customizability of components. Studies have investigated the benefits of modularity from multiple perspectives, including product functionality, design, agile manufacturing, service and repair, and recycling and reuse (for instance, Marshall et al., 1998; Mikkola & Gassmann, 2003). Volkswagen reportedly saved about $1.7 billion annually on development and production costs as a result of modularization (Dahmus et al., 2001). While modular designs offer efficiency and flexibility, integral designs, where components are highly interdependent, tend to yield higher performance (Schilling, 2000).

Henderson and Clark's (1990) made product architecture a central element in the research of organizations. Two new categories of product innovation emerged from their study – modular and architectural. Product innovation is no longer classified merely based on product novelty ("radical" versus "incremental"), new dimensions consider changes in product components or modules, and how they are linked together as a system. Henderson and Clark further argued that in organizations the product architecture becomes embedded in communication channels, information filters, and problem-solving strategies, as firms adjust to the set of components and interactions established by the product architecture. This argument can be expanded to supply chain organization. Product architecture characteristics define supply chain decisions regarding supplier selection, sourcing, delivery schedules, packing and shipping, postponement, customization, among others (Fixson, 2005; Nepal et al., 2012).

The modularity concept enabled a new product development perspective composed of three stages: the design of rules at the product system level, work on independent modules, and integration and testing of the system (Baldwin & Clark, 2000). Furthermore, reflection on Holland's (1996) complex adaptive systems theory led the product development literature to identify actions that can be performed to create value through modular systems enabling local operators to work independently on parts of the system, or modules, without having to redesign the whole product. A commonly held belief is that higher modularity will lead to outsourcing production, resulting in lower total supply chain cost (Anderson et al., 2007). Still, the benefits of outsourcing production tend to lessen as product complexity increases (Novak & Eppinger, 2001). Product complexity is linked to product architecture design decisions and the degree of product innovation.

Further modularity study sparked interest in a new phenomenon termed distributed product development (DPD) (Baldwin & Clark, 2000) – the use of multiple organizations separated by firm, geographical, or other organizational boundaries in product development processes. Modularization enables focal development firms to outsource the development of modules to key suppliers changing the organization of the supply chain. One notorious example of decentralized development chain is the Boeing 787 Dreamliner. Suppliers were responsible for the development of major components, while previously Boeing just outsourced parts production, in which suppliers followed specifications developed by Boeing engineers (Ülkü & Schmidt, 2011).

Reasons for DPD include access to technology, access to development resource capacity, superior quality of suppliers, and resolving market uncertainty. Alternatively, sourcing module development to suppliers adds to supply chain complexity and risk. For instance, suppliers need to comply with flexibility requirements while avoiding disruptions (Doran et al., 2021), which requires development of new supply network capabilities and supply chain redesign.

Researchers became interested in product integration as a core capability for successful DPD. Components that have been designed across organizational boundaries need to be brought together into a coherent system. Integration includes coordination of technical issues as well as dealing with cross-organizational problems. Organizational arrangements need to ensure appropriate information flows between the integrator and the firms in the DPD network (Ro et al., 2007).

Despite the theoretical alignment of modular product architectures and decentralized development chains, studies provide multiple instances where the alignment does not occur: Organizational design may not be fully modular even for modular products (Brusoni et al., 2001); successful development of integral product architecture can be achieved by a decentralized organization (Argyres, 1999); and often in industry practice modularity is not a dominant strategy for managing integration (Anderson et al., 2007).

This chapter will not attempt to further describe the evolution of distributed product development and the different organizational arrangements that support it such as outsourcing, offshoring, and alliances. Within this stream of research, the existence of work on open innovation models as organizational arrangement for product innovation is noted (Chesbrough, 2012). The term open innovation refers to a mode of organizing innovation in which the focal firm uses inflow and outflows of knowledge to accelerate internal product innovation. Academic research and managerial practice have focused mostly on inflows that complement internal innovation systems, based on the idea that most knowledge resides outside the firm boundaries; hence, the source of innovation is often external. The inside-out dimension of open innovation has been less explored, allowing unused or underutilized ideas to be used by outside firms. In this regard, Chesbrough (2012) suggests making business models more adaptive, which implies the ability to change supply network structure. The link between modularity and open innovation requires further development and research. While modularity also contributes to success of open innovation initiatives such as open-source development, user-innovators can contribute to designs with different architectures.

The work of strategy scholars contributed to the understanding of how modular product architectures give rise to modular organizations (Schilling, 2000), how firm boundaries change (Jacobides, 2005), and how network collaborations evolve (Jacobides et al., 2006). Jacobides et al. (2006) shift the question from how to protect a product innovation to how to appropriate most value. Their work explains how an industry architectural advantage, forged by collaborations and supply network configuration, enables firms to gain from innovation, for instance, appropriating substantial value without engaging in vertical integration or investing in assets and capabilities in the supply network that appreciate because of innovation.

The increasing scope of product architecture decisions has also been discussed in supply chain management research. Ro et al. (2007) note that modularity accompanied the reorganization of the automotive supplier industry, which had a significant impact on supply chain practices, outsourcing, product development, and supply chain coordination. The potential of modularity for mass customization has been largely untapped, and the reorganization of the supply chain has not included forging long-term partnerships.

In Fixson and Park (2008), the effects of increasing the integrality of product architecture on supply chain structure were examined. They examined Shimano Inc., a multinational company that develops, manufactures, and distributes cycling components. Shimano's move to an integral product architecture led to a more integrated supply network in the industry and market dominance. Success in product innovation required Shimano to work on the service element of the supply chain. Shimano distributed tools free of charge to dealers and trained dealers how to install and fix product component sets.

There are emerging concerns and research opportunities on the relationship between product architecture and supply chain configuration. The design implications of product modularization encompass bundled services, digital technologies, and supply chains. The concept of system architecture can be deployed to understand change beyond product architectures.

### 3.3 Design for Supply Chain Effectiveness

Lee and Sasser (1995) describe the implementation of principles of design for supply chain management at Hewlett-Packard Company (HP) and show how design decisions affect supply chain costs and service levels.

A myriad of design rules emerged associated with the idea of Design for Logistics (DFL) such as design products for efficient packing, transportation and storage, design packaging so products can be kitted at fulfillment points, design products for customer shelf space efficiency, and design products for easy customer assembly – the latter a notorious design principle of the furniture company IKEA. Some practices consider both product and process design such as design products so several manufacturing steps occur in parallel, or design packaging so products can be consolidated at cross docking points.

Globally, the supply chain and logistic innovations associated with the Belt and Road Initiative; a massive undertaking sponsored by China to promote global trade has been reviewed from an innovation and supply chain perspective (Lee & Shen, 2020). Examples include the impact of new value chain design at a macrolevel, promoting the competitiveness of entire nations and redesign of global supply chains for multinational companies and global industries.

The idea of design rules for supply chain effectiveness can be linked to design hierarchies that shape the evolution of products. Arguably, design for logistics is being driven by a technical agenda to improve efficiency of supply chains; for instance, redesign a plastic bottle to enable stacking more products on the same pallet. But it can also result from complex interactions of technical agenda and customer preferences.

Design for supply chain effectiveness is also focusing on product improvements to address environmental performance and the closed-loop supply chain, for instance, design for disassembly, design for recycling, design for end-of-life. The relationship between organizing for product design rules and sustainable supply chains is addressed below.

### 3.4 Product Innovation and Supply Chain Agility

Agile supply chains can respond rapidly and flexibly to changes in the supply chain and market environment. This response includes changes in demand or supply disruptions. Gaining agility requires deliberate changes in supply chain design, for example, reducing replacement times for materials and manufacturing throughput times, sourcing from alternative suppliers, etc. (Eckstein et al., 2015). Product variety creates a challenge for supply chain agility. Firms need to produce multiple products at lower volumes with lower predictability. Product modularity emerged as a response to increasing complexity, as it can generate options for product variations from combinations of modular components, ensuring supply chains can remain agile.

The link between product innovation and supply chain agility evolved from the work on postponement, mass customization, and modularization. The three concepts, how the concepts are related to each other, and the relationship to product innovation and supply chain agility are briefly reviewed.

The concept of postponement can be traced back to Alderson (1950). In the supply chain, postponement means delaying activities until customer orders are received (Van Hoek, 2001). The product customization step is delayed until customer preferences or specifications are known. The degree of postponement is related to the customer order decoupling point (CODP), the point at which customer orders enter the supply chain. Prior to CODP, decisions are made under conditions of uncertainty regarding customer demand. When the supply chain is considered early in the product development process, it is possible to ensure that the product design will allow for point of differentiation after the CODP.

The position of CODP in the supply chain represents different supply chain configurations: engineer to order (ETO), make to order (MTO), assemble to order (ATO), and make to stock (MTS). These concerns were primarily related to the relationship between production time and delivery time, with flexibility and agility forces pushing CODP upstream in the supply chain. Research on the strategic positioning of COPD gave emphasis to product design considerations, such as modular product design, and customization opportunities (Olhager, 2003). For instance, product complexity impacts production lead time.

Postponement contributes to the agility of supply chains (Yang & Burns, 2003; Can, 2008) and is used to move the CODP downstream in the supply chain, closer to the end user. Postponement can be achieved by merely reorganizing supply chain management activities, for instance, deciding to purchase parts from suppliers only after customer orders are received. Advanced postponement strategies require product redesign and may require re-sequencing process steps. From a design perspective, effective postponement requires that the differentiating elements of the product are limited to a few modules and that the product and process are designed to add those modules to the product at the end of the supply chain (Ulrich & Eppinger, 1995). Therefore, effective postponement strategies require product innovation.

The second concept is mass customization. Mass customization gained industrial traction in the mid-1990s, but it needed enabling technologies to support customer co-design, and it only began to penetrate the market a decade later (Piller, 2004). Academic research did start investigating mass customization (Pine, 1993) and related concepts of modularization (Ulrich & Tung, 1991; Pimmler & Eppinger, 1994), and CODP (Berry & Hill, 1992; Vollmann et al., 1997). Postponement plays a key role in enabling mass customization, moving the task of differentiating a product for a specific customer until the latest possible point in the supply chain, while considering productivity forces.

Postponement for mass customization requires appropriate product design, processes, and supply network. Feitzinger and Lee (1997) proposed three principles for mass customization. The first principle is product modularity; the product consists of different modules that can be assembled into different forms. *Modules can be assembled rapidly and economically* (Mikkola, 2007). Secondly, the idea of independent modules is used to design manufacturing processes, allowing them to be easily moved or rearranged for different distribution-network designs. Lastly, the supply network must have the flexibility and responsiveness to accept individual orders and deliver customized goods quickly (Feitzinger & Lee, 1997).

Product modularity decreases product complexity and enables quick assembly and cost-efficiency for postponement. Dell Computers, for instance, used modularity as part of a mass customization strategy to design streamlined supply chains and deliver build-to-order products (Ro et al., 2007). Still, not all mass customization strategies rely on product modularity. Multipurposefulness and continuous renovations can increase product customizability (Da Silveira et al., 2001). Kumar (2004) also provides examples of mass customization in the footwear and clothing industry that do not require product modularity, relying instead in digital technologies and flexible manufacturing systems.

While postponement became the cornerstone of responsive and agile supply chain, strategies, less work focused the connection of product innovation and other dimensions of the triple-A supply chain – *agility, adaptability, and alignment* (Lee, 2004), particularly adaptability, the ability of the firm to respond to fundamental changes by flexibly adjusting the configuration of the supply chain. Product innovation is crucial to supply chain adaptability when launching innovative products and breaking into new markets is the appropriate response to changes in the market environment. Product architecture decisions are also important, as there is evidence that product complexity moderates the links between supply chain adaptability and cost and operational performance (Eckstein et al., 2015).

## 3.5 Product Innovation and Sustainable Supply Chains

Sustainability goals drive innovations in supply chains to improve social and environmental performance. The chapter focus is on sustainability from an ecological (green) perspective, even though supply chain innovation can address social issues and improve human health and safety (Adams et al., 2016). The goal of green supply chain management (GSCM) is to minimize environmental degradation and protect the environment through the management of supply chains.

The relationship between product innovation and GSCM has been investigated from different perspectives. GSCM includes the management of collaborative relationships across the supply chain to drive product eco-innovation (Melander, 2017). In addition, product innovation is a key organizing element in the process of GSCM practice implementation (Silva et al., 2019b). By adopting GSCM practices, a firm may alter its technical system, resulting in conflicts with cost or safety attributes, requiring innovation in products. For example, to enable post-consumer recycling, firms must design products that are easily disassembled and separated.

Several of the previous topics connecting product innovation and supply chain configuration intersect the discussion of supply chain sustainability. First, design for supply chain effectiveness can focus on the goal of environmental performance. Product life extension strategies often rely on decision making during the product design stage such as design for durability and design for ease of maintenance and repair (Bocken et al., 2016). Secondly, a firm's effort to implement sustainable design practices internally can also benefit from involving suppliers in the PD process (Wang et al., 2021).

The ecological sustainability of supply chains has also been impacted by product modularity. Initially, modularity was viewed as a cost-effective means of increasing product variety. Then, the modular perspective evolved to support mass customization (Sanchez, 1995). More recently, modularity has been developed as a design principle to facilitate sustainability improvements. Combining product modularity with supply chain design provides benefits throughout the product life cycle, such as ease of replacement, upgrade, and recovery operations that are complementary to service (Sonego et al., 2018). Replacement parts should be inexpensive when compared with product replacement and repair services reliable and timely. Firms must incentivize the use of circular services to capture the sustainability benefits of product modularity (Amend et al., 2022).

Gu et al. (2019) study how an appliance manufacturer applied product modularization and digitalization to comply with extended producer responsibility (EPR). EPR is a regulatory measure to enforce the life cycle management of electrical and electronic equipment. Implementation of EPR requires data from every stage of the product lifecycle and information flows across the supply chain. The implemented product and system architecture provides high levels of information availability which support eco-design and end-of-life disposal. The product went from 354 parts to 25 modules, the bill of materials is fully traceable, and the product became customizable. At the supply chain level, the number of suppliers decreased from 14 to 3, data accessibility increased through deployment of RFID (radio frequency identification) readers, take-back schemes and closed loop-recycle became viable, modularized disposal is enabled, and disposers were selected as suppliers. The objective of product modularity now includes achieving reusable and standardized subassemblies and to maximize reuse and residual value.

Further inquiry is needed on how product architecture choices affect environmental impact. Sonego et al. (2018) argue for the limitations of modularity in reducing environmental impact during the use phase. Modular product designs can contain redundant structures, lead to overdesigned products, or sacrifice performance, which may result in excessive energy consumption. There are also concerns about using modules to upgrade product functionality. Due to the frequent introduction and replacement of modules, it can increase the environmental impact of certain products (Agrawal & Ülkü, 2013).

## 4 Emergent Concerns and Future Directions

This section discusses emergent concerns at the intersection of product innovation and supply chain configuration, highlighting future research directions.

### 4.1 Digitalization and Industry 4.0 Technologies in Supply Chains

A significant change affecting product innovation and supply chain connections is the implementation of digital technologies in supply chains, or supply chain digitalization. Digital technologies refer to a collection and paradigm of diverse, intelligent technologies that enable connectivity, digitization, and automation, such as the Internet of things (IoT), cloud computing (CC), blockchain, artificial intelligence (AI), big data analysis (BDA), and digital platforms (also designated as Industry 4.0).

The characteristics of digital technologies offers numerous benefits that can be leveraged across supply chain processes and products including simplified infrastructure, interoperability, scalability, simplified development and integration, improved accessibility and ubiquity, flexibility, customization, upgradability, rapid prototyping, scalability, remote monitoring, and management (Cardin et al., 2018). These advantages contribute to the seamless flow and utilization of digital content, enabling efficient data-driven processes and enhancing user experiences. For instance, vehicle tracking devices can be integrated with blockchain which facilitates vehicle tracking and enables improvement of delivery cycles and better purchase order management (Sheel & Nath, 2019). Supply chain systems are enhanced to become intelligent and interconnected, improving process efficiency and promoting higher profitability (Choudhury et al., 2021).

As digital technologies transform innovation processes, new research opportunities arise. Marion and Fixson (2021) provide multiple examples of how digital tools are enabling changes in skill sets, workflow, and collaborations in product development processes. Furthermore, digital technologies offer the possibility of front-loading in the product development process concerns related to supply chain configuration.

Digital tools also facilitate standardization and measurement of work, lowering transaction costs (Baldwin & Clark, 2000) and creating favorable conditions for open innovation models. Digital collaboration allows firms to more easily tap into knowledge assets that reside in the supply network. Further research can explore how the changes promoted by digital tools lead to new organizational arrangements in the supply network.

The implementation of digital technologies across the supply chain also enables product innovation through the incorporation of digital components (Choudhury et al., 2021; Khuntia et al., 2022). Digitalization allows firms to innovate their product offerings via complementary services, such as information and analytics services (Ehret & Wirtz, 2017). Digital technologies also enable efficient mass customization via end-user integration (see Ehret & Wirtz, 2017). In addition, digital service innovation can result from operational integration along the supply chain. A firm can detect unique product opportunities by building relationships with supply chain partners. For example, a customer can explore financing options with online banking and customize an auto loan that they can take to a car dealer's facility and have the dealer provide car information to confirm credit availability.

Architectural innovation may be required to enable product-service bundles. In addition, the shorter development life cycles for services often require firm to rely on external partners to create complementary services (Khuntia et al., 2022). Firms must be flexible in how they govern supply chain relationships and align the goals of internal and external actors. One solution is to construct digital service platforms. Using platforms allows others to build on top of your offering (the platform) to offer customization, resulting in economies from standardization.

Another interesting development is the use of Industry 4.0 technologies for supply chain innovation (Hahn, 2020). For instance, additive manufacturing supports rapid prototyping and enables customized production. Firms can integrate additive manufacturing in their supply chain network enabling postponement and local or near-shore manufacturing (Ramón-Lumbierres et al., 2021). Further research could be conducted on approaches to developing complementary offerings based on Industry 4.0 technologies and necessary adaptions through redesign of supply networks.

Finally, an interesting phenomenon associated with digitalization is that vertical integration is being initiated by information and communication technology (ICT) companies (Hahn, 2020). Information and communication technology companies, such as Amazon and Google, extend their digital services into industrial markets and integrate supply chain operations. How these firms are simultaneously reconfiguring traditional products and operations to benefit from digital technologies is an interesting line of inquiry.

### 4.2 Design Thinking for Supply Chains

The importance of design as a source of value creation is well understood and has been popularized by the design firm IDEO and their process of driving product innovation through design thinking. However, to a large extent, design thinking has evolved independently of innovation management theories. Several scholars argue that design thinking displays an action-oriented bias toward creative solutions that can benefit from the theoretical bias of systems thinking, which promotes understanding of complex problems independently of solutions. Practitioners and management consulting firms have started to combine the benefits of design thinking and systems theory, but there are still limited studies in the literature that combine these two approaches.

The merging of these two perspectives is particularly interesting when considering the application of design thinking to address supply chain configuration issues. Few studies exist at the intersection of innovation and organization (Verganti et al., 2021). A new perspective on design builds on the capability to make sense of a design problem among multiple stakeholders (Verganti et al., 2021). This approach is especially salient as design moves from solving problems for products or services into addressing organizational and supply network change. For instance, abductive reasoning and reframing a problem from the design thinking perspective can benefit from participation of supply chain partners in the interpretation of the problem and design space.

### 4.3 Limits to Product Modularity

There is some evidence of negative interaction between product modularity and complexity as it affects product innovation performance (Vickery et al., 2016). This raised concerns about over-modularity. For instance, excessive modularization may reduce visibility over important interactions between design choices and lead to inferior designs (Ethiraj & Levinthal, 2004). This concern gains further relevance with the emerging concept of system architecture as foreseen by Vickery et al. (2016):

> [. . .] the adoption of an intensive product modularity approach for a complex product, with the accompanying organizational and supply chain upheaval and the concomitant challenge of effectively integrating new organizational units and suppliers, could negatively affect new product introduction performance. (p. 763)

Further investigation can focus on the limits to modularity from a supply chain system perspective. One interesting finding from Ülkü and Schmidt (2011) is that the choice of product architecture depends on the nature of relationships between supply chain partners. They modeled DPD to show that modular product architectures are more likely when the parties have adversarial relationships, while long-term trust-based collaborative relationships facilitate integral product architectures. Recent studies suggest that this finding has not received sufficient attention (Yao & Askin, 2019).

Future research opportunities may arise by embodying the wider scope of product modularization as a process of rearranging product components and organizational systems to create modular architectures (Mertens et al., 2023). Further inquiry is needed to test the mirroring hypothesis, which suggests a correspondence between product and supply network architecture. Empirical support has been mixed. A recent study shows that firms seek the efficiency benefits of aligning product and supply network architecture only for low value components. When components provide opportunities to capture high value, managers chose non-correspondence, and despite the modularity of the product, they form stronger relationships with suppliers and even integrating vertically (Burton & Galvin, 2022). These strategic choices suggest that firms develop capabilities to manage the interdependence of supply chain processes to appropriate rents, rather than simply minimizing transaction costs (Gomes & Dahab, 2010).

### 4.4 Service Modularity Impact on Supply Chain Agility

Another area of emergent research is how modularity in service can enable supply chain responsiveness and adaptability. Modular systems can handle environmental uncertainty more effectively, allowing modular elements to evolve while retaining the overall architecture of the system. A modular service architecture can result from deliberate design efforts.

Services can be considered process-based products and modularization creates process modules that can be mixed and matched according to the specific situation. A recent study showed how supply chain processes can be conceptualized as modular, facilitating rapid process reconfiguration in the provision of humanitarian relief services (Saïah et al., 2023). The service modules can change in sequence, can sometimes be run in parallel, be activated or deactivated, executed at different performance levels, for example, a regular transport or emergency transport module, and change in level of resource allocation. Moreover, the study finds that the impact of modularity on supply chain responsiveness is moderated by information visibility, alignment of goals and interests and collaborative decision making, and effective resource orchestration, that is, resource development and coordination in the supply chain.

### 4.5 Sustainability Goals

More investigation is needed on the potential of modular product design for sustainability (Sonego et al., 2018; Mertens et al., 2023). For instance, modular product design is a promising strategy for product lifetime extension and material recyclability (Amend et al., 2022), and when combined with well-designed repair instructions foster self-repair behavior and positive customer experience.

Further work can investigate how product innovation to promote sustainability goals creates requirement for supply chain redesign. For instance, the extension of lifetime via upgrade shifts the focal firm focus to asset management, which also indicates a need for change in the existing supply network, involving supply chain partners in providing upgradability services.

Another emergent area of research is the use of open innovation models to promote eco-innovation, innovation intended to improve environmental performance (Chistov et al., 2021). Access to external knowledge and organizational collaboration may help reconcile economic and environmental objectives during product innovation. Eco-innovation faces specific challenges such as high development cost and incompatibility with existing production processes. External collaborations can spread risk of development and provide knowledge of technologies or disruptive changes that help identify alternative supply chain configurations.

For example, Shell's sustainability strategy involves investing in sustainable aviation fuel (SAF), which can reduce emissions by up to 80% compared to conventional fuel. The SAF is made from waste products and feedstocks and blended with conventional jet fuel. Shell created supply chain capabilities, namely, production sources, blending facilities, and distribution of SAF. The company brought together key stakeholders such as SAF producers and airline companies to safeguard the investment. Shell is also investing in carbon sequestration to fasten the pace of decarbonizing the aviation sector. At the same time, start-up companies around the globe are developing technologies to turn carbon dioxide into fuel, an opportunity for disruptive change in the industry. Combining different stakeholders into networks of knowledge can result in radical eco-innovation.

Finally, there is potential for further research of how digital technologies contribute to environmental performance (Gu et al., 2019; Birkel & Müller, 2021). The creation of digital twins of products and processes enables faster and more efficient design processes and allows the backflow of data from data in use to design across the supply chain. Digital product innovation can also address sustainability goals. Circular business models include product-as-a-service concept to improve environmental performance, extending the life of a product through reuse or promoting shared use to reduce environmental impacts. The integration of physical and digital through information networks generates opportunities for product and supply chain innovation toward sustainable business models.

## 5 Managerial Implications

Many insights and implications exist for managers and organizations. One important insight for managers is the opportunity created by integrating product architecture decisions with supply chain configurations decisions. While this seems clear, it is not a common practice. In a survey conducted by the Global Supply Chain Institute in 2021, fewer than 29% of respondents said their company identified and mitigated the supply chain risks of new initiatives effectively. Supply chain leaders actively participated in product innovation planning processes less than 65% of the time.

Firms need to recognize the interdependencies and implemented proactive connections between product innovation and supply chain sub-processes to cope with those interdependences. Firms need tools to analyze the product architecture. For instance, Fixson (1995) provides a multidimensional framework that enables comprehensive product architecture assessments. Second, firms need tools to map the connections between product design and supply chain design. One framework for integrating the supply chain configuration decisions with the product architectural decisions is provided by Nepal et al. (2012). One interesting element of this framework is that it incorporates the compatibility between the supply chain partners to ensure the long-term viability of the supply chain, leveraging the idea that the supplier relationship and product architectural design are interdependent.

Another insight is that in dynamic and competitive environments the practice of involving suppliers only after the product design results in long development cycles and high total costs of supply chain. Supply chain management professionals play an important role in identifying suppliers with the needed capabilities for the firm. Supply chain partners can effectively collaborate for product design and development, and environmentally capable suppliers can enhance the impact of a firm's internal sustainable design practices on environmental and economic performance. Recent research shows that a vast majority of firms engaged in eco-innovation did not cooperate with other firms in their supply chain network (Chistov et al., 2021).

Firms that aspire to be leaders in sustainability performance need to integrate product innovation and supply chain design. Li et al. (2008) propose a modularization method to implement Design for End-of-Life in the product design process. Design for sustainability requires adjustments in supply chain organization. For instance, supply chain partners may need to implement additional circular services, such as deposit systems for product take-back or managed secondary markets for used and refurbished devices.

As a final point, supply chain executives face a formidable challenge with the emergence of digital technologies. The embedding of digital solutions in products and operations of supply chains creates opportunities for product innovation and Supply chain integration. Supply chain executives must devise clear and coherent strategies to create value, redrawing supply chain relationships and forging collaborations with new partners to support their innovation efforts.

## 6 Summary and Conclusion

This chapter has provided a general overview of practical and research concerns at the intersection of product innovation and supply chains. It shows through distinct perspectives how product innovation and supply chain decisions are intertwined. A wider scope of product design can account for supply chain management choice (e.g., supplier location, production cost per supplier), the design of logistic-smart products, and minimize environmental impacts in the product life cycle. More importantly, an integrated approach to product design and supply chain configuration creates novel opportunities for innovativeness.

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# Product Portfolio Rationalization and Management in the Supply Chain

Joseph Quan and Qingyun Zhu

## Contents



**Abstract**

Products are of strategic significance to firm performance and long-term competitiveness. A successful product portfolio represents an optimized allocation of firm resources with maximized market share and revenues. The makeup of a product portfolio involves strategic planning of the organizational cross-functions including finance, operations, and marketing. Products typically go through a lifecycle – introduction, development, maturity, and decline. Throughout the lifecycle, products will be constantly evaluated by overall profitability level, sales, strategic alignment, risk tolerance, and customer satisfaction. Underperforming in any dimension may result in product adjustment, deletion, or replacement. Product portfolio rationalization derives from marketing management literature; few investigations have shed light on a holistic review of product deletion and rationalization in supply chains. Firms are no longer individual competing entities in the marketplace; products become the linkage that connects and interlocks firms on a supply chain network. Adding, altering, or deleting a product can bring significant changes to supply chains. These changes

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require collaborative efforts from actors across functions both inter- and intraorganizationally. This chapter provides a comprehensive review of product portfolio rationalization in core business management literature: finance, marketing, supply chain management, as well as sustainability. Research gaps and future research directions are discussed.

**Keywords**

Product portfolio management · Rationalization · Strategy · Supply chain management · Product deletion

## 1 Introduction

Product portfolio management is critical to firm strategic renewal and long-term competitiveness (Eggers, 2012). How firms can maintain a strong product portfolio and improve business outcomes is a key strategic question. Managing a product portfolio is a decisive business practice including defining products, evaluating related financial performance, as well as constantly revising, updating, and even making decisions regarding the discontinuation of products that are underperforming or ill-fitting.

Many corporations generate 80–90% of their profits from fewer than 20% of their overall product offerings (Kumar, 2003). In retailing, for example, Unilever made 1200 brands – that were unsuccessful or at best had marginal profitability – as candidates for deletion since 2000. In 2019, they removed more than 200 products from their product portfolio. The automotive industry discontinues models for strategic reasons. For example, the Chevy Spark was removed by General Motors as an example of shifting market trends. Product deletion is also evident during the times of crisis such as the COVID-19 pandemic. Red Robins pruned their menus during the first round of COVID-19 lockdown to offset the loss of revenue from closing all their stores. Product deletion decisions also relate to other product development moves. For instance, Apple Inc. removes products to make way for product innovation.

These examples reveal that firms do practice product portfolio rationalization – deleting and withdrawing products – on a regular basis. But product portfolio rationalization research has not paralleled business practices. Existing product management research has focused on product addition and proliferation – for example, new product development, product innovation, and product line extension. Limited attention is on product deletion research.

This chapter aims to provide a systematic and comprehensive overview of product portfolio rationalization considerations in corporate key cross-functions. These cross-functions include finance, marketing, supply chain management, and sustainability. We first summarize the existing findings in related literature streams, discuss how each finding can be expanded to enrich related literature streams, and provide future research directions given the identified literature gaps.

## 2 Background and Current Concerns

This section summarizes the relationship between product portfolio rationalization and various key organizational cross-functions, respectively, finance, marketing, supply chain, and sustainability. Discussions include both theoretical and practical perspectives. Some recent real-world examples provide insights to the critical strategic implications of product portfolio rationalization to firms.

### 2.1 Product Portfolio Rationalization and Finance

Many companies reevaluate their product portfolio for competitive financial performance, for example, profit maximization and loss minimization (Avlonitis, 1983). Product deletion from a financial perspective involves examining the financial impact a particular product has on the company, and across the other products within the same portfolio (Zhu et al., 2018). Although research has investigated product performance of all various dimensions, their direct impact and spillover impact on financial performance are still dominating (Muir & Reynolds, 2011).

Companies oftentimes focus on how new product development leads to a positive impact on organizational financial performance. Because many believe that having more products may increase overall demand and market share. However, product portfolio expansion should still be weighed with the increase of raw materials needed to produce a wide variety of products (Bayus & Putsis Jr, 1999). Too many products can lead to a weak product burden – some products have a costly burden higher than their economic potential. Hence the raw materials that go to the weak performing products may become a burden to organizations. The financial investment needed to manage these extra inventories and manage supply chains can also be saved through product deletion.

Another downside of product proliferation is financial and accounting resources being spread too thin within a company (Murphy & Enis, 1986). The time and effort put into maintaining the financial relevance of a given product may not be worth it when that effort could be spent on a product that has larger attention in the current market. Some companies have been able to streamline their products through product deletion while increasing sales (Hamelman & Mazze, 1972). Deleting weak performing products would help a company recover from the indirect costs that may be associated with that product, such as time required by management and marketing efforts, both of which could be used toward more profitable products. Having excess products that are not sold lead to additional inventory costs as well.

Even though the aforementioned negative consequences such as inefficient use of resources, product deletion continues to be neglected by both research and practice (Avlonitis et al., 2000; Zhu et al., 2021). Reasons may include a company having a false sense of security due to overall profits, management being unwilling to change, or difficulties with figuring out who has the managerial power to discontinue specific products if the company has multiple different departments; or managers may have certain emotional bond to certain products or, in general, being afraid of losing certain customer segments (Zhu et al., 2018; Zhu et al., 2020a, b).

The idea of a "weak product" burden is exacerbated during tumultuous times. Internally, companies are on an even stricter budget and factor in the immense amount of uncertainty in the macroenvironment. Externally, during times of crisis, such as COVID-19, marketers find that consumers exhibit limited purchasing power and tend to only buy essential products (Di Crosta et al., 2021). This situation means that a company may also need to delete profitable products which require materials that have too much uncertainty due to supply chain scarcities and uncertainties, or products that aren't essential to an organization's profits. An example of this is the effect that the COVID-19 pandemic had on restaurants. For consumers, going to restaurants was not even a consideration because of state and nationwide lockdowns. As a result, many restaurants had to downsize their menu by maintaining constant supply. Many larger companies such as Chili's or Red Robin's, which once had a variety of menu items, also had to cope with the pandemic by deleting many different variations of burgers or appetizers to only the core few, since certain specialty items may have required ingredients that were too niche to be considered financially viable (Sobaih et al., 2021).

Many companies are analyzing how they could have better prepared for the COVID-19 crisis, but that brings up a host of questions regarding product portfolio rationalization. One such question is to determine the level of variety and complexity of a product portfolio to sustain success during a pandemic. How can such experience be carried out when compared to business-as-usual?

It seems logical now that many companies failed financially during the COVID-19 pandemic due to only focusing on product addition, but that seems like the logical business model in a nonvolatile market. It would seem equally likely that a company that is focused on preparing for tumultuous times will get overshadowed by competitors who are taking advantage of the demand for luxury goods during times of nonvolatility. There is no clear balance between expansion and competitiveness with stability and safety during a pandemic, which just further highlights the need for businesses to analyze their product portfolio to protect their finances against pandemics, while also increasing profits during regular times.

## 2.2 Product Portfolio Rationalization and Marketing

Market strategy – such as brand repositioning and restructuring, can also result in product deletion or withdrawal (Hart, 1989). Products require extensive resources for marketing efforts (i.e., media resources), product deletion can free up resources from weak products to products that have greater marketing performance such as higher market share and better customer satisfaction (Varadarajan et al., 2006). However, a company must also be careful when deleting products, it may potentially leave openings in the market for competitors to fill that void with competing products or substitutes, eventually weakening the firm's overall competitiveness (Alexander, 1964).

Firms are encouraged to continuously develop and introduce products that are new and different from their competitors in the marketplace (Liu, 2003). Considering the limited resources, one way to do this is that a company can simultaneously delete products and replace them with new products (Saunders & Jobber, 1994). But the deletion side of this process is often overlooked in favor of constant innovation and creation (Argouslidis & McLean, 2004). Instead of deleting a product, firms would be more willing to improve the existing product through product enhancement or marketing it in different ways to reposition it in the current market (Houfek, 1952). Because product deletion is often viewed as a negative signal to the customers – market failure.

Firms also diagnose and evaluate product portfolios on multiple dimensions. Factors that relate to marketing performance include sales, market share, brand image, customer satisfaction, and strategic fit (Tsironis, 2020). Product elimination and withdrawal are found to have a great impact on customer relationship management (Argouslidis, 2007). One way to maintain customer relationships is to implement customer retention tactics within the product deletion process and ensure that customer satisfaction is greatly considered throughout (Harness & Harness, 2012). It is inevitable that deleting a product will sever ties with customers who solely used those products. One way to mitigate this, however, is to continue selling the product to that specific clientele and market it as "special," while closing it off to other segments of the market (Harness & Mackay, 1997). A company should also assess whether this deletion is a reactive response (i.e., product recall) to generally create a negative impact on the company (Temprano-Garcia et al., 2020).

In an industrial marketing supply chain perspective, having appropriate and more successful substitute product that is less likely to be deleted should be offered. This may require the organization to work with their customers to reengineer or redesign the processes or products that utilize their product. Clearly, additional investment may be required, but new markets may be established, and it will build a stronger relationship with the industrial customer.

A company that is excellent at product deletion and marketing is Disney: Along with its constant innovation, Disney can seamlessly phase out products and prohibit sales of its intellectual property, sealing it in the "Disney vault." Older movies such as *The Little Mermaid* and *Pinocchio* were deleted after a certain amount of time from their initial releases and sales of these movies were prohibited. Disney would then market anniversaries or special events around these movies and release them from the Disney Vault to allow purchasing for a short period of time, which further established customer relationships while also selling old products at a premium. Disney's ability to delete its products also helped with its creation of Disney+, since using that video service would give subscribers access to many older movies which were once not available to the public.

One marketing disaster, conversely, was Coca-Cola's attempt at deleting its "old Coke" in favor of "new Coke." In 1985, in response to its declining market share, Coca-Cola decided to delete its old coke formula, and replace it with "new Coke" to better compete with Pepsi's sweeter taste. Deleting old Coke proved disastrous because, although there was sufficient empirical data through taste tests and surveys, Coca-Cola failed to recognize the customer attachment that consumers had with the old flavor of Coke, and they failed to consider how customers would feel if old Coke got deleted from production. In just 79 days, thousands of phone calls, and one lawsuit later, The Coca-Cola Company brought back the old flavor, rebranding the new flavor as “Coke 2” (Schindler, 1992). While The Coca-Cola Company went through a rigorous product deletion process through empirical and financial analysis, it failed to adequately account for how the marketing of deleting old Coke would affect consumers on such a visceral level. These examples show the impact product deletion can have on customer satisfaction levels and marketing objectives.

It is important to note, however, that marketing objectives will change based on current trends. Trends such as environmentally conscious (green) initiatives create more demand for products that were produced in a “green” way, and companies may need to delete products that don’t follow that trend. Marketing is a downstream supply chain effort and care should be taken that their product deletions do not cause greater disruptions in supply chains – offering alternatives and forecasting and predicting risks would be important from this development perspective (Zhu et al., 2020a, b).

Future research can explore the relationships between product deletion and emergent marketing metrics, for example, as the platform economy is thriving, how customer reviews in online communities play a role in product deletion decision-making; along with this, the cognition, emotions, and behavioral elements of customer behavior can be further investigated to facilitate strategic product deletion decisions.

## 2.3 Product Portfolio Rationalization and Supply Chain Management

Product portfolio streamlining affects not only the firm internal performance but the entire supply chain actors relating to product portfolio structure and its inbound and outbound logistic flows (Zhu et al., 2021). Some issues related to financial concerns in inventory management, and disruption of industrial marketing downstream supply chains have been mentioned. But, the impact can be much broader upstream and logistics.

Despite the large ramifications of product deletion to a firm as well as its supply chain network, limited research exists at the nexus of product deletion and supply chain management – what supply chain–related factors should be considered in determining a product’s candidacy for deletion or withdrawal decision (Zhu & Kouhizadeh, 2019). Supply chain functions including product design, manufacturing, distribution, transportation, and supporting collaborative relationships with other firms (i.e., suppliers) can separately or jointly impact product portfolio rationalization.

Since the supply chain encompasses all aspects of a firm, it can be hard to imagine the ramifications brought by product deletion in practical settings. Ford Motor Company produced the Ford Pinto in North America from 1971–1980 to compete with other subcompact cars of the time like the Chevrolet Vega and AMC Gremlin. What made the Pinto the source of much controversy was its inherent design. Because of where the fuel tank was positioned, the Pinto was prone to explosion if hit from the rear end even at moderately slow speeds, but Ford continued to produce it even though it caused multiple fatalities because cost-profit analysis showed that lawsuits and recalls were outweighed by the financial profit. Ethical dilemmas aside, Ford's decision to not discontinue this product had serious repercussions downstream in its supply chain. Thousands of consumers were injured or killed because of explosions due to the Pinto's inherent design flaw, resulting in hundreds of millions of dollars in lawsuits (Birsch & Fielder, 1994). This would also tarnish Ford's overall public image because they were quantifying a dollar value to potential lives lost. This example is significant because it shows how powerful product streamlining can be, and the real-world ramifications of when product deletion has not been carefully evaluated incorporating supply chain considerations.

Organizational long-term competitiveness relies on supply chain performance – its agility, resilience, and reliability; and such supply chain performance is dependent on the optional variety and volume of product output within a marketplace, hence product portfolio rationalization is a critical supply chain decision (Zhu et al., 2020). There are negative repercussions that arise if products are deleted without both long-term and short-term considerations (Pourhejazy et al., 2020). Because of technological advances along with shorter product life cycles (Lin et al., 2006), there is a greater need for firms to be flexible and responsive to market dynamics – for instance, shifts in market competition and customer segmentation (Hirsch et al., 2020).

Deleting products requires corresponding coordination from supply chain systems such as manufacturing and logistics systems (Harness & Harness, 2012). For example, when a product is deleted, firms will need to alter the process and product layout for the remaining product portfolio. Hence, the operations system's flexibility can help firms to make timely and effective product deletion decisions. Deleting products can be risky when decisions are dependent on product performance data; market uncertainties and competitors' mimetic moves can cause the failure of a product deletion (Zhu et al., 2021). As product deletion on supply chains involve multiple stakeholders – including suppliers, distributors, and customers, incorporating multiple stakeholder views into a systematic decision-making procedure is recommended for sound product deletion.

Supply chains involve tangible – material and product – and intangible – information and financial flows. The information and documentation associated with the goods of a firm, and physical aspects, the flow, and storage of the products themselves are both critical for the product deletion (Lewis & Talalayevsky, 2004). Integrating technology with its informational flow is critical for a firm to remain competitive (Patterson et al., 2003). With the emergence of disruptive technologies such as blockchain technology, and their integration into the supply chains (Casado-Vara et al., 2018), the achievement of data accuracy, traceability, and transparency can enable sound product deletion where advanced big data analytics can enhance the predictivity of product deletion outcomes. Product deletion may also have implications for the physical aspects of a firm's supply chain as well. Products that consume the majority of resources while subject to lower productivity and profitability can be considered for deletion. The resources including labor hours that are freed up from the deleted products can be reorganized and reallocated to better-performing products, such as products that have higher resource efficiency rates and productivity.

Supply chain relationships also affect product deletion. Long-term strategic supplier relationship management requires ongoing activity and constant communication (Zsidisin & Ellram, 2001). Whether or not potentially severing a particular relationship is worth the financial gain from a certain product collaboration. Regardless of what products are being discontinued, it is important that all parties relating to that product, whether downstream or upstream, be well informed, since uncertainty poses many problems for suppliers, and trust and effective governance has been important (Ryu & Eyuboglu, 2007).

## 2.4 Product Portfolio Rationalization and Sustainability

Because the goal of most organizations is to maximize profits, there is often a question of sustainability and how to maximize profits in an environmentally sustainable way (Sarkis & Zhu, 2018). While product deletion does affect an organization economically and socially, there can also be profound environmental implications (Zhu et al., 2020a, b). Calculations and equations are being developed to delete products that are the least sustainable based on multiple factors (Bai et al., 2018).

While government-implemented regulations that often entail restrictions on pollution-causing practices are a major factor for the long-term competitiveness (Dubey et al., 2015), voluntary regulation may have additional benefits such as cooperation in environmental efforts (Lorenzen et al., 1994). This may prove difficult, however, since an organization's focus on sustainability tends to be on developing more green products, not deleting products that are less green.

Firms may also be hesitant on adopting product deletion practices since the literature in this field is still new and developing. An initial predicament for organizations with respect to sustainability is that, oftentimes, green products require more resources such as a longer lead time for quality control and more expensive materials. In addition, there are often products that require large amounts of energy to store which increases an organization's carbon footprints (Kazemi et al., 2018). Hence, not only the product itself but storage and maintenance of the product should be considered when considering product deletion.

One consideration for product deletion with respect to sustainability is which products come from environmentally conscious suppliers because it affects a firm's competitiveness (Hutchins & Sutherland, 2008). Traditionally, product deletion may be evaluated from brand image – for example, products that aren't environmentally friendly may be deleted since green brand positioning is often tied to an overall positive brand attitude (Hartmann et al., 2005). Questions of implementation of these practices often arise, but new technologies such as blockchain technology may prove vital.

Blockchain may be used by firms to increase environmental friendliness across the supply chain (Rejeb & Rejeb, 2020). Specifically with product deletion, since there are so many aspects involved such as identification of unsustainable products and implementation, blockchain may prove useful for information gathering and organization. Although blockchain technology may be useful, integration of this technology into product deletion methods is still in the early stages (Zhu & Kouhizadeh, 2019).

After the BP oil spill in 2010, which is the largest petroleum oil spill in history, immense pressure was put on organizations to adhere to stricter environmental policies. This event also shifted public perception as well, making it competitively and economically advantageous for many organizations to adopt environmentally friendly products. An example of product deletion and sustainability to gain a competitive advantage can be seen in the automotive industry, which produces roughly one-third of all US air pollution. The Ford F-150 has been the best-selling truck in America for decades. One of its most popular engines, the 3.0-liter V-6 diesel was deleted in 2021, with Ford saying it was due to the popularity of its more environmentally friendly engines, the EcoBoost V-6 options. With increasing environmental concerns over issues such as global warming and pollution, some companies are doing even more than just deleting single products. GM announced it will cease building diesel- and gas-powered vehicles by 2035, setting a goal to become completely carbon neutral by 2040. If automotive giants are willing to delete unsustainable products, questions arise on the implications this has on other products as well. Every product, from clothing to air freshener sprays, has some effect on the environment. If the automotive industry serves as an indication for the future, many other firms may decide to delete products, in favor of more sustainable options.

## 3 Emergent Concerns and Future Directions

Traditional product management literature and studies have focused on product addition but overlooked product deletion and its significance to organizational cross-functional development and long-term competitiveness. Future research can promote a better understanding of product deletion on underinvestigated cross-functions such as supply chain and sustainability.

One promising future research question can be: What are the organizational processes and routines for product deletion? What is the role of the supply chain in these processes and routines?

Increasing technological and market dynamics present companies with both business opportunities and risks which require organizations to develop their capabilities to remain competitive. Greater market dynamics require organizations to develop product portfolios in consonance with their competitive environment.

Product and product portfolio development – which is the essence of product management strategy – has led to an interest by both academics and practitioners in product proliferation, innovation, and new product development. Only focusing on product addition has led to an incomplete understanding of product portfolio management. Identifying and withdrawing products that no longer contribute to organizational competitiveness remains a gap in both literature and practical exercises.

Various theories such as the resource-based view and relational view can inform strategic product deletion management. Future research can explore how product deletion can alter organizational resource structures, how product deletion can contribute to organizational dynamic capabilities, and how product deletion can affect organizational capabilities that are embedded in inter- and intraorganizational relationships. There are also relationships to broader societal events and technology evolution concerns. Some industries move more quickly in introducing new products and brands. Planning for product deletion to make room for innovation – even before the innovations exist – can free up resources to focus on research and development. Thus, forecasting and predictive methodologies and scenario planning for new technological and social movements can be very powerful for product deletion decisions. Investigating how and what type of tools to utilize for these purposes – do new tools have to be developed? – are concerns for future development.

Product deletion, often a marketing decision, is triggered by consumer needs and is led by the research and development and/or the product management function. However, the findings of this chapter indicate that product deletion not only affects the product management function but also influences several aspects of inter-actor relational rents. These actors include customers, distributors, suppliers, and competitors. These influences relate to government, social norms, and community concerns that are integral to holistic product deletion management. Thus, does there need to be more stakeholder input into these decisions? For example, sustainability-oriented and ethical products may require significant care before deleting – going beyond green product deletion – given that in some cases the livelihoods and health of people may be at risk. How to incorporate ethical concerns into this decision is an important business ethics concern.

Another potential research question for future research can be: Will supply chain and sustainability dimensional factors impact product deletion decisions? How influential are these supply chain and sustainability factors when compared to other organizational factors, such as marketing and financial factors?

Product deletion typically goes through identification, evaluation, analysis, and implementation. Product deletion antecedents can be manifold, specifically marketing, supply chain, finance, and sustainability. Market performance including sales and financial returns are often the most common aspects of product deletion triggers. Findings also provide evidence that companies also delete products because of operational reasons and sustainability concerns within supply chains. The supply chain and sustainability functions and antecedents are in addition to the existing product deletion literature. The tools used for new product development such as the stage-gate model are used in practice. Whether these models and tools need adjustment for product deletion is an important research and practical concern.

There are currently concerns and emerging sustainability and economic innovations such as the circular economy. The circular economy requires some form of stability of materials flows; if products are deleted, some materials may dry up. The determination of designs for product deletion in a circular economy perspective should be considered, issues such as deletion of modules within products rather than the complete product may be considered. Also, circular economy practices include leasing and sharing of services and products. What happens when leased products are targeted for deletion, does the service weaken and does the circular economy practice get affected? These are open questions that could be considered for closed-loop supply chains.

Product deletion routines occur on different time bases for different firms. The finance function often initiates product deletion processes and involves supply chain and marketing functions. Collaboration and communication among key functions are based on organizational strategic planning goals. Although financial performance is still the most common antecedent for product deletion candidate identification, supply chain characteristics form a more comprehensive performance metric to determine a product's candidacy for deletion.

## 4 Summary and Conclusion

Organizational long-term survival depends upon their product portfolio management, including adding new products to the portfolio, replacing existing products with new ones, or modifying existing products. Deleting a product is also a critical decision in product portfolio management. Product deletion may benefit firms across various aspects including organizational, financial, supply chain, marketing, and sustainability dimensions.

The spillover effect also occurs among organizational functions. For example, resources freed up from the deleted products (operations function) can be redeployed into stronger products that can deliver greater returns (finance and marketing function). Although product deletion offers several advantages to a firm, it is a complex strategic choice as multiple factors influence and is influenced by this decision, such as financial performance metrics and drivers, internal and external stakeholders, the organization's strategies, missions, and goals. Sound product deletion calls for a systematic and comprehensive review process.

Not only is product deletion decision-making complex, but product deletion implementation is also complex. There are foreseeable implementation risks. One of the direct risks is loss of sales from certain customer bases. One of the managers told us "The removal of products is a huge endeavor that requires considerable resources and often does not meet our expectations." Therefore, both inferencing and predictive models to simulate business scenarios and predict possible outcomes are needed for managerial implementation support.

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# Part VI

# Technology

# Cross-Border E-commerce and Supply Chain Management

Arkadiusz Kawa, Aidatu Abubakari, and Kwame Simpe Ofori

## Contents




**Abstract**

Customer desire for fresh experience and products from foreign markets has fueled rapid growth of cross-border electronic commerce (CBEC). Selling online and delivering goods to customers in other countries presents many challenges. In addition to standard electronic commerce retailer (e-tailer) problems in domestic markets – such as the risk of not receiving a shipment and relatively low-customer loyalty – CBEC involves the need to communicate in different languages; legal and taxation conditions; forms of payment; payment currency; the cost, time, and quality of delivery; and handling returns. In this chapter, we examine the links



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between CBEC and supply chains highlighting several CBEC supply chain challenges. We provide some best practices that firms can use to improve their CBEC operations.

**Keywords**

Cross-border e-commerce (CBEC) · Supply chain · Logistics · Africa

## 1 Introduction

Modern information and communications technology (ICT) has brought radical change to many daily activities (Ulas, 2019). Global business activities have also seen significant shifts due to widespread ICT adoption of and advancements. The positive effects and efficiency of the World Wide Web have led to the acceptance of the Internet for business transactions (Pencarelli, 2020). The increasing popularity of electronic commerce (e-commerce) can be attributed to its ease of use and convenience for businesses and customers. The ability to shop for goods and services online offers several benefits to customers many of which have only recently emerged.

E-commerce can contribute to economic growth and development. Further, e-commerce development could have a significant influence on trade, surpassing the changes witnessed over the past few decades (Kawa, 2018; Li & Bode, 2020). Gradually, the physical presence of consumers and suppliers is becoming less important in trade. E-commerce enables consumers to buy products by placing orders electronically and provides several options for where the products should be delivered (Nurruzzaman & Weber-snyman, 2020). The decreasing importance of the physical presence of exchange parties in business transactions means goods purchased electronically can be delivered to workplaces, click and collect points, homes, and parcel lockers. Furthermore, the electronic placement of orders supplants trips to brick-and-mortar locations, and the modes of delivery of consignments eliminate the need for consumers to personally pick up purchased goods (Kawa, 2018).

Unlike traditional trade, e-commerce is inextricably linked with the delivery of orders to final consumers, the so-called *last mile* which is one of the most complex and expensive processes in the entire supply chain (Gomez-herrera et al., 2014). The complexities are further increased by the global expansion of e-commerce activities beyond the borders of a single country – which is also known as cross-border e-commerce (CBEC).

CBEC demand derives from businesses attempting to expand their market share by searching for customers abroad and from customers seeking access to multiple suppliers across the globe. CBEC has become a major modern form of international business (Wang et al., 2015). It offers a new impetus for developing economy foreign trade growth. It is also beset by several obstacles, such as high delivery costs and long delivery times, language barriers, and cross-border tax and regulatory issues (Liu et al., 2021b). Although CBEC firms continue to reap benefits from participating in global markets, they face some prominent CBEC supply chain risks including terrorism, natural disasters, cybercrime, cybersecurity, financial challenges, political crises, and legal disputes (Liu et al., 2021a). These threats and challenges make CBEC supply chains highly vulnerable and increase the danger of supply chain disruptions.

For developing countries, CBEC can be a relatively inexpensive alternative because of its use of the Internet, which is inherently global, easily accessible, and based on open standards (Li & Bode, 2020). Given that the variable and fixed costs of the Internet are low, with greater flexible, and richer, means of electronic data interchange, CBEC is thought to offer businesses in developing countries novel opportunities to compete globally by minimizing transaction costs and barriers to entry (Wang et al., 2015). The ability of CBEC to reduce coordination costs can have a significantly positive effect on developing country global trading relationships and supply chains and encourage businesses to deal with the best producers regardless of location (Liu et al., 2021b). CBEC is a complex technological and operational concept, it is important to develop a more nuanced and realistic assessment of CBEC supply chains and their implications, especially given the advantages and risks involved (Moodley & Morris, 2004).

This chapter provides an overview of the complexities associated with CBEC and its implications. The chapter provides an overview of various approaches firms use to overcome challenges and outlines some best practices that businesses can adopt for more effective CBEC. The chapter seeks to facilitate the understanding of the contextual and organizational issues and practices involved. This chapter discusses the effects of CBEC on supply chains, the challenges faced in CBEC, and the ways of tackling some of these challenges. The next section provides a review on e-commerce, CBEC, CBEC logistics and supply chain management, CBEC supply chain challenges, best practices, and policies. A chapter summary is provided in conclusion.

## 2 E-commerce

The popularity of online shopping has been growing rapidly for several years. In 2021, global e-commerce was worth $4.94 trillion (17% more than in 2020), accounting for about 19% of total trade. This figure is expected to grow by 10–15% over the next few years, which means that the share of e-commerce in total retail sales will increase. By 2022, the value of e-commerce is expected to reach $5.54 trillion, thus increasing its share to 20% (Cramer-Flood, 2022).

The rapid development of e-commerce is influenced by increasing mobility and the growing popularity of smartphones. Currently, more than 2.14 billion people worldwide shop online (Coppola, 2021). Over the past two years, the coronavirus pandemic has further contributed to the growth of e-commerce (Bhatti et al., 2020). To comply with lockdowns and remain safe from spreading or catching the virus – isolation and social distancing situations – people order products that they need without leaving home and have them delivered to an indicated place. This growth has also been influenced by the continually increasing number of online retailers: There were approximately 9.1 million retailers online in 2021, 7.5 million of which were selling on marketplaces (Etailinsights, 2022). The most popular product categories are clothing, footwear, electronics, and home and garden. However, almost all types of products are offered online – from small to large and even oversized goods such as household appliances, furniture, and construction materials. Recently, groceries have also developed into a dynamic product category for online sales.

The growing share of online sales does not mean that in-store – *brick-and-mortar* – sales will completely disappear in the near future. The opening of stores after the first lockdowns in response to the coronavirus pandemic has shown that consumers will return to physical retail locations as well as to shop online. The same is true for order pickups, which give customers flexibility depending on their preference and availability. The best scenario for the customer is to be able to freely switch between the different channels of sales (offline, online) and pick-up/delivery of the ordered product (home delivery, parcel lockers, PickUp DropOff (PUDO) points, in-store, etc.) – or have omnichannel opportunities.

## 3 Cross-Border E-commerce

The dynamic development of the Internet has opened up new opportunities for both businesses and consumers. The advent of the digital era has made the world smaller and flatter than ever, and the spatial and temporal distance between product and market has been reduced. There are no boundaries or borders to e-commerce (Xue et al., 2016). The literature even speaks of the "death of distance" to reflect the decreasing relevance of geographical distance (Gomez-herrera et al., 2014). Sellers can have customers from throughout the world. Similarly, buyers can take advantage of offers from a very large number of sellers. Global competition is not only between multinational corporations but also between smaller companies that can attract customers worldwide.

E-commerce – with the Internet as a platform – is characterized by general accessibility, allowing customers to shop and receive products at their desired location at any time. Although the majority of customers still choose domestic online stores (about 78%), e-tailers are paying greater attention to expanding their businesses beyond national borders. A very important trend in this market is CBEC, in which a customer shops in a country different from that in which the seller is located (Kawa, 2017).

Although CBEC may seem similar to traditional international trade at first glance, as a sphere of e-business it is characterized by globalization, immediacy, personalization, and rapid development. In other words, CBEC is the international application of e-commerce. With the Internet, CBEC breaks the barriers of time and space, conducts paperless transactions, and expands the development channels of enterprises (Giuffrida et al., 2017; Hu & Luo, 2018).

Cross-border trade is not a new phenomenon. People have been trading goods between countries for thousands of years. This trade has been mainly due to a lack or limited quantity of goods in the local market. Fabrics, spices, vegetables, fruits, and many other valued products were exchanged. Trade shaped the development of international cultural and economic ties through to modern times and gave rise to many important trade routes that still exist today. Over the centuries, however, the means of transportation, the types of products traded, and the scale of operations have changed. The advent of e-businesses has been the largest recent influence on the development of trade. The ubiquity of the Internet has made it possible for businesses to compete on a global scale.

The opportunities for market access are equalized by the ability to present offerings in the same place – such as on the Internet – without incurring high costs. As businesses can sell their products to a worldwide market without a global distribution and sales system, they do not need to be physically present in foreign markets to expand beyond their home country (Qi et al., 2020). The resources that are used in traditional international trade are therefore not needed.

The smallest companies benefit the most from this situation as they often do not possess the financial resources for international expansion but have experience in online activities and can break through barriers with greater ease. They are more frequently competing with traditional domestic retailers. Meanwhile, manufacturers have the opportunity to sell directly to end customers, thus eliminating the costs of multilevel distribution and retailing (Wang & Lee, 2017); this allows them to serve more customers and thus increase their revenue.

The main reasons why retailers sell abroad include (Kawa, 2020):

- Improved competitiveness through internationalization
- Entry to the global market without the need for a physical presence or trademark licenses
- Access to new customers
- Building the brand before targeting the traditional market
- Gaining the ability to offer products abroad easily without knowing the local market characteristics
- Filling the sales channel (toward multiple channels)

CBEC is also influenced by customers who are looking for new experiences and new products from foreign markets. Customers who do not want to be limited to a single country in their choice of e-tailers are able to satisfy this desire through the Internet. The customers who play a special role here are the so-called digital natives – people who grew up in the Internet age. They are well versed in the Internet, which is for them a natural environment, and they have no problem trusting foreign sellers. The main reasons why customers buy from abroad include (Kawa, 2020):

- Lower prices
- Higher quality of products (premium brands)
- Access to new or unavailable products
- Wider range of products
- Desire for new shopping experiences

The share of foreign sales in total e-commerce continues to increase – from 16% in 2016, it is expected to reach 22%, or $1.22 trillion, by 2022. The growth projections are very promising, with CBEC expected to reach a value of at least $2.25 trillion in 2026 (Globenewswire, 2021a). More optimistic prognosticators predict that this value could be as high as $4.8 trillion (Globenewswire, 2021b).

The largest country for CBEC is China, where 42% of e-consumers choose to shop abroad and cross-border sales account for as much as 58% of the e-commerce share. To explain this, market analysts point to Chinese shopper interest in luxury goods that are often unavailable in their country. In comparison, CBEC is much less prominent in the United States. Although 34% of Americans buy abroad – mainly from China, Canada, and the UK – cross-border sales only make up a 12% share of total e-commerce in the USA. This low share of total e-sales is most likely due to the ability for US consumers to meet their shopping needs at local e-stores (Paypers, 2020).

A diverse range of products are purchased abroad, and customers of different countries differ in their preferences. For example, Europeans often buy clothes, shoes, and books abroad, whereas the Chinese consumers often buy cosmetics and groceries. Nonetheless, it is possible to distinguish the products that are purchased most frequently in cross-border sales globally. According to the value of sales, 33% of the products are clothes and shoes, followed by electronics (28%) and miscellaneous products (19%; accessories, gifts, flowers, etc.); health and beauty account for 7%, as do car parts and accessories. A minor share of cross-border sales is represented by furniture and home furnishings (3%), sports products (2%), and grocery items (1%) (Paypers, 2020).

CBEC is dominated by global online marketplaces. The top 100 online retail platforms earned $3.23 billion in 2021, accounting for more than 90% of all platform revenue and about 67% of total e-commerce worldwide (Joung, 2022). The large share of CBEC taking place on these platforms and their rapid growth (by 18% compared to 2020) is very important in shaping e-commerce, both domestically and internationally. The largest marketplace in terms of turnover in 2021 was China's Taobao ($711 billion) and Tmall ($672 billion), owned by the Alibaba Group. It was followed by Amazon ($390 billion), JD.com ($244 billion), and eBay ($87 billion) (Joung, 2022). These platforms offer advantages of immediate access to a very large number of customers, high recognizability, and serving as the place of first contact. They also offer ready-made technical solutions and payment systems. They can assist with the translation of offers and provide legal advice. They also offer a good opportunity to test products and new sales markets and to collect information from customers.

Without large investments in sales and distribution channels, it is possible to release a few signal goods, observe the demand, and collect customer feedback. Some limitations of these online marketplaces include a very high level of competition, the bid entry system, the need to communicate with customers from different countries, and platform fees. Increasingly, platform marketplaces not only allow businesses to sell products but also provide logistics services, from receiving goods into the warehouse through to storage, taking orders, packing, shipping, and returns.

However, these services come with an additional cost that not every organization can or wants to accept. Furthermore, some businesses prefer to be self-reliant and independent from other entities.

In addition to the marketplaces, there are also many small and medium-sized stores that focus exclusively on e-commerce (the so-called “pure players”). Other e-commerce stores are operated by bricks and mortar players, for which online sales are an additional source of revenue. Moreover, large companies that implement the omnichannel sales strategy are playing an increasingly important role. They often have experience in developing stationary stores and possess logistics infrastructure that facilitates expanding their business to include online sales.

## 4 Logistics and Supply Chain Management of Cross-Border E-commerce

E-commerce growth requires management tools suitably adapted to it. Internet sales are different from traditional channel sales in that they involve selling not only the product itself but also a certain kind of promise to fulfill the order in the right place and time and for a low cost. Logistics is therefore one of the key tools of online trade (Colla & Lapoule, 2012). It allows not only attracting new customers – through the availability of goods, different forms of delivery, and a low shipping cost – but also the retention of those who have already placed an order, through timeliness, compliance of the goods with the order, and no damage in transit. Until recently, efficient logistics in e-commerce was a source of competitive advantage – today it is a prerequisite. The most successful companies are those that implement new logistics solutions tailored to the needs of the market (Kawa, 2020).

The business-to-consumer (B2C) segment, in which goods are ordered by individual customers, dominates e-commerce in terms of the number of orders. E-customers often make one-off purchases in small quantities. Once an order is placed, the products are picked, packed, and prepared for shipping. They are transported by external logistics companies, especially CEP (courier, express, and parcel services) and postal operators – who are also termed third-party logistics providers.

In the case of CBEC, there is also the movement of shipments between the hubs of individual countries. This transport is completed by air, sea, rail, or road transport, depending on the urgency of the delivery and the value of the products being transported (Kawa & Zdrenka, 2016). Once the shipment arrives in the recipient country, it is transferred to a sorting facility, from which it is forwarded to local branches. The last stage is the transportation of the consignment by a courier to the place designated by the customer, which is most often the customer’s door. This *last mile* is one of the most important phases of the Internet order fulfillment process because it is usually the only direct contact between the courier company and the customer. It is also the weakest link in the supply chain – the service quality at the last mile depends on the delivery person, who must deliver the shipment on time and in a proper condition, whereas the logistics processes at other stages (e.g., picking and packing) are often automated and optimized.

The operating activities of CEP companies are based on the hub and spoke (H&S) concept, which is a system for distributing many loads of small size or weight. In contrast to direct deliveries, hubs are used to connect the individual places from which shipments are posted and at which they are received. The H&S concept minimizes storage costs and reduces the individual costs of transportation. Although a single consignment is transported over a long distance, the total distance for all shipments counted separately is shorter than in the case of direct deliveries. This solution works very well when there are a large number of items posted and received in multiple locations. An example is distribution within a country in which most large cities are connected with one another by means of one or more hubs (Kawa, 2017).

A problem with the H&S system is the presence of routes along which few consignments are transported. Underutilization of the vehicle cargo space along these routes causes the unit cost of transportation to increase significantly. Moreover, in the case of small packages – which prevail in e-commerce – the total delivery cost rises considerably when the consignment passes through many local terminals and hubs, because of the additional costs of sorting and handling.

CBEC is by design a complex system, integrating many types of services, such as logistics, customs declaration and inspection, legal advice, and electronic payments (Wang et al., 2020). CBEC supply chains are also much more complex, with nonlinear flows of goods and information. Moreover, they include many more entities that are often independent, such that the influence a retailer can have on them is limited. They are also influenced by many additional factors, such as the political situation, international regulations, trade restrictions, and the economic situation.

Researchers note that the distribution channels for CBEC are more comprehensive compared to their domestic counterparts. CBEC involves contact with different cultures, which affects logistics management, for example, the expected service levels and the propensity to return goods. In addition, country-specific legal conditions must be observed. These and other challenges affect how CBEC is managed, and an understanding of these issues is very helpful for foreign companies (Liu et al., 2021b).

Another characteristic of CBEC is the need to obtain and manage the information that accompanies all e-commerce activities. Research has attended to the issues of asymmetric information and insufficient data (Ma et al., 2018). It is important for the logistics company, retailer, and customer to have access to up-to-date information about the product and the shipment. The primary means for this access is to integrate the flow of operational, tactical, and strategic information that is exchanged between the online retailer and its supply chain partners. However, unlike traditional sales, e-commerce relies more on information technologies for more efficient information flow. This efficiency is possible thanks to information systems and solutions based on them, such as track and trace. On this front, increasing attention is being paid to blockchain technology (Liu & Li, 2020). By continuously communicating with customers and better meeting and responding to their needs, companies can obtain targeted, specific data and valuable market information that can provide an important basis for making various business decisions (Wang et al., 2020).

## 5 Challenges of Cross-Border E-commerce for Supply Chain Management

Alongside its many advantages, selling online and serving customers from abroad involves many challenges. In addition to the standard problems faced by e-tailers in the domestic market, for example, the risk of not receiving a shipment and relatively low customer loyalty, other factors must be taken into account when dealing across borders. These factors may include communication in different languages; legal and tax conditions; forms of payment; payment currency; the cost, time, and quality of delivery; and handling returns (Kawa & Zdrenka, 2016).

Operating in foreign markets requires additional work resulting from the need to prepare offers in the native languages of the customers or in languages generally accepted as international such as English. Furthermore, entrepreneurs are obliged to know the international trade law, as well as the local legal conditions of the countries in which their customers reside. Keeping up to date on this knowledge can be very cumbersome as regulations vary from country to country.

Taxes and additional fees are also an issue; they are still not clearly and unambiguously defined for online purchases. Uncertainty about the total price of a product including all taxes, duties, and bank fees may discourage customers from buying abroad. Payment methods and currency are also important. The customer should not be restricted to a single method of payment and should be given a choice of, for example, payment by bank transfer, debit or credit card, or on delivery. The same goes for the payment currency, which should match the buyer's currency or another currency preferred by the customer.

A considerable amount of literature is devoted to CBEC costs. One of the two most important barriers to cross-border shopping is expensive shipping (45%) (Keve, 2021). Transaction cost theory is often used to explain the differences between domestic and cross-border e-commerce (Shen et al., 2017). Selling abroad not only involves operational costs (Qi et al., 2020), but also transaction costs and additional costs associated with such activities as searching, managing information, negotiating, and monitoring (Kabadayi, 2011).

Although there have been significant changes in delivery prices in recent years, there remain large disparities in price between domestic and international delivery. Depending on the source and recipient country and delivery time (express, deferred, and postal), the cost of international delivery can be up to several times higher than the cost of a consignment realized within a single country. This raises the issue of asymmetry in the costs of logistics services. A lower price of the product sold often does not compensate for the cost of delivery, which discourages buyers from buying abroad. The cost of delivery can be reduced by extending the delivery time, but this may not meet customer expectations (Kawa, 2017).

Indeed, slow product delivery is the second most important barrier to cross-border shopping (36%) (Keve, 2021). Delivery time is a significant factor in customer satisfaction and presents a particular challenge for CBEC because of the distance between the retailer and the customer. In most cases, mainly outside border areas, an international shipment will take much longer than a domestic shipment. The disparity is exacerbated by the additional operations that are often involved in international shipments, such as tax collection and customs inspections (Kawa & Zdrenka, 2016).

In addition to delivery speed, customers need to be certain of a successful product delivery. When ordering from foreign stores, customers are concerned not only about when but whether, and in what condition, they will receive the shipment. Track and trace restrictions are also a problem. When a product is ordered from a distant country, its shipment is often handled by several separate companies, so the customer can only track and trace the shipment at certain stages of the transportation process, usually at the very beginning and end. This makes it very difficult to plan for even an approximate delivery date.

There are also problems with the standardization of loading units, procedures, and information exchange. Despite the growth in international trade, there remains a lack of standardized specifications for the marking of shipments and an interface for data exchange between individual companies. Another problem lies in a deficit of guidelines for the size and weight of shipments. For this reason, one logistics operator may treat a certain shipment as standard size, while another operator might consider the same shipment as oversized.

In international transport, there is a close relationship between the time and cost of delivery. A faster delivery of a product is associated with a higher transport fee and vice versa; thus, the longer deliveries are, the cheaper the transport fee. In domestic transport, especially in Europe, this relationship is relatively rare. Therefore, cross-border sellers should offer various delivery times and costs according to the following principle: the longer the waiting time, the lower the delivery cost.

In the case of very distant dates, the delivery may even be free of charge. For example, sellers in marketplaces with delivery times of over 30 days often do not charge for delivery. Research results show that customer perception of value is more sensitive to delivery cost than delivery time. According to Kilcarr (2014), some customers are even willing to pay more for products in order to get free shipping. For this reason, online retailers should implement and advertise free shipping offers or shipping promotions. At the same time, for some customers, a very distant delivery date may not be acceptable and may become a reason to switch suppliers. Retailers therefore should give a choice of delivery time and cost so that customers can customize their purchase to their own perceptions of the value associated with buying products online and according to their needs.

It is also important to remember that in e-commerce, logistics flows refer not only to activities related to the distribution of goods from the point of production to the final consumer but also to reverse flows in the form of product returns from consumers. Depending on the reason for return and a company's policy and strategy, returned goods are sent to the seller's warehouse, a logistics service provider, or another company (Wang et al., 2020). The challenges associated when shopping overseas also arise in the return of goods including the following: language – the seller must be contacted to establish the terms of the return; the currency and form of payment – the customer may not know how the money will be refunded; delivery costs – the customer has to face the cost of return shipping, which is higher for domestic shipments; and delivery time and quality – the customer receives the refund only after the seller receives the product, and this may take up to several weeks.

The indicated constraints affect customer evaluations of the costs and benefits involved in obtaining the product when deciding whether to buy online from a foreign store. The perception of value is individual and will vary depending on the specific person. The benefits in this case might be a lower price, better quality of product, or the opportunity to purchase products that are not available in the local market. Some of the likely costs are relatively long product waiting times, higher costs of shipping or possible return, limited tracking possibilities, and more time spent on getting to know the rules and regulations of a given seller and the regulations of the country from which the product is purchased (Kawa, 2017).

## 6 Best Practices and Policies in Cross-Border E-commerce

A firm's ability to create value and benefit from its investment in e-commerce is a function of the efficiency of its business model and how it is able to attract and retain customers on its website. This section discusses some of the best practices and policies firms can use to improve value creation and benefit from their investments in CBEC.

To be successful in cross-border e-commerce, it is important for firms to take advantage of the speed of information provision on the Internet to save on inventory costs, by generating accurate and regularly updated stock-level reports, and making products to order (Elia et al., 2021; Zott & Donlevy, 2003). In this way, obsolescence is minimized because the Internet offers firms a more efficient means for testing and refining new products. As online businesses are able to gauge customer responses in real time, they can adjust product offerings and prices quickly to meet customer needs (Gomez-Herrera et al., 2014).

Firms can take advantage of the richness and reach of the Internet to strengthen the ties that bind their supply chains and determine whether each function is performed efficiently and whether every link is appropriately strong (Zott & Donlevy, 2003). The reorganization of supply chains has created a wave of new intermediaries – firms that act as portals to the products and services of other firms. Although outsourcing all services is not desirable or feasible for all firms, outsourcing some services could be cost-efficient in CBEC (Bertrand, 2011). Outsourcing some services allows companies to realize greater effectiveness by strengthening the links to other participants in the transaction.

CBEC businesses should also carefully manage the range of products and services that are offered to the customer. CBEC enables businesses to overcome physical barriers to offering several products and services to customers. Nonetheless, although broader ranges of goods and services might allow firms to meet almost all the needs of their customers, there is a danger of overwhelming the customer with too much information (Ding et al., 2018). CBEC firms should recognize this information overload and limit the number of options they give in order to simplify decision-making for customers.

Alongside making purchasing decisions appear simple to consumers, the overall shopping experience should be convenient and reduce the overall stress levels of the customer (Zott & Donlevy, 2003). The process of completing transactions should not be unnecessarily complicated, and the number of steps that customers need to complete to make a purchase online should be reduced to the barest minimum (Wang et al., 2015). A good rule of thumb is that there should not be more than three clicks needed to make a purchase. Where too many clicks are needed, customers are likely to abandon the purchase (Zott & Donlevy, 2003).

Another way to simplify transactions is to avoid the use of overly graphical pages as this slows down page loading, which can adversely affect purchases in areas with poor Internet connectivity. The return policies of CBEC firms should be such that physical goods can be returned with little difficulty; the current policies of some CBEC firms – for example, repackaging and resending products – make returning goods challenging for customers.

CBEC firms should also take advantage of the Internet to reduce information asymmetry. Online transactions can increase information for both buyers and sellers. This is very important because value is created for all stakeholders when information-based market inefficiencies and asymmetries are minimized (Shao & Yin, 2019; Shih et al., 2013). Through CBEC, businesses gain from having more information regarding their buyers, including their preferences and demographics, which allows them to better target their product specifications and marketing efforts. Customers should also have access to information on the parties they are dealing with and detailed product and pricing information so they can make informed choices.

Another key to efficiency in CBEC is saving transaction time for customers. Significant reductions in transaction time can be achieved by reducing search times through effective search engines and clear color-coded product classes with reasonable numbers of subcategories (Liang et al., 2019). Companies can further reduce search time for customers by providing or offering complementary products. These complementary offerings could either be a part of their own product offerings or those of a partner, for which customers only have to click on a hyperlink to be taken to the partner's website.

Loyalty programs can be used to encourage repeat purchases (Stathopoulou & Balabanis, 2016). Giving rewards to buyers in the form of points that can be accumulated and redeemed for products is very popular in the bricks and mortar retail sector. This strategy could also be employed in CBEC to generate frequent purchases from overseas customers and higher sales volumes in the long term (Zott & Donlevy, 2003). Loyalty programs can also aid in creating a better relationship with overseas clients. In exchange for the reward, the seller can gather information about their customers' buying patterns and preferences and use this information to serve them better in future.

Another good practice for CBEC firms to adopt is to customize or personalize their products to suit the needs of customers in different geographical areas (Hu et al., 2016; Rihova et al., 2015). Customization can take diverse forms. Products can be made to order, personalized by the seller (i.e., the website that a consumer sees when visiting the site) or the interface, or adapted or customized by consumers. Customization is easier if a firm has enough knowledge about customers, which is a by-product of the richness in online markets (Zott & Donlevy, 2003). This knowledge fosters stronger relationships with buyers. Knowledge of a customer's preferences and tastes is a good marketing tool. It allows firms to target product offerings through banner advertising or sending e-mails to notify customers about special offers, which can entice customers to return to a site and buy a product.

Creating virtual communities based on geographical locations is a practice that can benefit consumers and CBEC firms (Moliner et al., 2018). Virtual communities allow consumers to share their purchase experiences, access competing firms and ideas, and shape the content they receive (Carlson et al., 2019). Thus, vendors are better able to target their offerings to particular customers that have segmented themselves. As customers organize themselves based on interests, virtual communities could act as a means of leveraging the reach of the Internet to enhance the flow of communication (Zott & Donlevy, 2003).

Finally, applying techniques of improving trust in CBEC will increase the frequency and volume of transactions (Pei et al., 2017). Consumer perception about the lack of security in e-commerce is a great impediment to the growth of CBEC. Lack of trust results partially from the absence of physical representation on the Internet, which prevents buyers from touching or feeling products, and partially from issues related to the abuse of credit cards (Ferm & Thaichon, 2021).

CBEC firms should find ways of addressing customer need for security through safe payment procedures and guaranteeing the confidentiality of information provided. The encryption of exchanges using a *secure service* (e.g., Secure Socket Layer (SSL), Veri-Sign) has become the norm in e-commerce. In CBEC, it is important to show the logo of the securing agency on home pages and also assure users of their security when they are making a purchase. Famous securing brands offer benefits because buyers will be more likely to trust a retailer who displays such a brand on its site.

Another approach that can be used to address trust issues is through the confirmation of a purchase via email. This email follow-up allays fears of technological failures blocking the completion of transactions (Zott & Donlevy, 2003). Trust can also be improved by displaying a link with a well-known partner brand or by linking buyers to the history of the business' bricks and mortar activities. Affiliate networks also help improve trust in e-tailers. Affiliate marketing gives businesses that do not have a strong brand recognition the opportunity to link up with established brands, thus gaining credibility through association.

## 7 The Case of Africa and E-commerce

Cross-border e-commerce is gradually gaining acceptance in Africa due to the presence of online shops such as Konga, Takealot (Koranteng et al., 2021). This has increased the quality of life by increasing the availability of diverse products to consumers and creating opportunities for individuals to start their businesses (Amofah & Chai, 2022). Despite its numerous advantages, users are pessimistic due to the danger of information leakages, cybercrimes, quality issues, and delivery (Sarfo & Song, 2021). In 2018, the Internet crime report from the Federal Bureau of

Investigation (FBI) indicates that 351,936 complaints were lodged and these involved monetary losses of over USD 2.7 billion. Scams from electronic purchases, personal data breaches, and extortion topped the list (Federal Bureau of Investigation, 2018). These problems are not only limited to advanced countries in the west like the USA, but they are also prevalent in Sub-Saharan Africa. For instance, Ghana lost about USD 35 million, USD 69 million, and USD 105 million in 2016, 2017, and 2018, respectively, to cybercrime (Ghana News Agency, 2019). Apart from this, there is a myriad of challenges that pose challenges to cross-border e-commerce in Africa. Lack of trust in systems, payment methods, and poor address systems in most parts of Africa have negatively impacted the widespread diffusion of CBEC. As Africa works toward building the African Continental Free Trade Area (AfCFTA), simplifying cross-border e-commerce activities will be crucial to increasing trade. In addition, removing the bottlenecks to cross-border e-commerce will be a relevant step in ensuring that CBEC is inclusive, and its benefits extend to poor and deprived regions.

African countries have not been heavily involved in international e-commerce negotiations. Of the 84 countries to sign a joint statement on an initiative to begin negotiations on the trade-related dimensions of e-commerce, only 5 are African countries (Cote d'Ivoire, Benin, Burkina Faso, Kenya, and Nigeria) (Banga et al., 2021). However, this is expected to change soon as, at a continental level, there is an intention for the African Continental Free Trade Area (AfCFTA) negotiations to include a protocol on e-commerce under its phase III, offering a special opportunity to collectively establish a unified position on e-commerce, synchronize digital economy regulations, and leverage the benefits of e-commerce (Banga et al., 2021).

As AfCFTA recognizes the importance of protecting personal data and promoting it without exception during trade, the AfCFTA could offer a common and unified framework for data protection, which would facilitate the building of online consumer trust in African countries and increase the extent of B2C e-commerce (Banga et al., 2021).

Facilitating a regional dialogue in Africa to create avenues for CBEC activities is key to enhancing efficiency. The African Union Digital Transformation (AUDTS) 2020–2030 recognizes the AfCFTA negotiations as a special platform for discussions on harmonization and the minimization of regulatory burdens on cross-border services and e-commerce in the continent. ICT services are an aspect of the priority areas adopted by the African Union, with AUDTS championing intra-African integration in digital trade to gain a broader participation by firms in national, regional, and international e-commerce. As such, the AUDTS proposes a reduction of bottlenecks to CBEC and market access by supporting the creation of a continental digital single market in line with the objectives of AfCFTA to remove legal and technical barriers to trade.

A problem that the AfCFTA could tackle to boost CBEC is the requirement of a local presence imposed by many African markets to deliver services. For example, Jumia, a Pan-African e-commerce platform, had to incorporate and create offices in each country of operation. This local presence is an expensive undertaking and implies that only businesses with huge capital can scale e-commerce in the continent.

A study of Ugandan ICT firms revealed that local presence requirements imposed by Rwanda (one of the main export destinations), coupled with the requirements on the nationality of foreign business partners, were limiting CBEC (ITC, 2019). Numerous regional blocks have made advancements on expediting CBEC that the AfCFTA e-commerce negotiations can draw on to ensure consistency.

When considering the laws to adopt in terms of CBEC facilitation, the AfCFTA could explore alternatives beyond electronic signatures and include other relevant contractual terms, such as the time and place of dispatch and receipt, party location, and utilization of automated message systems (UNECA et al., 2019). According to Banga et al. (2021), two major options could be explored in this regard: The first is technology-neutral, while the second outlines which kinds of signature technologies are acceptable. For instance, ECOWAS selected to enact a technology-specific law on the basis of major public infrastructure. Other issues around CBEC facilitation within the remit of the e-commerce protocol in the AfCFTA include banning unsolicited commercial electronic messages, ensuring the validity of electronic contracts, and protecting online consumers from fraud.

## 8 Emerging Technologies in Cross-Border E-commerce

Cross-border e-commerce relies on technology to connect sellers and buyers on web platforms; hence, it is important that both buyers and sellers quickly adopt emerging technologies. As technology becomes sophisticated and advanced over time, its importance becomes very relevant in the e-commerce value chain; some emerging technologies that are likely to impact cross-border e-commerce the most include sophistications in mobile devices which has made ubiquitous e-commerce possible. It has also led to the launch of new e-commerce apps. The rise of digital supply chains is also another emerging technology that will continue impacting cross-border e-commerce. New trends such as autonomous freight shuttle debuts, hack-proof RFID chips, invisible digital markers to aid in fighting counterfeiting products, robot technology for collaborative automated order picking, deployment of drones to inspect bridges, and the use of drones to deliver shipments. These emerging trends will positively influence management of extreme market and spiked demand. In addition, AI powered personalization is another emerging trend in CBEC. For instance, the India-based AI firm – Artificia – utilizes visual search and discovery devices to connect individual images with a buyer's interests to recommend products that they are more likely to purchase.

## 9 Conclusion

Cross-border e-commerce is gradually changing the face of cross-border trade and is gaining in popularity across the globe. In this chapter, the links between CBEC and supply chains were examined. An analysis of the literature revealed that CBEC is similar in many ways to international trade, but its use of the Internet means that it is characterized by globality, immediacy, personalization, and rapid development. These features create both opportunities and challenges for CBEC. On the one hand, CBEC overcomes spatial and temporal barriers, conducts paperless transactions, makes information flow more efficient, and enhances the development of enterprises. On the other hand, CBEC presents some major challenges, such as high costs, language barriers, and asymmetries in the cost of logistic services. Best practices that firms can adopt to improve their CBEC operations include strengthening supply chains, limiting the number of products offered to simplify decision-making, and offering convenience to customers by simplifying processes and reducing transaction time.

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# Internet of Things

## Applications and Challenges for Supply Chain Management

Himanshu Shee

## Contents




**Abstract**

The Internet of Things (IoT) is a growing ubiquitous technology, powered with radio-frequency identification (RFID) tags embedded in devices with wireless, mobile, and sensor capability, which can capture and share data seamlessly in an information network. The scholarly and practice fields of IoT has been growing rapidly and is indicative of this technology's maturity. Its applications are widespread with enormous potential for future deployment across industry sectors. To understand the development of IoT in supply chain management, this chapter reviews IoT for digital transformation (SCM 4.0) within Industry 4.0. We put forth some technological and business challenges facing the adoption decision. This chapter summarizes the latest development of IoT applications and trends, and identifies other disruptive technologies that can complement IoT and supply chain management amid technological and business challenges. Areas of future concerns and directions are also presented.



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**Keywords**

Internet of Things · Supply chain management · Disruptive technology · Industry 4.0 · Supply Chain 4.0

## 1 Introduction

Internet of Things (IoT) is one of the most prominent disruptive technologies and has drawn attention of academics, industry practitioners and society. It is described as ubiquitous technology with pervasive computing (i.e., embedded computational) capability over a network of hardware, software, devices, databases, objects, sensors, and systems all work together (Egwuonwu et al., 2022). The IoT ecosystem helps smart objects to effectively collect and analyze data eventually turned into useful information. Ben-Daya et al. (2019) described it as "... a network of physical objects that are digitally connected to sense, monitor, and interact within a company and between the companies and its supply chain enabling agility, visibility, tracking, and information sharing to facilitate timely planning, control, and coordination of the supply chain processes." (p. 4721).

Chui et al. (2021), at McKinsey and Company, projected the potential economic value of IoT at about \$5.5 trillion to \$12.6 trillion globally by 2030. It is gaining traction in every domain for its capability to capture, store, and share data that can be used for business intelligence.

This capability of IoT offers unprecedented visibility in supply chains that often faces challenges like counterfeiting, physical tampering, and theft (Ben-Daya et al., 2019; Egwuonwu et al., 2022). Although, IoT devices do exchange data with millions of other devices, the system can be an easy target for attackers (Stoyanova et al., 2020). Knowing these challenges provides supply chain partners warnings about internal and external situations that require quick remedial measures for its best performance.

Supply chain management (SCM) is defined as "the design and coordination of a network through which organizations and individuals get, use, deliver, and dispose material goods; acquire and distribute services; and make their offerings available to markets, customers, and clients" (LeMay et al., 2017).

Information sharing is key in any SCM for faster business decisions (Fawcett et al., 2007). In order that the right products in right quantity and condition arrive the right customers in right place, time, and cost (i.e., the 7Rs), real time information sharing is critical (Russell, 2000; Shee et al., 2021). The increased communication and visibility of goods flow using real time data capture and sharing are an added competitive advantage for those companies who embrace the latest information and communication technologies (ICT) in their smart operations.

The concepts of "Smart Manufacturing" and "Factory of the Future" in the context of Industry 4.0 have greatly influenced SCM. Industry 4.0 envisions cyber-physical systems (CPS) that allow machines to interface with minimal human interaction and supports autonomous information exchange between machines and production facilities. IoT, being placed at the center of Industry 4.0, provides a unified platform that enables CPS to use sensors, actuators, and smart devices connected to a 5G network (Taboada & Shee, 2021). The 5G network is an advanced networking solution where a number of smart devices can communicate with each other anywhere and at any time at higher data speed (up to 10 Gbps) and zero latency (less than 1 millisecond) (Rao & Prasad, 2018; Taboada & Shee, 2021).

The 2021 Gartner Digital Business Acceleration Survey found that: 80% of executives expected to increase spending on digital business initiatives in 2022; 65% would increase the pace of digital business; and 72% would shorten timelines for implementing digital business initiatives (Gartner, 2022). The questions are: to what extent is IoT used in supply chain management; what benefits have accrued so far; and what challenges face supply chains when it comes to its adoption? Summarizing all these will offer a consolidated view of IoT applications and its adoption potential.

This chapter, therefore, aims to identify the breadth and diversity of existing IoT in SCM applications highlighting the benefits of deployment, challenges of digital transformation (SCM 4.0), and opportunities for its adoption within Industry 4.0.

This chapter is organized as follows. Section 2 provides a brief discussion on IoT including its origin, enabling-technologies and platforms, Industry 4.0 and SCM 4.0. Section 3 focuses on IoT applications in supply chains and some concerns around its adoption and security. Section 4 offers discussion and direction for the IoT in SCM adoption against current challenges. Section 5 draws upon the theoretical and practical implications. Finally, Sect. 6 concludes with summary and limitations.

## 2 Background

### 2.1 Internet of Things (IoT)

The IoT is an ecosystem of several complementary technologies combined to connect the digital and the physical world (DeVass et al., 2018). IoT includes the sensors and actuators connected by networks to computing systems that monitor the health and actions of connected objects and machines. The term *Internet of Things* dominating application descriptions today dates back to 1999 and the Massachusetts Institute of Technology's (MIT) Auto-ID Center where it was coined to track items in a value chain. The members of the MIT Auto-ID Center developed Electronic Product Codes (EPC) that served as a universal identifier which was then used as radio-frequency identification (RFID) tag to identify items.

Today the notion of *Thing* is not limited to RFID but it encompasses many real and physical things – sensors, actuators, smartphones, smart items – that can be uniquely identified, read, sensed, located, addressed, and controlled autonomously via the Internet (DeVass et al., 2021b; Mishra et al., 2016; Tu, 2018). Traditional RFID is less satisfactory for its capability of too little information – identification, time, and other data – IoT can provide much richer information through sensor portfolios, advanced sensor data processing capability, and high level information fusion (Pang et al., 2015).

As more research is undertaken in this space for its continued use (Koohang et al., 2022), IoT vision and applications can be newer areas for users (Mishra et al., 2016). Citing the International Telecommunication Union (ITU), Mishra et al. (2016, p. 1333) state that IoT is envisioned, although the story is over 20+ years old, as a technological development for item identification ("tagging things"), sensors and wireless-sensor networks ("feeling things"), embedded systems ("thinking things"), and nanotechnology ("shrinking things"). IoT is still evolving in itself and portrayed as a technology that works well in combination with other technologies such as Blockchain (Egwuonwu et al., 2022), big data analytics (BDA) (Aryal et al., 2020; Hopkins & Hawking, 2018), Artificial Intelligence and Robotics (Payal et al., 2021), and others.

Earlier in its development, Atzori et al. (2010) defined IoT as having two visions because of its two words: Internet and Things. Essentially it says, IoT are "things" oriented using RFID tags that are connected to Internet network to transmit identification information, that is, numbers, names, and/or location addresses of entities. Borgia (2014) suggests 6As, from his perspective, as "Anytime-Anywhere," "Anyone-Anything," and "Any path/network-Any service," as a vision to observe IoT. Here, both products and even vehicles embedded with web-enabled communication devices – for example, RFID tags, sensors – are connected to location-based global positioning systems (GPS) enabling effectively the above "6As" vision. For example, technology like RFID tags, surveillance cameras, sensors, Zigbee/Wi-Fi, actuators, smart mobile phones, tablets, and personal digital assistants (PDA) are increasingly making their way into smart-logistics space where the conventional communication process is transformed into real time information flow (Autry et al., 2010).

As the technology adoption progresses in workplaces, IoT has become more effective and affordable. Its adoption and deployment in supply chain management progressively grows despite challenges (Verdouw et al., 2016). Shee et al. (2021) have summarized smart logistics functionalities, IoT and related technologies, and their suitable applications – see Table 1.

## 2.2 IoT Technology and Supply Chain Applications

IoT is a global network of many connected devices that rely on sensory, communication, networking, and information processing technologies that use RFID readers to identify, track, and monitor objects embedded with RFID tags automatically (Xu et al., 2014). It is often termed as "ambient intelligence," "ubiquitous network," "ubiquitous computing," "pervasive computing," and "cyber physical systems." With many applications across all sectors of economy, the innovative technology include RFID tags, wireless sensor networks (WSN), machine-to-machine communication, human-to-machine interaction, middleware, web services, and information

**Table 1** Smart logistics functionalities and related technologies

| No | Smart logistics functionalities | Related technologies | Suitable applications |
|---|---|---|---|
| 1 | Identification | Barcode, RFID, wireless sensors, retina scanner | Ensure a secured identification of objects at all stages of the supply chain |
| 2 | Location services | Global positioning systems (GPS) | Satellite navigation used to determine ground location of objects/people in real time |
| 3 | Condition monitoring | IoT sensors (cooling unit, missing parts/cargo, tire pressure, vehicle brake) | Allows to view the current state of products/vehicles to ensure good condition, error detection, missing parts and so on |
| 4 | Connectivity | 4G, 5G network | Communication network supports IoT-enabled objects connected to cloud |
| 5 | Visibility | GPS | Real-time tracking and tracing of movement of goods/vehicles |
| 6 | Environmental scanning | IoT wireless sensors | Able to interact with environment and communicates data at granular level (temperature, pollutants) |
| 7 | Autonomous | Embedded IoT sensors and actuators | Allows human to delegate activities to smart products and machines |
| 8 | Compatible | Middleware between warehouse management systems (WMSs) and enterprise resource planning (ERP) | Integrate existing technologies with new technologies |
| 9 | Data analytics | WMS and ERP systems | Analyze data and generate reports for business intelligence |
| 10 | Safety and security | IoT wireless sensors | Real-time data help in safety of objects, reliability and also security (e.g., food items and dangerous goods) |

Source: Shee et al. (2021, p. 827)

systems as we adopt and deploy this technology within supply chains (Pang et al., 2015).

As per Xu et al. (2014), IoT network has four essential layers:

(i) A sensing layer that integrates different types of “things” like RFID tags, sensors, actuators to sense/control physical world and capture data
(ii) A networking layer that supports data transfer through wired/wireless network (i.e., WSN)
(iii) A service layer that integrates services and applications through a middleware technology
(iv) An interface layer allows interaction methods to users and other applications

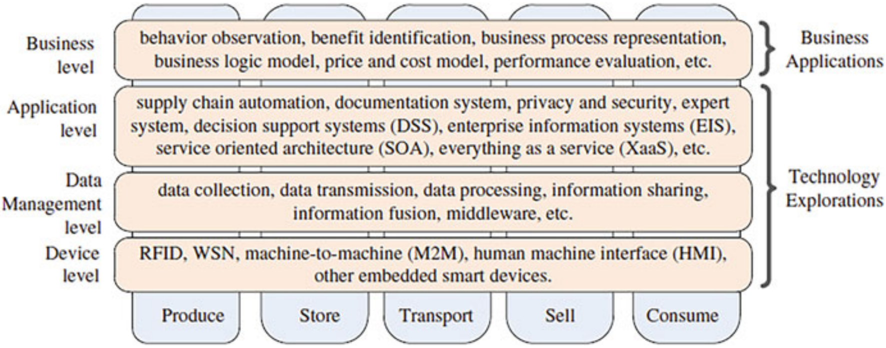



**Fig. 1** IoT taxonomy for technology exploration and business applications. (Source: Pang et al., 2015, p. 292)

Pang et al. (2015) presented IoT taxonomy for a food supply chain (Fig. 1) that possibly could be extended to other supply chains as well. In a supply chain – produce to consume – there are four levels including device, data management, application, and business levels. RFID tags are embedded (i.e., device level) to collect, transmit, and share data to all supply chain partners using middleware (i.e., data management level). The application level offers supply chain automation with decision support systems for *everything* as a service. The business level includes user behavior, benefits of IoT, and overall performance of the technology.

Mishra et al. (2016) have categorized IoT applications into four major domains: Industry, Healthcare, Smart environments, and Personal and Social domains. In the industry domain – such as retailers, distribution centers, transporters – accurate and timely information related to products can help organizations to rapidly respond to market changes. RFID and near field communication (NFC) technologies can keep track of products from design to distribution and then delivery to the end users. Similarly, sensors fitted into a truck driver cabins can monitor tire pressure, fuel consumption, location, and speed, and then the data can be shared with control room by global positioning systems (GPS) (Hopkins & Hawking, 2018).

In the healthcare domain, IoT helps track patients in hospitals, their entry and exit points in a ward, identifying incidents such as infant mismatching, wrong dosage of medicines, and incorrect procedures (Mishra et al., 2016). Xu et al. (2014) report that personal computing devices (e.g., laptop, mobile phone, tablet, etc.) using Internet access (WiFi, 3G) facilitate mobile and personalized IoT-based healthcare services. This situation has expedited the IoT-powered in-home healthcare services. IoT does not stop at data collection stage. Using NFC – such as Bluetooth, Zig Bee, Wireless HART (Highway Addressable Remote Transducer), and ISA100 wireless network – these data can be transferred to server where medical staff diagnose them for timely action.

In the smart environment domain, IoT is used to transfer data to control rooms through vehicle-to-vehicle and vehicle-to-infrastructure communication systems (Mishra et al., 2016). Sensors in parking lots help identify illegal vehicles, and, at toll booths it makes the payment easier. In the personal and social domain, IoT can be used in a range of applications such as mobile phones, laptops, personal computers, TVs, speakers, appliances, plugs, surveillance cameras, and lights. In case of loss or theft or displacement of any household things, users may receive a text messages via applications. These are each growing in unprecedented ways.

Over two decades since its inception at MIT's Auto ID Center, IoT applications are still new for many organizations and their supply chains. At the same time, it is effectively operating in some form or other for many. DeVass et al. (2021a, p. 611), in their qualitative investigation, find the RFID effectively used at the unit-level – pallet or container – in warehousing and transportation. The RFID tags are still expensive for item-level use.

Other affordable technologies such as bar-codes and scanners, PDAs (Personal Digital Assistant), RF (radio frequency) guns, Laser, light emitting diode (LED) scanners, and camera-based scanners are used extensively in receiving, slotting, picking, packing, and dispatching of goods to retail destinations. In a retail store environment, hand-held devices, point-of-sale (POS) devices, video analytics (facial recognition for customer recognition and context-aware offers), video Cameras, sensors (unique for perishable items), and mobile payments, including Apple-Pay, have been in use.

Chui et al. (2021) have offered a long list of IoT applications over three periods (2020, 2025, and 2030) where they have estimated its economic value of about 26% in manufacturing, hospital and other areas; and 10–14% in human-health settings by 2030. Table 2 shows various settings and examples where the IoT devices are, or, can be deployed for higher economic values. For example, in a human health setting, the devices can be attached internally or externally to monitor the health and wellbeing, and fitness. For a retail environment, IoT can be deployed in areas of higher consumer engagement in aisle and checkout counter, in-store offer, and inventory stock checking.

DeVass et al. (2021a) summarize how the IoT deployment integrates the supply chain processes; improves supply chain performance based on cost, quality delivery, and flexibility; and ultimately improves environmental, social, and economic sustainability of retail firms (Table 3). Building on organizational capability theory, they point out that IoT has an inherent capability to sense and capture data through object-to-object interaction. As IoT facilitates internal and external supply chain integration, it has the capability of real time visibility, auto-capture, real-time information sharing, and intelligence.

In a collaborative environment, information sharing is not only important but information quality is equally critical. Inaccurate and incomplete information will lead to wrong decision following the old adage "garbage in, garbage out." Information quality represents the accuracy, adequacy, completeness, timeliness, and credibility of information shared (Najjar et al., 2019). While IoT has the capability to collect volumes of data, managing the quality data appropriately for business intelligence is a real challenge. Arunachalam et al. (2018) have put BDA as the latest form of business intelligence (i.e., BI 3.0).

**Table 2** IoT use in various settings with examples

| Setting | Description | Examples |
|---|---|---|
| Human health | Devices attached to or inside the human body | Devices (wearables and ingestibles) to monitor and maintain human health and wellness; disease management; increased fitness; higher productivity |
| Home | Buildings where people live | Home voice assistants; automated vacuums; security systems |
| Retail environments | Spaces where consumers engage in commerce | Stores, banks, restaurants, arenas – buildings where consumers physically consider and purchase products and services; serf-checkout; in-store offers; inventory optimization |
| Offices | Spaces where knowledge workers work | Energy management and security in office buildings; improved knowledge-worker productivity |
| Factories | Standardized production environments | Manufacturing plants, hospitals, and farms; operating efficiencies; optimizing equipment use and inventory |
| Work sites | Custom production environments | Mining, oil and gas exploration and production, construction; operating efficiencies; predictive maintenance; health and safety |
| Vehicles | Systems inside moving vehicles | Vehicles, including cars, trucks, ships, aircraft, and trains; condition-based maintenance; usage-based design; presales analytics |
| Cities | Urban environments | Public spaces and infrastructure in urban settings; adaptive traffic control; smart meters; environmental monitoring; resource management |
| Outside | Between urban environments (and outside other settings) | Railroad tracks, autonomous vehicles (includes level 2 autonomy and up outside urban locations), and flight navigation; real-time routing; connected navigation; shipment tracking |

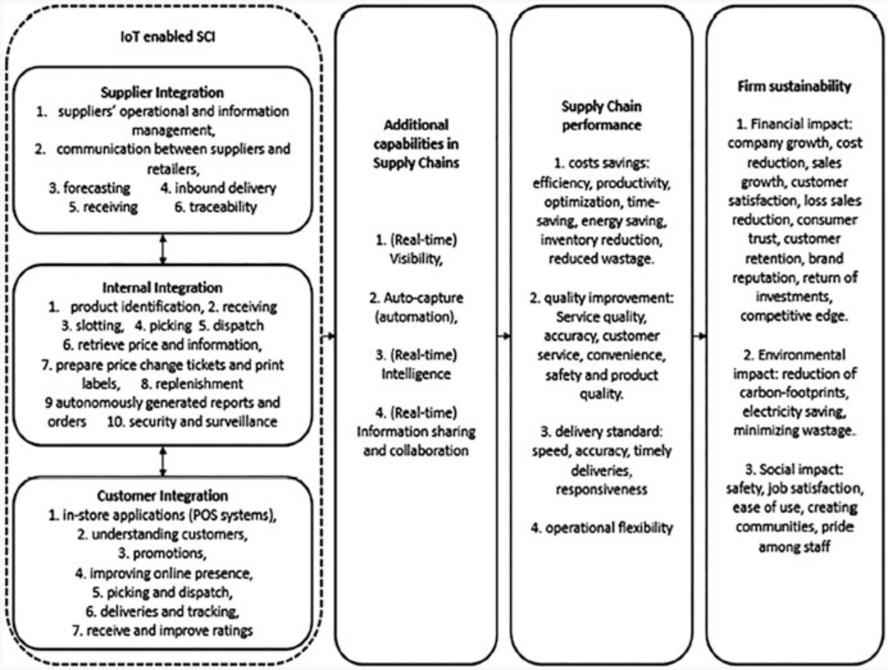
Source: Chui et al. (2021, p. 6)

## 2.3 Industry 4.0 and SCM 4.0: The Role of IoT

Industry 4.0 is the fourth industrial revolution that envisions cyber-physical systems (CPS), which allow machines to interface with each other with minimal human interaction. This technology creates a manufacturing environment where smart machines not only communicate with one another but also analyze and understand production issues to fix them as the need arises. This progressive thinking is labelled as a move toward smart factory or advanced manufacturing or Industrial Internet of Things (IIoT).

This factory of the future concept intends to use innovative digital technology like IoT among other technologies such as advanced robotics, artificial intelligence, hi-tech sensors, cloud computing, BDA, and 3D printing to manage manufacturing activities in an interoperable global value chain (Tjahjono et al., 2017). CPS is

**Table 3** IoT enables firm sustainability in retails




Source: DeVass et al. (2021a, p. 618)

composed of broadly four interconnected technologies: automation of knowledge work, IoT, advanced robotics, and autonomous/near-autonomous vehicles (Mishra et al., 2016). Kamble et al. (2018) propose a framework where Industry 4.0 will likely to facilitate business processes through the cyber-physical interaction of connected elements making the manufacturing system more flexible, economical, and environmentally friendly.

Prior to Industry 4.0, earlier versions focused on water and steam power to mechanize production (Industry 1.0); electric power to create mass production (Industry 2.0); and electronics and information technology to automate production (Industry 3.0), respectively. Now, it is the time that CPS in Industry 4.0 integrates information and communications technologies (i.e., IoT) with industrial technology.

With devices including cameras and sensors that remain handy, man-machine interaction is likely to be enhanced. CPS thus support autonomous information exchange between machines by connecting them in a production environment (Kagermann et al., 2013). Embedded with sensors and actuators, these smart machines will have the potential to connect through the Internet. In other words, it is not just an amalgamation of technological gadgets into the existing industries and practices, but it is a space where the products, processes, technologies, and employees are intertwined for higher efficiency.

Industry 4.0 has significant impact on Supply Chain 4.0. Supply Chain 4.0 proposes performance improvement by means of digitalization of logistics processes which lead to a faster, flexible, granular, accurate, and efficient next generation supply chain (Alicke et al., 2016). Previously, Supply Chain 2.0 leveraged in low level of digitization with “mainly paper-based” business decisions. Later, Supply Chain 3.0 was characterized by “basic digital components in place.” Even today, digital capabilities remain an ongoing agenda for many with basic algorithms used for planning/forecasting to improve digitalization in business decisions. Recently with Supply Chain 4.0, the highest maturity level, supply chains are intended to leverage the available data (even big data), for improved, faster, and more granular level of decision-making (Alicke et al., 2016). The potential impact of Supply Chain 4.0 is huge claiming 30% lower operational costs, 75% reduction in lost sales, and 75% reduction in inventory (Alicke et al., 2016, p. 10).

As collaboration between suppliers, manufacturers, transporters, and customers is critical to increase transparency and visibility of goods flow, digitalization, and automation of logistics processes using IoT will likely help capture, store, and share data across the supply chain. The objective is to integrate supply chain processes – supply chain integration (SCI) – using various technologies deployed at various nodes as suitable. DeVass et al. (2018, p. 4) define SCI as “collaborative inter- and intra-organizational management on the strategic, tactical and operational business processes to achieve effective and efficient flows of products, information and funds to provide the maximum value to the end customer at the lowest cost and the greatest speed.”

The increased benefits of flexibility, improved quality, higher efficiency, and productivity enable mass customization, meets customer demands, and creates value through new products and services to the market. All these benefits can be achieved through Industry 4.0 technologies. Tjahjono et al. (2017) find that implementation of Industry 4.0 technologies such as virtual and augmented realities, 3D-Printing and simulation each result in opportunities to support various key performance indicators (KPIs) – including product availability, customer experience, response time, time to market. Further, they find that BDA, cloud technology, cybersecurity, IoT, miniaturization of electronics, RFID, robotics, drones, and nanotechnology could be opportunities or threats on supply chain. Not realizing its benefits will be a threat for survival in the market.

Although several technologies are disrupting the traditional ways of working, and mostly appearing as standalone technologies having their own merits and advantages, they are highly interconnected. IoT in the form of sensors and actuators is getting increasingly powerful due to its decreasing cost that makes its use ubiquitous. For example, in a CPS environment within Industry 4.0, IoT is the foundation technology that automates data capture, storage, and sharing using the Internet. It integrates multitude of physical devices equipped with sensing, identification, processing, communication, and networking capabilities (Xu et al., 2014). Egwuonwu et al. (2022) suggest that blockchain technology and IoT together can improve trust among value chain partners in many areas, for example, technical challenges (i.e., confidentiality, authenticity, and privacy) and security challenges (i.e., counterfeiting, physical tampering, and data theft).

## 3 IoT Adoption and Current Concerns

Despite its advantages and strategic uses – as a key technology at the core of digital transformation – across range of supply chain settings such as factories, retailers, vehicles, warehouses, human health, city traffic control, home safety, and security, IoT has its own limitations and concerns that influence the adoption decision. It has faced challenges in relation to cost, interoperability, talent and skills availability, change management, and cyber security, particularly in enterprises (Chui et al., 2021).

Cost is the affordability of IoT where end users are worried about its value proposition or return on investment (ROI). Is it worth investing in this emerging technology or is the organization is just okay with ICT legacy they have in place? Without a business case demonstrating a clear ROI, any IoT-related project will not go beyond the proof-of-concept stage.

Interoperability is the extent of compatibility of IoT architecture with the existing sensors, ICT systems, or platforms. Does it require extra skills and investment while adopting IoT into the existing practices? Talent and skills refer access to technical competencies required to implement, scale, and operate IoT. Change management draws attention because IoT needs procedural, organizational design, or cultural changes within an enterprise that currently seen as a hurdle. Cyber security is the extent to which data is secured from external intrusion and attack where IoT is quite vulnerable (Chui et al., 2021). Against this backdrop, Chui et al. (2021) reveal many real-life applications that build confidence among future users.

DeVass et al. (2018) argue for IoT applications that help achieve supply chain integration capability, and they claim that co-existence of IoT capability in combination with ICT capability (i.e., interoperability) has significant effect on supply chain performance as well as sustainable firm performance. Effectively managing technology compatibility and interoperability issues will mean success in this race of technology adoption.

Using a case study, Abdel-Basset et al. (2020) argue that communication, technology, privacy, and security are some of the challenges associated with IoT deployment in businesses. Each of these constraints are discussed in the Table 4.

## 4 Emergent Concerns, Outstanding Research, and Future Directions

We have characterized IoT as an umbrella technology of sensors and actuators that are used predominantly to sense and capture data within an organization. The applications are widespread in manufacturing, warehousing, transports, and retailing

**Table 4** The main criteria for transition difficulties of enterprises to IoT technologies

| Main criteria | Abbreviation | Description |
|---|---|---|
| Communication | COM | The ability of devices and related devices to communicate using standard protocols. |
| Technology | TECH | The design and configuration of devices to ensure the Internal usability. The heterogeneous devices can communicate. Devices must be accessible and available. The hardware structure is different from device to another; however, technology can make a direct communication between different devices. |
| Privacy and Security | PandS | The privacy and security keep resistance for any vulnerabilities either from internal or external sources of the enterprise. To assure the security of all enterprises devices, objects, and data. |
| Job | J | Job measures the growth of medium-sized enterprise based on IoT technology. In addition to evaluate the customers' expectation of extending enterprise with IoT technologies. |
| Legal Regulations | LR | The legal regulations ensure the copyrights for data generated from any device or object to the produced company. |
| Culture | CUL | The culture provides a trained materials for employees or workers in enterprises to assure the enterprise successful progression. |

Source: Abdel-Basset et al. (2020, p. 10)

in fragmented way but yet to be extended to the supply chain where these organizations partner together (DeVass et al., 2021b).

As the focus shifted to data insights and business intelligence for timely action (Arunachalam et al., 2018), capturing and sharing more data at every transaction along the supply chain became paramount. IoT research using single organization context is always convenient where the authors use the perceptions of the partners rather than directly involving them in the study (DeVass et al., 2021a). This limitation has paved way for further study into the supply chain context involving upstream suppliers and downstream retailers. This type of dyadic or triadic business-to-business supply chain study helps gains insight into the transparency and visibility of goods flow which remains a critical issue.

Real time decision-making using IoT will likely mitigate delay and risk, improve efficiency in production, distribution, locations of goods, quality assurance, and transport efficiency. Therefore, implementing IoT in supply chains can improve efficiency, minimize operating costs, and increase customer loyalty (Egwuonwu et al., 2022). Rejeb et al. (2020) posit that "integration of IoT in the supply chain is still in its infancy (p. 12)." Therefore, future research needs more attention along a supply chain.

The digital supply chain is still viewed as plagued by difficulties such as a lack of provenance, transparency, and confidence Muduli et al. (2022, p. 3). The Pharmaceutical supply chain, for example, requires real time communication, transparency, and visibility of drugs and medicines to arrive at hospitals to save lives. That means investigation into the extent of data sharing using technologies – such as IoT in combination with other technologies – will help hospital pharmacies, wholesalers, and manufacturers avoid drug shortages, counterfeit, adulteration, and like.

In particular, opportunities and challenges of IoT, blockchain, and big data analytics adoption need to be explored. For example, perishable fruits and vegetables, consumer goods, and other supply chains can use IoT for real time data capture and business intelligence to improve warehouse productivity, delivery efficiency, waste minimization, and vulnerable partner identification. As IoT applications exist in some forms (e.g., bar code, RFID, sensors) in retail, warehousing (DeVass et al., 2021a; Shee et al., 2021), and transport (Hopkins & Hawking, 2018), question remains as to what extent these data are utilized effectively with analytical tools (e.g., big data analytics) for improving existing practices. Data availability has been a major issue – IoT deployment may well resolve this issue. But question is what extent these data will be appropriate for business analysis. Overall, IoT and BDA joint adoption challenges in supply chains need further investigation.

Blockchain technology (BCT) is gaining traction because of its potential to trace and track, reduce risk and uncertainty, protect items from counterfeiting, physical tempering and pilferage, and secured all transactions from the point of origin to the consumption. As IoT brings in more data through machine-to-machine, human-to-machine interactions, they are highly vulnerable to cyberattack and hacking from external sources. BCT offers a secure and protected environment for data security against these risks and uncertainties.

Nabipour and Ülkü (2021), in a systematic literature review, find that BCT and IoT will undoubtedly impact supply chain strategies and solutions. It points out that IoT and BCT adoption is reasonably a good decision to go together to collect and protect data in a secure way. An investigation into the challenges facing the organizations and supply chains in BCT and IoT adoption will be worth considering. In support of this, Müllner and Filatotchev (2018) suggest a future research to explore the effects of BCT in combination with IoT system in supply chains beyond geographical boundaries to explain different institutional and legal challenges.

Chui et al. (2021) posit that IoT applications are slowed down due to organizational challenges, technology cost, cybersecurity, and interoperability issues. This has resulted in "pilot purgatory," that is, about 70% of manufacturers are unable to go beyond pilot projects. However, as IoT integrates various devices equipped with sensing, identification, communication, and networking capabilities in a complex CPS, they are getting increasingly powerful, miniaturized, less expensive, and pervasive in use (Xu et al., 2014).

Importantly, organizations of all sizes are increasingly building up their digital operations through technological competency, resources, and capability for their Industry 4.0 targets. This action was quite visible during the recent crisis of COVID-19 pandemic where organizations were urged to mostly rely on technology for their business continuity. But it was not clear how many organizations adopted new technologies or whether their current technologies were adequate to manage and recover businesses during lockdown, social distancing, and border closure disruptions.

As organizations live on their technological legacy, they are often vulnerable to external disruptive technologies (Radu, 2020), such as IoT, BCT, and BDA, that the organizations need to undertake an assessment of their adoption. Technology adoption is generally measured using the TOE (technological, organizational, and environmental) framework that helps scan the technological, organizational and environmental aspects. In a liberalized, privatized, and globalized (LPG) environment, any organization is free to go ahead with the adoption but it is always good to refer others' action within the sector. So, future research can use TOE framework to assess the adoption challenges of these technologies (i.e., IoT, BCT, and BDA).

## 5 Theoretical and Managerial Implications

A range of implications related to IoT and the supply chain exist for academic researchers, practitioners, and society as a whole. From theoretical perspective, IoT and other associated technologies enhance the technological capabilities thereby extending the organizational capability theory to incorporate IoT capability as a value add to the current ICT capability.

This comprehensive perspective portrays a clear picture of the reality of IoT applications in organizations that reap the benefits of data capture and sharing in contrast to mostly a conceptual and rhetoric approach to data sharing in a supply chain management. It reveals the opportunities as well as challenges of IoT adoption in organizations and supply chains – that need to be investigated going beyond the possibilities and understanding the various elements from motivation to adoption and improvement.

IoT technology, its architecture, and benefits (e.g., fast, flexible, and efficient) are discussed alongside the inherent issues related to technology cost, interoperability, cybersecurity, access to talents, and privacy and confidentiality (Chui et al., 2021). Further, it adds that as organizations and their supply chains are in a path of transformation into a digital supply chain (SCM 4.0), this chapter highlights, what Alicke et al. (2016) call, the "innovation environment with a start-up culture." The concepts here offer organizational freedom and flexibility to adopt state-of-the-art IT systems enabling rapid cycles of development, testing, and implementation of solutions. This chapter highlights the power of big data and data analytics (BDA) that are associated with IoT deployment. As data availability within IoT ecosystem is no more an issue, BDA must be integrated for predictive analytics in demand planning as a flexible, continuous process.

For managers, this chapter brings actual applications of IoT across various settings in combination with other technologies (i.e., BCT and BDA) and develops confidence in managers who have still watch and wait policy on technology adoption. Although, IoT applications within organizations are gaining popularity, managers need to understand that its benefits can be best realized if all partners in supply chain be connected by IoT for data capture, sharing, and data insight using Internet, in particular, the emerging 5G technology (Taboada & Shee, 2021).

The chapter informs managers that IoT is broadly a means of data collection among other features, and they, their organizations, and supply chain partners need to think about how to exploit the volume of data optimally for business intelligence. However, several technical challenges – such as confidentiality, authenticity, and privacy; and security challenges, such as counterfeiting, physical tampering, and data theft are associated with IoT deployment (Egwuonwu et al., 2022).

Managers need to understand how BCT can protect data security against fraud and theft while BCT with IoT can lead to improved scalability, security, and traceability. Building talent and IoT-related skills, a major challenge in this journey, organizations can proceed with a startup culture allowing a high degree of flexibility that enables a group of skilled people to go for a rapid cycle of development, testing, and implementation.

Another foreseeable benefit for practitioners is the collaborative planning using IoT-enabled supply chain clouds over a 5G network for a joint platform between customers, transporters, and suppliers, providing a shared logistics planning solutions. This chapter should inspire practicing managers, industry associations, and policymakers to speed up spending on IoT, and related policy, that promises better ROI and serves customers at a lower cost while preserving the environment and up-keeping social aspects (DeVass et al., 2021a).

Beyond business benefits, IoT contributes significantly to society. For example, IoT devices (wearables and ingestibles) can monitor and maintain human health and wellness, fitness, and higher productivity. In home setting, voice assistants, automated vacuums, security systems, and lighting can be managed by IoT. In urban settings, IoT can control traffic lights, rubbish bin, smart meters, environmental monitoring and so on (Chui et al., 2021). DeVass et al. (2021a) state that IoT can impact job satisfaction, safety, ease of use, creating social communities, and pride among staff. Further, as IoT is transforming the supply chain into a semi/autonomous ecosystem, it creates a requirement for digital talent and skills around IoT.

## 6 Conclusion

IoT, in a complex CPS, integrates various devices equipped with sensing, capturing, communicating, processing, and networking capabilities. Its adoption, utilization, and multitude of applications are growing wider as the sensors and actuators are increasingly powerful, cheaper, and smaller. IoT has existed in warehousing, retailing, and transport in the form of various technologies such as bar code in items, RFID in units, RF guns for scanning, video surveillance camera, mobile phone scanner, and sensors in distribution center’s sortation facility.

Truck telematics has been integrated with GPS to better understand and improve the driving behavior by monitoring live sensor data on speed, location, braking, and engine condition from a fleet of vehicles (Hopkins & Hawking, 2018). Undertaking a survey in Australia in 2018, Edwards and Hopkins (2018) find IoT as the most used technology with 48% of supply chain and logistics organizations using it. Other applications include human health, home, and offices (Chui et al., 2021).

As IoT has been is use in some form as legacy systems, logistics organizations need to know that traditional RFID has its limitations (i.e., identification, capture, and sharing) as compared to the broader and more recent IoT. This new IoT offers much richer information due to additional sensor portfolios, advanced sensor-data processing, and high level information fusion (Pang et al., 2015). But, challenges and concerns remain due to a lack of trust among supply chain partners. For example, technical challenges (i.e., confidentiality, authenticity, and privacy) and security challenges (i.e., counterfeiting, physical tampering, and data theft) are very common areas of concern (Egwuonwu et al., 2022).

These issues obviously influence the technology adoption decision for those who are going through "wait and watch" policy and worried about return on investment (ROI). Based on theories of diffusion of innovation (DOI) (Rogers, 2003) and technology-organization-environment (TOE) framework (Tornatzky et al., 1990), Shee et al. (2021) suggest for assessment of technological (i.e., interoperability and compatibility, ease of use versus usefulness), organizational (i.e., top management support, employee skills, readiness and adaptability, resources availability, and allocation), and environmental (i.e., competitors' move, alternate technology option, regulations, cyber security) factors that determine likely adoption success.

As no technology stands on its own, IoT applications are gaining momentum in conjunction with other technologies such as blockchain, big data analytics, cloud, Artificial Intelligence (AI), 5G, etc., as it is adapted in organizations and supply chain management. Blockchain enhances supply chain management by improving IoT scalability, security, and traceability for creating more value for partners (Egwuonwu et al., 2022). IoT has expanded its focus beyond supply chain and business information management to include supply chain design, model, and performance using the power of big data analytics (BDA) (Aryal et al., 2020). Business analytics and business performance links are moderated by the level of IoT adoption, IT integration, and trust (Ramanathan et al., 2017).

Shee et al. (2018) claim that cloud-based technology has positive effect on supply chain integration. Cloud technology is a good way to get things connected in real time and beneficial for all sizes of businesses. Hopkins and Hawking (2018) suggest IoT data (e.g., camera-based technologies) to store directly to the cloud and use of BDA can improve truck routing, exact times/locations of fuel refill, and to forecast predictive and proactive maintenance schedules. Linking AI to create Internet of Intelligent Things will characterize future IoT as "self-configuration, self-optimization, self-protection, and self-healing" (Arsénio et al., 2014). Taboada and Shee (2021) emphasize that high bandwidth and low latency features of 5G network will offer a unified platform for multiple device connectivity (i.e., IoT) in real time. Therefore, IoT integration with other disruptive technologies is not only based on technology-centric approach but it adds values (i.e., traceability, cost reduction, quick response) in supply chain management.

This chapter only presents as a snap shot of the latest but selective published articles and Internet sources on IoT applications in supply chain management. It provides some general working principles of the technology and its architecture and adoption challenges. Although the interest in IoT in supply chains is continuously growing from a variety of forces, the road has many twists and turns with significant untapped potential for this continuously disruptive technology. Supply chain applications are the frontier with greatest promise.

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# Virtual Project Teams in Supply Chains

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## Contents



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**Abstract**

Virtual project teams have become popular across various sectors. Studies indicate that virtual teams offer advantages including additional knowledge creation and skills development. They also provide organizations with wider perspectives when compared to traditionally collocated teams. Utilizing theoretical concepts from virtual teams and project teams, this chapter describes how virtual project teams can be applied for supply chain project management. It highlights the crucial role played by people, processes, and technology in supply chain project management. The chapter justifies the need for supply chain project teams to be well prepared to deliver their projects with effectiveness and proposes certain strategies for attaining resilience.

**Keywords**

Post-covid era · Projects · Resilient teams · Supply chains · Team development · Virtual project teams

## 1 Introduction: An Overview of Supply Chains

Today's business environments continue to remain dynamic for various reasons. For instance, globalization in several industry operations has caused most individual companies to not operate autonomously but to become parts of wider supply chains to remain competitive and respond to client requirements with more agility. There is also continuing growth of rural areas worldwide with wealth moving towards underserved regions – expanding business frontiers (Alicke & Rachor, 2016).

As a major fallout from COVID-19, many companies have had to contend with the pandemic effects while trying their best to maintain supplies of components and raw materials required within their supply chains. It is becoming more difficult and less economically viable for individual companies to produce on their own.

As a response to the above mentioned and several other global pressures, many companies are acknowledging the need to concentrate on their core competencies outsourcing noncore operations as a way to survive competition. These increased outsourcing activities – locally, national, and internationally – have resulted in extensive supply chains. Businesses are still grappling with increasing diversity in customer requirements. Companies are required to collaborate with others to meet end customer requirements while remaining competitive.

Supply chains have existed in various shapes and forms for centuries. But there are certain indications that the seminal studies by Forrester (1958) on system dynamics theory and his efforts to examine product delivery systems brought it to theoretically and academically into the limelight.

A recent GOOGLE search (2022) for "supply chain definition" returned about 3,340,000,000 results in 0.51 s. As part of this chapter, a selection of these definitions is highlighted. According to APICS Dictionary|ASCM (2013) , a supply chain is *"the global network used to deliver products and services from raw materials to end* *customers through an engineered flow of information, physical goods, and cash.”* Stevens (1989) defined supply chain as a connected series of activities which is concerned with planning, coordinating, and controlling materials, parts, and finished goods from supplier to customer. Chopra and Meindl (2010) stated that supply chain consists of all parties participating, either directly or indirectly to satisfy a customer request. Part of their explanation noted that the main objective of any supply chain is to accomplish the customer requirements while generating profit for itself.

Supply chains also maintain information movements, cash flows, and relationships apart from product movements. These movements mostly occur through networks in which manufacturers might obtain products from several suppliers and send these products to distributors or end customers.

The definitions highlighted above equally suggest that managing supply chains might not be a straightforward task from technological and human resources perspectives, especially with various players becoming active at different instances. Several technologies have emerged that are altering traditional ways of working within supply chains. From a human resources perspective, supply chains have become more dispersed and dynamic with most supply chain members becoming geographically disparate and linked to organizations with different interests.

Human resource management has always been a critical element in supply chain management (SCM) (Sweeney, 2013). Noting that the supply chain is essentially a “human chain” and one of the overarching priorities of the SCM domain should be on the people who manage supply chains. Within the remaining part of this chapter, the focus is more on the latter – with a special focus on implications for virtual project teams in supply chains.

## 2 Explicating Project Teams

Teams provide opportunities for combining diverse skillsets, talents, and perspectives to realize business or other defined objectives. There are many different notions about what a team is because people have different reference points including discipline, sector, or vocation (Zuofa & Ochieng, 2017). Teams have been defined as a group of people working together in collaboration or cooperation towards a common goal (APM, 2019). According to the Project Management Institute (PMI), a project team includes the project manager and the group of individuals who act together in performing the work of the project to achieve its objectives (PMI, 2013). Granted, there are several other ways to define teams, but in this chapter, project teams are described as a collection of people working together to achieve common project objectives.

As people work together, they are essentially striving to optimize their creativity, novelty, problem-solving, and decision-making abilities to actualize stipulated tasks or project performance. The gathering of people with the purpose of making them a cohesive whole and ensuring the benefits of all stakeholders should be fundamental when configuring teams. Given the nature of supply chains, its project teams are increasingly being formed not just from within one organization but from several organizations and often geographically disparate. For example, a technician in a Durban assembly plant inspecting an equipment for installation may now be connected to a subject matter expert in Houston using a headset. Through remote collaboration, the subject matter expert can provide detailed guidance and help resolve any complex installation issues. This illustration presents an additional set of benefits and challenges further examined as this chapter progresses.

## 3 Conceptualizing Virtual Teams

Virtual teams are groups of geographically or administratively dispersed coworkers linked by means of telecommunication and information technologies (IT) to accomplish set organizational objectives (Zuofa & Ochieng, 2017). Virtual teams represent people "working together but separately." Previous studies including Cascio and Shurygailo (2003) outlined specific criteria like teleworkers (with one manager in one location), remote team (with one manager of a distributed virtual team), matrixed teleworkers (multiple managers in one location), and matrixed remote teams (multiple managers across multiple locations) as key factors required for distinguishing virtual teams from other forms of teams. While in other cases, most virtual teams have also been defined based on the following characteristics:

- Teams that operate totally or partially through IT and telephonic communication tools.
- Teams where members have diverse roles and are often geographically dispersed across varying time zones.
- Teams with flexible structures, lasting over a finite period aligned with the project durations – for instance, during new product development or when providing a solution within a supply chain network.

Despite the above characterization, Flavian et al. (2022) maintained that virtual teams should not be mistaken for teleworking. They maintain that teleworkers do not have to work as a team and that within virtual teams, certain forms of interactions maybe undertaken face-to-face. Conceptualization of virtual teams has arguably remained problematic because of the varying contexts or disciplinary adaptions in which virtual teams have been studied. Nevertheless, dispersion, diversity, and technological support appear to be the underlying characteristics and convergent points when attempting to conceptualize virtual teams (Zuofa & Ochieng, 2017).

Virtual teams are more significant in organizations and their advancement while their popularity continues to increase. One major recent factor attributed to the advancement and popularity of virtual teams has been societal changes due to the COVID-19 pandemic. Reports from Statista (2020) indicate the number of employees in the United States working virtually has exponentially grown from 17% to 44%. With this type of increase, affected employers are left with a crucial dilemma on where work should take place and a contemplation on what to do with existing office spaces.

## 4 Exploring the Benefits and Shortcomings of Virtual Teams

Consider a software development team in London that can hand over a project to colleagues in Mumbai at the end of the London day. When London is just waking up to a new day, Mumbai is already in full swing work mode and vice versa. Likewise, imagine a time where an intended humorous or satirical email or instant message was misinterpreted by a recipient to mean something more serious. Indeed, even during live video conferencing, the act of speaking in-person cannot be completely replaced. The simple action of sitting next to another team member in a *project war room* can make available positive moods and reassurance during a tense status update meeting, but this is not a possibility in a Teams or Zoom room. The above narration succinctly summarizes two possible scenarios in virtual teams. It also provides the basis for the rest of this section to further identify the benefits and shortcomings of virtual teams.

Extant literature (Pangil & Moi Chan, 2014; Pinjani & Palvia, 2013; Bergiel et al., 2008; Townsend et al., 1998) is replete with evidence indicating that organizations may benefit from using virtual teams. Team members geographically dispersed can collaborate on the same project without physically being at the same location (Zuofa & Ochieng, 2017). Some benefits of these collaborations include enhanced productivity, increased competitive advantage, and improved customer service. Virtual teams equip companies with greater flexibility and responsiveness (Pangil & Moi Chan, 2014). Other benefits include reduced cost, and working in virtual teams may enhance reduced travel budgets. Since virtual teams have potentials of bringing together multiple perspectives, they facilitate more synergy and innovation (Townsend et al., 1998). Lastly, by using virtual teams, organizations can react to their dynamic business and client requirements in more agile ways.

Despite the outlined benefits and its increasing popularity, virtual teams are still associated with various shortcomings (Fang & Chiu, 2010; Krumm et al., 2016). There is a lack of everyday nonverbal, face-to-face communication; a lack of social interaction; a loss of team spirit; and a lack of trust and cultural clashes, all viewed as disadvantages of working virtually (Bailey, 2013). Other shortcomings include the lack or absence of physical interaction and the synergies that often accompany face-to-face communication. Furthermore, the unwillingness of team members to spontaneously share their knowledge was discussed by Fang and Chiu (2010). On a final note, notable shortcomings affecting the performance of virtual teams include the relative lack of opportunities for virtual team members to engage in social and nonwork activities as another challenge (Furst et al., 2004).

## 5 The Development Stages of Virtual Teams

For several years, many studies (Fisher, 1970; Gersick, 1988, 1989; Tuckman, 1965) have examined the team development. Tuckman's (1965) popular model initially highlighted four sequential stages consisting of forming, storming, norming, and performing, then subsequently included the adjourning stage, now known as the fifth stage.

- The forming stage typifies a period in which members try to determine their positions in the group, procedures to follow, and the rules of the group.
- The storming starts when conflict arises as team members resist or question the influence of the group and dissenting views on ways to fulfill the accomplishment of tasks emerge.
- The norming stage starts when the group "normalizes" by attaining a level of cohesiveness, commitment to its tasks, outline norms for appropriate conduct, and identifies more common approaches to accomplish their tasks.
- The performing stage occurs when the group displays proficiency in collaborating to achieve its goals and develops ample flexibility as they work together.
- The adjourning stage encompasses the completion of the group's task and the eventual disbanding of the team.

The steps outlined in the Tuckman's model are considered vital for teams, and like most linear models, the success of an initial stage is usually crucial for the latter stages. Another model is the punctuated equilibrium model (Gersick, 1988, 1989). This model consists of different stages and posits that irrespective of group structure, objectives, or deadline, all groups tend to undertake their tasks in a common progressive pattern. At the onset of the first stage of the model, groups outline their objectives and basic assumptions about both the project and their members get established. Usually, this first stage is characterized by high levels of ease and socialization. Towards the end of the first stage, the level of inertia is usually higher – resulting in relatively reduced performance. Group members assume that deadlines are still faraway in the future and so there is limited sense of urgency towards completion of the project or associated tasks.

The second stage of the model is a transition phase, usually denoted as the "mid-life crisis" period, that stimulates a sense of urgency among the group members. As such, members put forth a significant amount of effort to complete tasks in relatively shorter amounts of time. At this stage, problems are usually confronted, and criticisms about the project or group start being considered more seriously, resulting in high performance.

The final stage is characterized by changes in the group that facilitate the achievement of their tasks. At the commencement of the final stage, the group embraces new perspectives, identifies new directions for their goals while discarding any old unsuccessful patterns. The higher levels of performance relative to time is usually the result of the group acknowledging that there is limited time and their deadline is short. Therefore, the group puts in a final burst of energy to complete their tasks.

The punctuated equilibrium model can also be assumed to be governed on the premise that internal group processes focus on the durations outlined for any project. In summary, the punctuated model proposes that groups may repeatedly experience the storming and performing stages (i.e., evolutionary changes), with revolutionary changes taking place during short transitional intervals. Usually, any disruptive interval is considered as an opportunity for innovation and creativity.

The time, interaction, and performance (TIP) model (McGrath's, 1991) suggests an alternative view of group development. This model believes that the group development process is multifunctional rather than sequential. Thus, TIP proposes that groups perform three separate functions: production, well-being, and member support. As such, group members concurrently engage in and maneuver to one of four functional approaches: inception, problem-solving, conflict resolution, and execution.

Quantitative methods have been used to identify the development stages of virtual teams. In one quantitative model (Lin & Roan, 2021), there are three identified stages – inclusion, control, and affection. These stages are consistent with the previous qualitative studies. The initial or inclusion stage is characterized by an intensity and has an upward trend. During the second or control stage, centralization has an upward trend. For the final or affection stage, intensity and density have upward trends while centralization has a downward trend. However, density and centralization became smooth in this final stage. One merit of this quantified approach is that it provides managers and leaders with a simple but useful approach to understand the needs for managing different aspects of team behavior at each stage of development. Once this approach gets established, managers and leaders can make plans to improve existing processes and priorities, and embrace suitable principles that result in improved virtual team performance.

A few noteworthy observations bring this discussion on the development of teams to an end. Firstly, Haines (2014) proposed that the fundamental development processes of virtual teams have to be experienced similar to face-to-face teams, provided that the virtual team members freely communicate with each other in the shared workspace. Thus, some of the stages mentioned above might be tenable during the development of virtual teams. However, it is worth mentioning that virtual teams need to follow a development process to effectively work together (Hertel et al., 2005; Sarker & Sahay, 2003). Some of the perspectives discussed (see Sect. 4) may still impede virtual team development. Consequently, significant amounts of systematic effort are needed for virtual teams to develop to the point where their members can readily collaborate and achieve their objectives. Perhaps, for this reason, Furst et al. (1999) and indicated that theoretical development and empirical research are still required to better understand and respond to the challenges that virtual teams encounter.

## 6 Virtual Project Teams in Supply Chains

As observed from the literature (Alicke & Rachor, 2016; Olhager, 2013; Fisher, 1997), supply chain operations and their supporting project teams are comprised of members who work together, are located in proximity, have regular face-to-face communication, and coordinate their activities. In most cases, they were considered as simple sequential or serial systems, with raw materials entering from one end and being transformed into semifinished or finished goods (outputs) that leave at the other end.

Because of several factors like globalization and the expansion of IT, the need for the colocation of supply chain operations and their project teams has been greatly reduced. Other reasons can be attributed to the need to exploit the core capabilities of all the partner enterprises through strategic and operational alliances that augment competitiveness by integrating value-added activities and knowledge in the fulfillment of projects (Swarnkar et al., 2011). Recently, the World Economic Forum – in reaction to the COVID-19 crisis – indicated that *"the products that consumers demand, factory processes and footprints, and the management of global supply chains are being re-shaped to an unprecedented degree and at unprecedented pace"* (WEF, 2021).

Currently, managing virtual supply chain project teams can be considered a complex task due to differences in the roles and responsibilities of various team members, divergent approaches to coordination and task handling among entities (see Vignette 1), and performance assessments.

**Vignette 1: Let Me Say Something to You**

Several years ago, while delivering a particular project on a DP3 pipelay and accommodation vessel situated about 70 miles offshore Nigeria, a standstill occurred because of differing opinions about the best approach to handle a particular modification issue on a pumping system. While on a review call, the following conversation occurred between one of the authors of this chapter (Mr. A) and a team member then based in Houston (Mr. B).

*Mr. A: Let me say something to you Mr. B? Why don't I just produce a quick sketch and send it across before we continue discussing?*

*Mr. B: But we already have working diagrams. I am not sure about the value of this. I really believe this is unnecessary and won't bring anything new here. We do not really want to spend more time without progress. Also, I might need to go on a tea break shortly.*

After deliberating, Mr. B accepts the proposal from Mr. A to review the sketch together.

*Mr. A: I have just forwarded it to you. Once you receive it, let me know.*

*Mr. B: Received, carry on.*

A discussion ensues between both project team members.

*Mr. B: Ok, well I was under the impression that you meant a total replacement of the valves, now this makes sense. Gotcha!*

Although the scenario in Vignette 1 occurred in an offshore engineering project team, it still confirms the need to correctly communicate and explore options when working in any virtual project teams. In another vein, it is challenging for those involved in making manufacturing (internally/process-focused) decisions and those making marketing (externally/customer-focused) decisions to arrive at agreement (Tang, 2010; Oliva & Watson, 2009; Swink & Song 2007).

The dispersion of individuals does challenge how relationships among virtual teams are managed (Fernandez & Jawadi, 2015). From a technological standpoint, the high potential for digital disruptive technology adoption (including digital twins) in supply chains all further complicate existing technological interfaces and how team users engage with them. The nature of supply chain project teams make them prone to dealing with members located in different time zones, hence there maybe several language and cultural differences, as well as other concerns over the establishment of interpersonal relationships.

Within virtual project teams in supply chains, building trust and fostering a team spirit that boosts tacit knowledge transfer cannot be disregarded. But how can this be achieved? Accordingly, Maynard et al. (2020) advocated that team management should be adopted for supply chain management, as a means of ensuring that individuals across various functions share their diverse information and experiences with each other.

Team leadership is another factor that affects virtual project teams in supply chains and explains why they should be managed differently compared to traditional teams. But there are limitations on the effectiveness of virtual team leadership (Hoegl & Muethel, 2016). Virtual project teams in supply chains require alternative leadership approaches rather than traditional face-to-face leadership because project leaders in virtual supply chain environments need to integrate and maximize available resources to reach their project aspirations within stipulated delivery schedules. For instance, delegating and empowering are crucial for effective virtual team management (Hertel et al., 2005). Because of the inherent diversity associated with virtual supply chain project teams, altering the team leader's role from a more traditional controlling role to a role that requires coaching of certain members, influencing teams, and moderating functions is imperative.

Recent reports by McKinsey & Company and Deloitte have even detailed that managing work-life boundaries and ensuring virtual team member well-being are some of the challenges facing traditional leaders who had to transit into being virtual team (Comella-Dorda et al., 2020; Deloitte, 2020a).

In today's global economy, the coordination and control of dispersed supply chain project teams are also significant competitive issues attributable to increased outsourcing and specialization of activities. Consequently, what lies ahead is the need to develop virtual project teams in supply chains that can focus on the skills that matter more in virtual settings, using diverse and effective learning methods for embracing new technology, and incentivizing participation and engagement while still driving for impact on the overall operating performance of the projects. Hence, subsequent sections of this chapter address important questions on how supply chain project teams can leverage on extant capabilities to augment the success and effectiveness of their projects.

## 7 Prerequisites for Developing and Implementing Virtual Project Teams

Virtual project teams in supply chains have many benefits; however, the inter-reliant nature of collaborative activities among supply chain various members introduce complexities into their teams and project processes. As alluded to earlier, processes can become complicated and time-consuming, thereby creating obstacles to collaboration. Thus, exploring certain fundamentals required for developing and

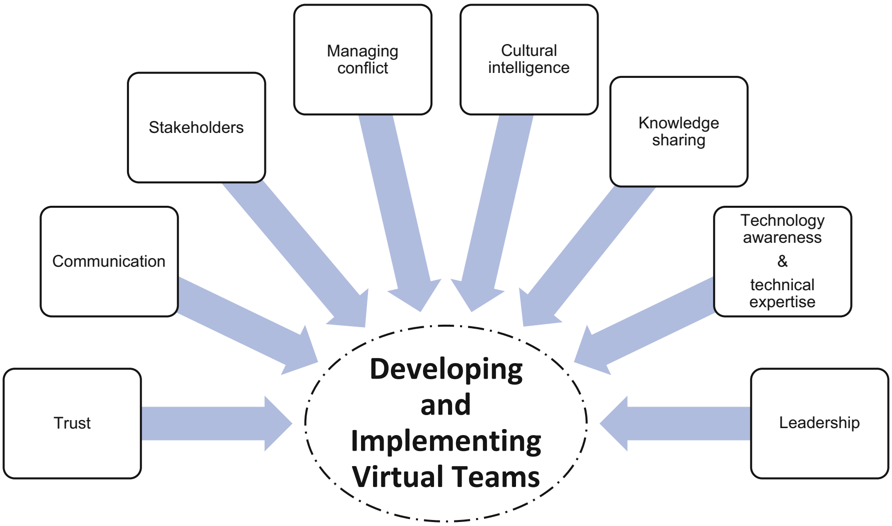


**Fig. 1** Prerequisites for developing and implementing virtual project teams

implementing virtual project teams is critical to the success of virtual project teams with supply chain networks.

Several years ago, Bell and Kozlowski (2002, p. 45) asserted that "virtual teams are here and they are here to stay." The current global business climate and recent developments in many organizations further validate this assertion. Therefore, based on our experiential knowledge and literature, some prerequisites (see Fig. 1) required for developing and implementing virtual teams are now briefly introduced.

## 7.1 Trust

Trust is a significant factor in any economic and social relationship. Trust has been described as the positive and confident expectation of another party's behavior (Palvia, 2009). According to Mayer et al. (1995), trust is the readiness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a specific action to the trustor, regardless of the ability to monitor or control that other party. Their study considers three antecedents on which the trustworthiness of the trustee is gaged:

- Ability: the competencies and skills of the trustee.
- Benevolence: the motives and intentions of the trustee for a particular action.
- Integrity: the antecedent of the trusting process that relate to the principles governing the behavior of the trustee.

Within the context of project teams, trust can also be an indication of the level of confidence team members have in one another. “Virtuality requires trust to make it work” (Jarvenpaa & Ives, 1994, p. 44). Trust is a vital quality for effective virtual project teams and other supply network exchanges. In virtual environments, there is a limitation, the conventional mechanisms – such as body language, use of face-to-face interaction and nonverbal communication – through which trust is developed are limited. Despite these limitations, trust among virtual team members may be improved through various forms of social communication that complement rather than replace task communication.

### 7.2 Communication

Although previous studies (Jarvenpaa & Leidner, 1999) showed that effective communication is easier to accomplish in co-located teams, communication has remained central for virtual project team dynamics and has formed a significant research theme (Marlow et al., 2017; Lin et al., 2004; Jarvenpaa & Leidner, 1999). As most virtual project team members may never get to meet physically, their only means of interaction is via technology-enabled communication channels.

Experience has shown that the absence of nonverbal communication, time delays, and the variable interpretations of written texts frequently present considerable challenges to effective communication. Accordingly, teams that do not clearly communicate their objectives or experience these challenges may disagree on priorities and processes for accomplishing objectives (see Vignette 1). It therefore becomes expedient to overcome these difficulties.

One way of facilitating effective communication in virtual project teams is through contextualization or the provision of explicit background in the message. Contextualization refers to the situation in which messages are created, detailing such issues as who is communicating with whom, when, and under what conditions without ambiguity (Te’eni, 2001). Another option is through the provision of common understanding of operational terms. For example, Lin et al. (2004) reported that those who work in a particular company or group tend to develop their own vocabulary for things their work. However, when such people need to collaborate with others from different groups or companies, they tend to experience two common types of communication problems. One being that the same term is being applied albeit to different concepts (a semantic problem). The next problem being that different terms may be used to represent the same concept (syntax problem).

There is a recurrence of this communication problem in manufacturing projects, especially those taking place virtually. Consequently, a manufacturing system ontology that provides a common understanding of manufacturing-related terms and facilitates the reuse of knowledge resources within virtual manufacturing teams is needed (Lin et al., 2004). Such ontologies can be extended to virtual teams in supply chains as a means of boosting communication and achieving shared meaning among dispersed team members.

## 7.3 Knowledge Sharing

Knowledge is an important strategic resource and managing knowledge effectively is an important dimension for the success of any project. Knowledge sharing has been defined as the intention to share knowledge by means of common storage to attain economic reuse of knowledge (Kankanhalli et al., 2005). It also refers to individual readiness to share their acquired knowledge, beliefs, and assumptions with their peers (Singh 2021).

During the process, a knowledge source is encoded and provided, and then a knowledge receiver acquires, decodes, and internalizes the knowledge. Individuals who possess diverse knowledge promote an organization's ability to innovate to a greater degree through interactions than any one person does unaided (Chen & Hung, 2010). But then, knowledge sharing depends on several factors including the willingness of individual team members to share any unique knowledge they possess. Unfortunately, the perception for some virtual project team members is that sharing knowledge may lead to a loss of their knowledge ownership and its accompanying power within their teams. This perception, if sustained, can result in knowledge hoarding by certain team members and a reluctance to share. As knowledge sharing is crucial for virtual team collaboration, any effective virtual project team in supply chains requires its members to put the success of the team ahead of any predisposition to hoard knowledge.

## 7.4 Leadership

Leadership constitutes a rich domain that has been extensively studied from different perspectives. Past studies advocate that the leadership concept is conditional on context, environment, and organizations rather than it being a "one-size-fitting-all" (Singh et al., 2019). There is a proliferation of definitions and perspectives on the leadership concept in general; we will not go into the discussion on these variations at this time, but see Daft (2015) for some of the discourse.

In terms of leadership with virtual teams, Huang et al. (2010) considered the roles of inspirational, transactional, and transformational leaders in virtual team settings and their impact on performance. Findings from their study showed that transactional leadership behaviors enhance the task cohesion of the team, while transformational leadership behaviors improve the cooperative climate within the team, which leads to improved task cohesion.

Shared leadership and self-leadership have also received growing attention as novel approaches for investigating teams (Bligh et al., 2006). Studies (Manz et al., 2013; Stewart et al., 2011) indicate that shared leaders take forward or backward steps depending on the status quo, all in a bid to achieve enhanced team performance, while self-leaders lead themselves to accomplish tasks.

The self-leadership approach can be beneficial for a team where individuals rarely meet (Houghton & Neck, 2002) – typical of virtual project teams in supply chains. As team members and leaders work remotely, leader influence can decrease.

Moreover, since project team leaders in several virtual supply chains are unable to physically observe their team's activities and performance, self-leading team members easily become a good fit. Overall, the choice of self-leadership should be made among virtual team members who can lead themselves, share knowledge, and manage their individual performance towards collective team performance (Xue et al., 2011). Alternatively, shared leadership encourages individuals to step forward to lead others or to step back and allow others to lead, depending on the circumstances (Stewart et al., 2011). This form of leadership accommodates the distribution of the influence of leadership between different individuals such that an individual can take the role of an influencer or follower based on prevailing circumstances.

Shared leadership can be more effective in contexts of change and competitive environments (Manz et al., 2013). The nature of supply chain projects makes them highly prone to constant competition and change from various stakeholders at various project phases. In this context, the shared leadership approach can commence with leaders who accept that the phases or circumstances of their projects may require some adjustments – such as during project commencement, implementation, or closeout – requiring them to become influencers or followers at certain stages (Hoegl & Muethel, 2016).

### 7.5 Technology Awareness and Technical Expertise

The technologies used in virtual project teams play a significant role in team effectiveness, ease of communication, and relationships among team members. Currently, supply chains are facing a dynamic and competitive environment that require levels of flexibility and agility. The ongoing advancements in technology provide the opportunity to achieve this and facilitate successful project outcomes. So, technology literacy has become a necessary competence.

Studies have also indicated that virtual team members' technical expertise matters both for performance and satisfaction (Piccoli et al., 2004). For instance, limited technical expertise can influence the virtual team dynamics and also negatively affect individual satisfaction and performance (Kayworth & Leidner, 2000; Van Ryssen & Godar, 2000). For this reason Jarvenpaa and Leidner (1999) believed that team members with technological skills may tend to develop higher levels of trust in each other than those who are unskilled. In general, this means recruiting teams with the relevant technological know-how or those with tendencies to develop their technological abilities.

### 7.6 Stakeholders

Stakeholders are defined as any individuals or groups or organizations whose interest on the project may be positively or negatively impacted because of the outcome of the project execution. It is common that different stakeholders have different expectations, and these expectations are not always straightforwardly managed. To a certain extent, the problem of managing stakeholders in supply chains projects is easier if the members of a supply chain are owned by a single authority. A central controller hypothetically could basically control the decision-making for the supply chain activities based on all information that could be gathered from subordinates.

As demonstrated in this chapter, most supply chains and their virtual project teams currently consist of various entities, with each having its own unique sets of core competences and priorities. This situation implies that some form of stakeholder integration – albeit temporal and only needed for the project duration – is required when managing the supply chain virtual project team to achieve a particular set of goals during a defined period.

## 7.7 Managing Conflict

Conflict is a process that results from tensions between team members because of real or perceived differences (De Dreu et al., 1999). Conflict must be managed for effective goal achievement (Baba et al., 2004; Montoya-Weiss et al., 2001).

Conflicts can hinder teamwork at group and interpersonal levels. Three main categories of conflicts exist (Jehn, 1997; Jehn & Mannix, 2001):

- Relationship conflict: a form of conflict that emerges from individual issues such as personality clashes, dislike, or affective events like team tensions.
- Task conflict: this conflict results from dissimilar opinions regarding job allocation and delegation of duties.
- Process conflict: stems from differing perceptions among team members in understanding how the team is required to proceed to accomplish tasks.

The nature of virtual teams makes them open to any of these conflict categories. Conflicts can result in team discomfort and diminished team satisfaction through limited goodwill, which creates an adverse impact on overall satisfaction and project performance.

Sometimes, certain types of conflict – for example, task or process conflict – can have positive effects on teams, resulting in more creativity. Nonetheless, conflicts within virtual teams need to be addressed before they intensify. This situation makes a good case for proactive conflict management to minimize the adverse effects of conflict. Virtual project teams can benefit from a better understanding of factors that trigger conflicts as well as the possible impact of conflicts on their performance.

## 7.8 Cultural Intelligence

Currently, teams and projects across different cultures have become a favorable option for multinational companies to succeed (Neeley, 2015). Despite this support, the cultural aspects of international work, especially concerning teams, have not been extensively studied (Davaei et al., 2022). This gap is particularly remarkable with the growing number of business activities (including supply chain projects) becoming more international and virtual.

Within virtual teams, cultural diversity facilitates innovation and problem-solving. Cultural differences impede collaboration and produce obstacles to effective communication. However, with an understanding and accepting of the differences, the adverse effects of cultural differences can be mitigated. This mitigation means that virtual project team members intentionally develop capabilities that enable them to adapt effectively to new cultural contexts. One way of facilitating this is through cultural intelligence, which is the ability to succeed in a cross-cultural environment (Van Dyne et al., 2017). In general, given the value of cultural intelligence in our modern globalized world, understanding its antecedents is deemed a prerequisite for developing and implementing virtual project teams since cultural intelligence usually results in more effective functioning during cross-cultural interactions.

## 8 Reimagining Virtual Project Teams: Effectively Working Separately but Together in the Post-COVID Era

Earlier in this chapter, it was acknowledged that the fast pace of change in businesses and the demand for new products and services has created a highly competitive environment requiring permanent efforts to transform ideas that result in value creation. Furthermore, the chapter noted that globalization trends have equally unlocked newer local markets to foreign corporations, thus further intensifying competition. For these and other reasons, like the advancement in Industry 4.0 systems as well as the aftermath of the COVID-19 pandemic on working patterns, virtual project teams now represent essential organizational structures in modern corporations, including those responsible for delivering projects in supply chains.

Although virtual project teams were already common in large supply chain associated companies, such as DHL and Colgate-Palmolive, following recent events, other smaller and medium-sized enterprises (SMEs) have now been prompted to make modifications that support virtual project delivery. Others such as Microsoft 365 rethought on how their delivery patterns can better support their workforce and clients alike in the post-COVID era. For instance, Jared Spataro, Corporate Vice President for Microsoft 365 indicated that they have reached an inflection point. As the global response to COVID-19 evolves, communities around the world have moved from an era of “remote everything” into a more hybrid model of work, learning, and life.

As all organizations scramble to keep up, the future of work and education is being reshaped. At Microsoft, they spent time learning from customers and studying how they used Microsoft tools. They have also worked with experts across virtual reality, artificial intelligence (AI), and productivity research to help understand the future of work (Spataro, 2020).

This chapter also identified that virtual project teams can bring together the best specialists despite dispersion. Additionally, delivering projects virtually may result in lower maintenance costs for office facilities and greater potential for better work-family balance, as examples of its benefits. Nevertheless, there are always associated managerial, leadership, trust, and cultural challenges.

The COVID-19 pandemic has been unarguably one of the most defining global crises recently witnessed. Davison (2020) and Richter (2020) revealed how some companies altered their work arrangements to adopt innovative IT systems, while for others the crisis led to a whole rethink of their business models. Within supply chains, Ivanov and Dolgui (2020) explained how the pandemic has been a severe supply-chain disruptor. Consequently, the remaining part of this section considers practical ideas for managing the daily activities of virtual project teams in the supply chain – especially given current developing situations.

## 9 Post-COVID Era Considerations for Virtual Project Teams Within Supply Chains

Putting together a virtual project team that delivers on its mandate from the onset is always desirable but may encounter hurdles. Therefore, to help get a virtual project team started on the right path, spending some time to ensure a seamless commencement is important. Getting the team excited about the opportunities ahead of them through available communication channels is important. Although this occurs in the early stages, sharing an aspiration for the project overall and what the team can achieve is vital at this point. For certain teams, even getting the buy-in from senior management might be a lengthy process. Nonetheless, the team can still spend time to get acquainted with themselves.

Like traditional projects, virtual projects are also finite endeavors. Managing the daily activities of virtual project teams has always been a challenge for team leaders. For instance, picking up a telephone to make a quick call is not always straightforward, especially when time zones are several hours apart. However, with several collaboration tools – for example, Teams, Zoom, Shared CAD Systems, Mural, Webex, and SharePoint – and portals certain communication challenges can be alleviated. With a plethora of tools enabling virtual project teams to engage, choices need to be made based on available resources albeit with communication ease and a tool that provides a "suitable meeting place" as the main priorities.

Feitosa and Salas (2021) questioned existing knowledge about virtual teams and collated items to address the challenges of today's virtual teams (see Fig. 2). One significant inference from their study is that applying the previous norms to virtual project teams is likely to be unrealistic in the post-COVID era.

As highlighted in Fig. 2, the following are key lessons for virtual teams from the pandemic: monitoring trust, focusing on process gains, cultural intelligence, promoting inclusion through psychological safety, and the frequent assessment of teamwork. A major deduction from these items is that, despite the peculiar challenges of virtual teams, productivity can still be achieved using novel and humane options. Beside these findings that provide useful insights into key priorities for addressing current virtual teams challenges, Deloitte (2020b) applied its extensive

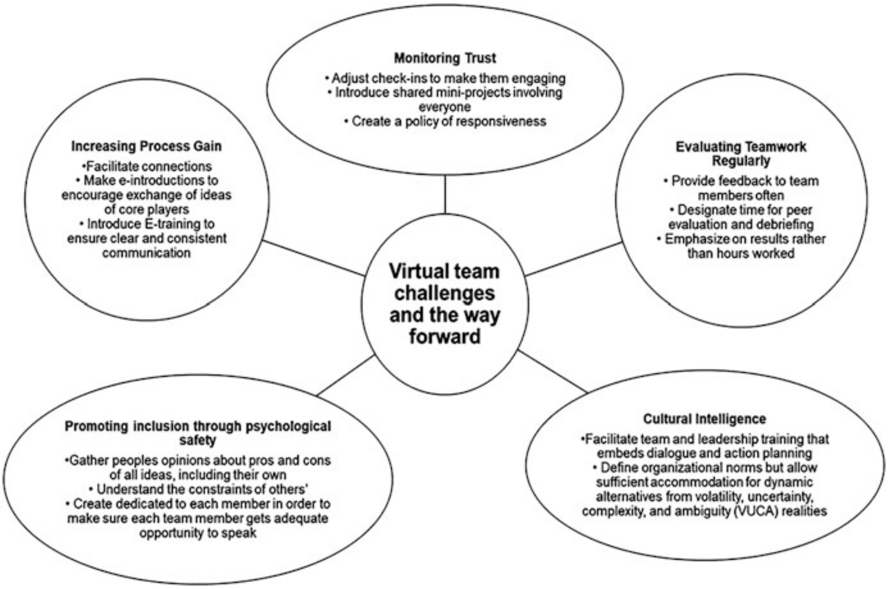


**Fig. 2** Virtual team challenges and the way forward. (Adapted from Feitosa and Salas (2021))

experience with remote working to offer the following good practices for virtual working:

- Encourage everyone to set up an organized and quiet workplace and embrace "distractions" that cannot be avoided under the current circumstances.
- Establish buy-in from everyone and focus on the benefits of virtual meetings, workshops, or labs.
- Ensure everyone is familiar with the technology and tools, communicate ground rules, and provide fast support to solve unexpected technical issues.
- Schedule compact sessions, use breakout sessions, frequently check-in with colleagues to see if they are still able to focus, and schedule breaks accordingly.
- Encourage video calls and do not forget about socializing with colleagues and leaders to avoid a social disconnect.
- Support employees to maintain an appropriate work-life balance.

Building on the good practices outlined by Deloitte (2020b), the following practical steps have been outlined for virtual project teams in supply chains:

- Daily visibility that ensures that team members are seen using videos during meetings where practically possible.
- Maintaining an approachable demeanor using a status function in the collaborating platform to keep the team informed about your availability.

- Going verbal where necessary. Rather than lengthy email threads, clarifying contentious projects areas using a telephonic option.
- Embracing technology. Familiarizing and understanding the technology and collaborating platforms
- Remaining patient with difficulties or disruptions associated with people.

From the foregoing, the people (i.e., the teams), their processes, and technology play a dominant role in defining how virtual project teams in supply chains can adjust to “the new normal” and effectively work separately but together.

## 10 Towards Resilient Virtual Project Teams in Supply Chains

Dynamic capability theory states that to attain a competitive advantage, organizations need to respond promptly to changes in their environment (Teece et al., 1997). To achieve this goal, organizations require a dynamic capability that enables them to integrate, build, and reconfigure internal and external competences to manage their rapidly changing environments. These changes could be a result of a response to a crisis where organizations may have to alter their routines (a good illustration being changes in work patterns from COVID-19 such as replacing site-based activities with homeworking).

Raj et al. (2022) noted that COVID-19 sanctioned a rapidly changing environment where companies need to adopt, respond, and proactively mitigate disruptions by dynamically synergizing, integrating, and rebuilding their competencies, resources, and overall capabilities. Project teams within companies also need to make changes and adopt as their environments dictate. Consequently, virtual team resilience becomes a significant area of consideration.

According to Kirkman and Stoverink (2021), virtual team resilience is the capacity to bounce back from a setback that results in a loss of virtual team processes. Their study recognized that setbacks occur when critical virtual team processes deteriorate. Nonetheless, virtual team potency, team mental model of teamwork, capacity to improvise, and the team’s psychological safety were identified as the main ingredients or resources that would be necessary in a virtual team’s path to becoming and staying resilient. Accordingly, they proposed the following:

- A virtual team’s potency – a shared belief that team members can be effective at accomplishing all their tasks.
- A virtual team’s mental model of teamwork – the knowledge among team members of their roles, responsibilities, and interaction patterns and familiarity with each other’s knowledge, skills, and preferences.
- The virtual team’s capacity to improvise the team’s ability to swiftly develop new things from existing resources.
- A virtual team’s psychological safety – the shared belief that a team is safe for members to undertake interpersonal risks.

Similarly, Degbey and Einola (2020) identified regulating and leveraging emotional expression, team inclusion practices, and self-reflective practices as underlying mechanisms that facilitate the cultivation or loss of team resilience when dealing with task- and relationship-oriented goals.

A significant aspect of the above studies on resilience suggests that, if well prepared, virtual project teams tend to exhibit resilience when setbacks are encountered. Relating this to our earlier discussion (see Sect. 4), it can be concluded that any of the main shortcomings associated with virtual project teams can form the basis for resilience development. With virtual supply chain projects becoming more complex and requiring them to encounter changes, their teams need adjustment mechanisms to maintain progress and still accomplish project success. Achieving resilience under such conditions entails teams having the necessary capabilities to deal with the unknown and still successfully navigate through altered project processes.

## 11 Conclusion

In this chapter, we have described how virtual teams support knowledge creation and skills development and give organizations a wider perspective compared to traditionally collocated teams. As virtual teamwork continues to become an integral aspect of the contemporary workplace, understanding how they evolve and operate is vital to develop novel approaches that can provide practical insights into how their success can be facilitated.

This chapter took a step in this direction by utilizing theoretical concepts from virtual teams to discuss wider applications for supply chain projects. It concluded by identifying lessons and key strategies future virtual project teams in the supply chain can adopt in light of the pandemic.

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# Applying Artificial Intelligence in the Supply Chain

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## Contents




**Abstract**

This chapter covers the applications of artificial intelligence (AI) in supply chain management (SCM). We elaborate on the applications of seven categories of AI – namely, artificial neural networks, expert systems, machine learning, genetic algorithms, agent-based systems, fuzzy logic, and rough set theory – to supply chain management processes using the supply chain operations reference (SCOR)



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model which are elaborated. A framework for SCM practitioners is provided. This framework highlights the AI task context and the AI knowledge source context (the *What)* in the SCOR activity (the *Where*). The framework also includes an algorithmic description (the *How*).

**Keywords**

Artificial intelligence · Supply chain management · Artificial neural networks · Expert systems · Machine learning · Genetic algorithms · Agent-based systems · Fuzzy logic · Rough set theory

## 1 Introduction

Supply chains have evolved from local physical networks into globally dispersed networks involving significant levels of coordination among supply chain entities. Supply chain activities became highly data-intensive and analytical to be able to effectively respond to the fluctuations in demand, supply, and other external environmental factors. Firms with complex supply networks naturally embraced available data-processing and analytic techniques for making better business decisions (Klubnikin, 2021). AI techniques became useful for managing complex business problems and to solve them at par with or better than human intelligence. In this chapter, we overview various AI techniques that have been developed and applied to supply chain management (SCM) processes using the supply chain operations reference (SCOR) model (Nandi et al., 2021).

The chapter is organized as follows – in Sect. 2, we describe the evolution of AI techniques and the seven categories of AI techniques that are commonly used in business applications. In Sect. 3, we contextualize each of the seven identified AI techniques using the popular supply chain operations reference (SCOR) framework. In Sect. 4, we provide an applicability framework for managers highlighting the AI task context and the AI knowledge source context (the *What)* in the SCOR activity (the *Where*), and their algorithmic description (the *How*). The framework helps to decide how AI techniques are to be chosen and applied to each of the SCM functions. Section 5 provides a summary of the chapter.

## 2 Artificial Intelligence: The Evolution, Key Concepts, and Techniques

AI refers to a group of intelligent computer programs that are designed to perform activities associated with human decision-making with little or no involvement of humans. These programs mimic human intelligence in terms of thinking humanly, acting humanly, thinking rationally, and acting rationally (Kok et al., 2009; Min, 2010).

The field of AI emphasizing human thought mechanization evolved since 1950 with the concept of intelligent machines – introduced by Alan (Turing, 1936). The introduction of LISP, a computer-programming language capable of processing symbolic structures, in 1956 and a series of developments in symbol processing during the following years generated huge interest and large investments to transform the AI concept into a reality. These investments, however, were curtailed in the early 1980s as the economic success of AI fell short of expected results (Ertel, 2017).

Later the field of AI experienced a renaissance, with the introduction of Nettalk – a neural network-based system capable of learning and reading texts aloud – in 1986. Developments in dealing with uncertainty using Bayesian networks and fuzzy logic along with several other contributing developments in the fields of knowledge engineering, statistics, image processing, control engineering, and distributed computing also contributed to this renaissance (Ertel, 2017).

Currently, AI is a vibrant and interdisciplinary field comprising several subdisciplines using a wide variety of techniques. These techniques are used to perform activities such as recognizing data patterns, understanding certain behaviors from experience, acquiring knowledge for future problem-solving, and developing various forms of inference in problem-solving. For this chapter, the field of AI is classified into seven categories based on their theoretical underpinnings, including the following: (1) artificial neural networks (ANN); (2) expert systems (ES); (3) machine learning (ML); (4) genetic algorithms (GA)X; (5) agent-based systems (ABS); (6) fuzzy logic (FL); and (7) rough set theory (RST) (Min, 2010). A brief description of these seven AI categories is presented in the following sections.

## 2.1 Artificial Neural Networks (ANN)

ANN are computational models that are inspired by and function like biological nervous systems. The models comprise artificial neurons – also known as neurodes or perceptrons – interlinked by connections called artificial synaptic connections (Chen et al., 2008). Typically, the neurons are arranged in a layer or vector and the synaptic connections have assigned weights. Each signal between the neurons is multiplied by the associated weight of the synaptic connection and is transported to the subsequent neuron. The output of one layer of neurons serves as input to other subsequent layers. ANNs typically consist of three layers, namely, an input layer, an output layer, and a hidden layer(s).

Learning is emulated through the adjustment of the synaptic nodal weights during the training phase of ANN development. Accordingly, ANNs can be divided into two basic classes based on the direction of the information flow between the input and output layers. In a *feedforward neural network,* the information flows from input nodes to the output nodes in a single direction whereas in a *recurrent neural network* some of the information flows in the opposite direction as well (Imran & Alsuhaibani, 2019).

## 2.2 Expert Systems (ES)

ES refer to knowledge-based systems that solve problems in a nonprocedural manner using knowledge from human experts to simulate human reasoning (DeTore, 1989). ES are typically used to solve domain-specific decision problems since they are developed domain knowledge culled from human experts. The knowledge includes pertinent facts and relationships about the subject as well as the rules of thumb to effectively search through those facts to solve problems. Based on the inputs provided through responses to questions, programs of the ES begin at different points in the flow of logic and execute the logic differently with different information (DeTore, 1989).

ES enable businesses to leverage expert knowledge and thought processes and make consistent decisions while solving complex problems (DeTore, 1989). Some of the notable successes in expert systems include MYCIN for aiding physicians to diagnose and prescribe medicines for bacterial infections, PROSPECTOR to aid geologists in the evaluation of mineral deposits in a geographical area, DENDRAL to aid chemists identify the atomic structure of a compound, and R1 to aid Digital Equipment Corporation to transform customer choices of requirements to working configurations of computers (Gill, 1995).

The basic components of ES include a *knowledge base*, an *inference engine,* and a *user- interface*. The *knowledge base* contains the domain-specific knowledge collected from the domain experts and coded into the system using a special knowledge-representation formalism. ES shell or ES builder tools having in-built domain-specific knowledge-representation formalisms are used to develop the knowledge base. The *inference engine* consists of a group of algorithms that coordinate the searching, reasoning, and inferring based on the rules of the knowledge base (Min, 2010). This process of reasoning the problem is referred to as *chaining* (DeTore, 1989). With *forward chaining,* the system attempts to reason forward from the facts to the solution. With *backward chaining*, the system works backward from the desired solution to supporting data conditions. Lastly, an ES interacts with the user through the *user interface*. Apart from solving complex problems, an ES is considered to be a good system if it can provide explanations on how it concluded, why it needs a particular piece of information, and why it has not reached a particular conclusion.

## 2.3 Machine Learning (ML)

ML refers to the ability of computers to learn without being explicitly programmed. As defined by Tom Mitchell, "*A computer program is said to learn from experience E with respect to task T and some performance measure P, if its performance on T, as measured by P, improves with experience E*" (Mitchell, 2006). Experience E here refers to training data. ML has a long-standing history encompassing interdisciplinary knowledge and techniques and a wide variety of applications. Computer processing advances have aided ML developments including storing and processing massive amounts of data for achieving intelligent algorithms.

ML algorithms can be classified as *supervised*, *reinforcement*, and *unsupervised*. In supervised learning, an algorithm is provided with a training data set and correct outputs. The algorithm learns to respond more accurately by comparing its output with those that are given as input (Alzubi et al., 2018). In reinforcement learning, an algorithm generates a predicted output based on some observed patterns in the training data set. For each output, the algorithm gets a reward or penalty from its environment (Alzubi et al., 2018). The algorithm learns from the repeated actions through these rewards and penalties. In unsupervised learning, the algorithm is provided only with a training data set and gets neither outputs nor rewards. The algorithm performs the task by finding recurring regularities in the input dataset (Alpaydin, 2010).

## 2.4 Genetic Algorithms (GA)

GAs are adaptive methods that may be used to solve search and optimization problems. GAs derive their name from the fact that they are based on underlying principles of population evolution – natural selection and *survival of the fittest* (Holland, 1975). A GA has three basic elements: (1) a *fitness function* that determines the fitness score for each *chromosome* – representing a potential solution; (2) a *mating operator*, which produces offspring for the next generation through selection and mating of the parent chromosomes; and (3) *genetic operators* that determine the genetic makeup of the offspring through *crossover*, *mutation*, and *inversion* methods (Üçoluk, 2002).

Using these elements, GAs incrementally produce new populations containing a higher proportion of the good characteristics or *highly fit* individuals. Eventually, the population will converge to an optimal solution to the problem.

GAs are robust in their ability to exploit accumulating information in a large and unknown search space and bias subsequent search into useful subspaces. GAs are useful for solving complex and unknown problems where other methods might fail. GAs are generally good at finding *acceptably good* solutions to problems *acceptably quickly*. However, they may not reach a global optimum solution to a problem.

GAs have been extensively used for numerical function optimization, image processing, problems involving combinatorial optimization such as traveling salesperson problems, bin packing, job shop scheduling, and design problems such as designing a bridge structure and a fire hose nozzle. GAs also offer great hybridizing potentials to other AI techniques to improve performance and accuracy.

## 2.5 Agent-Based Systems (ABS)

ABS is an AI technique that evolved in the last two decades with advancements in distributed programming, enterprise modeling methodologies, and AI (Madejski, 2007).

ABS involves decomposing a decision problem into subproblems using entities called agents (Min, 2010).

An agent as defined by Jennings (2000) is: "*an encapsulated computer system that is situated in some environment and that is capable of flexible, autonomous action in that environment in order to meet its desired objectives*" (p. 280). Going by the definition, agents are characterized by having: specific goals to achieve; environments with well-defined boundaries and interfaces to operate; control over their internal state and behavior; and capabilities to receive inputs from their environment through sensors and act on their environment through effectors (Jennings, 2000).

A multiagent system is a collection of autonomous agents that communicate between themselves and coordinate their activities to be able to collectively solve a problem and achieve their designed objectives. ABS emulates problem-solving activities of complex real-world systems which typically require distributed knowledge resources of multiple entities in different roles with different loci of control (Jennings, 2000). ABS needs to be designed for flexible interactions and negotiations among the agents.

ABS has been broadly applied to problem domains in purely digital environments (e.g., telecommunication and static optimization), electromechanical environments (e.g., robotics, intelligent highway systems), and social environments (e.g., electronic commerce, computer-supported collaborative work) (Parunak, 2000).

## 2.6 Fuzzy Logic (FS)

FS (Zadeh, 1976) generated a paradigm shift in the generic approach to uncertainty and imprecision. The generic approach to uncertainty, which is the classical probability theory hinges upon the concept of crisp sets, where an object is either a member or a nonmember of the crisp sets. This logic was used by the *hard* science approach which dealt with simplified mechanistic systems to describe their behavior in precise quantitative terms. However, in the real world, problems usually are complex comprising a large number of variables, subjectivity, and human judgment (Zadeh, 1976).

FS enable formalizing and solving such real-world problems using the linguistic approach. For example, in the linguistic approach, the human responses for the probability of an event – quite likely, not very unlikely, and highly unlikely – are translated into corresponding fuzzy subsets, which serve as approximations without sharply defined boundaries. The membership of an element in a fuzzy set is not a matter of acceptance or denial with a representation of 0 or 1, but rather a matter of a degree with a value between 0 and 1 (Celikyilmaz & Turksen, 2009).

Fuzzy logic consists of five basic components, namely, (1) linguistic variables, (2) linguistic values, (3) fuzzy sets, (4) fuzzy logic functions, and (5) fuzzy relationships represented by IF-THEN rules (Min, 2010; Celikyilmaz & Turksen, 2009). Fuzzy logic can come in handy in understanding complex systems, where the relationship between the causes and effects is generally not understood, but often can be observed. Fuzzy logic can also be useful to solve problems that do not necessarily require exact solutions, but rather require useful and fast approximations.

### 2.7 Rough Set Theory (RST)

RST (Pawlak, 1982) is usually used for classification by discovering structural relationships within imperfect or vague data. RST establishes *equivalence classes* for each attribute, within the given dataset. The data points within equivalence classes are *indiscernible* – where the samples are identical to the attributes describing the data. Based on the available data for attributes, *rough sets* for a *decision attribute* class are approximated in terms of two sets – a *lower approximation* set comprising of data points that certainly belong to the decision attribute class and an *upper approximation* set comprising of data points that cannot be described as not belonging to the decision attribute class. RST can be used for developing *decision tables* through feature reduction and relevance analysis. RST-based models are commonly used for knowledge discovery, data mining, and classification (Han, 2012).

## 3 AI Applications in Supply Chain Management: Dominant Techniques, Research, and Contexts

SCM encompasses a wide range of processes spanning numerous organizations. Given the breadth of the field, it is necessary to have a framework of constituent domains to effectively explore and understand the developments of AI applications in SCM. Toward this end, the Supply Chain Operations Reference (SCOR) model serves as a standard model for several studies that analyze, design, and implement any interventions to supply chain management (Hervani et al., 2022).

The SCOR model is popular among supply chain managers as it can be deployed to analyze and measure a wide variety of supply chain performance attributes, such as reliability, responsiveness, flexibility, cost, asset metrics, and sustainability (Stohler et al., 2018), and to benchmark their effectiveness against the competition (Bolstorff & Rosenbaum, 2007).

The SCOR model delineates measurable supply chain activities into five categories – *plan*, *source*, *make*, *deliver,* and *return*. These five categories of processes can be translated into five domains of SCM, namely, demand planning, purchasing, manufacturing, logistics, and customer service. Some of the applications of AI in each of these domains are discussed in the following sections. The discussion is limited to empirically tested AI models that are reported in the literature and does not include conceptual models.

### 3.1 Artificial Neural Networks (ANN) in Supply Chain Management

ANN, as an information-processing technique, is most prominently used to find patterns, knowledge, or models from extensively large historical datasets in different industry segments. Due to its multilayered, bidirectional information enrichment capability in the form of *feedforward and recurrent* neural networks, ANN can be applied to a wide variety of supply chain functions to solve problems where setting clear rules or guidelines is a major challenge, despite having access to data (Chen et al., 2008).

Table 1 highlights a few SCOR-based examples of ANN implementation use-cases in different supply chain functional areas. Utilities and gas industries apply ANN techniques on the available historical production data for demand forecasting and planning (SCOR-Plan) activities. For example, a feedforward ANN model was developed and tested to support energy production forecasting of a Romanian solar power plant (Gligor et al., 2018). Similarly, a Saudi Arabian electric utility firm explores historical production records through a multilayer perceptron ANN algorithm to bring preciseness in its electricity load-forecasting situations (Al-Saba & El-Amin, 1999). In the oil and gas sector, ANN-based dual-layered feedforward network models are utilized to visualize oil production-forecasting scenarios (Sheremetov et al., 2013).

In the purchasing realm (SCOR-Source), ANN can be deployed to solve supplier selection and evaluation options. Healthcare providers have developed hybrid ANN models for supplier selection purposes. Further, more complex neuro-fuzzy algorithms can be modeled and trained to perform supplier evaluation and selection in real time in traditional manufacturing settings (Vahdani et al., 2012). These ANN models may help firms to optimize their inventory costs.

In the manufacturing context (SCOR-Make), despite having access to large production records, firms face industrial engineering challenges, such as cycle time estimation, quality inspection, machine failure, and production performance analysis at their production facilities. For example, electronic circuit manufacturers can deploy Bayesian regularized multilayer ANN models to improve the assembling efficiency and accuracy of their circuit board production systems. ANN can also be deployed to improve complex visually dependent quality assurance processes to identify manufacturing defects in the soldering joints of microelectronic devices, to categorize faulty insertions in assembling processes, and to understand the operating statuses of machines in the production plant environment (Küfner et al., 2018).

In logistical functions (SCOR-Deliver), ANN suits for logistical data extraction and intelligence in inventory management. For example, a railway logistics park in China developed an ANN- and GA-based hybrid model to use historical records for artificially generating logistical decision-making intelligence concerned with inventory management (Gao & Dou, 2020). ANN can further be applied to optimize routes for automated guided vehicles within (and between) warehouses. More complex route-planning models can be created by integrating established routing

**Table 1** Artificial neural network (ANN) applications across SCOR activities and functions

| SCOR | Supply chain function | Implementation use-case |
|---|---|---|
| **SCOR-Plan** | Power production forecasting | A multilayer feedforward ANN model to perform energy production forecasting. The model has been tested at a photovoltaic power plant in Romania (Gligor et al., 2018) |
| | Oil and gas production forecasting | A two-layer feedforward network ANN model using a Gamma classifier to perform production forecasting tool. The tool is applied in the real scenario of oil and gas production (Sheremetov et al., 2013) |
| | Electrical load forecasting | A multilayer perceptron network with a back-propagation training algorithm to forecast long-term load. Applied the model at a Saudi Arabian electric utility (Al-Saba & El-Amin, 1999) |
| | Oil production forecasting | A multilayer neural network with multivalued neurons to forecast oil production |
| **SCOR-Source** | Healthcare (service) supplier evaluation | A hybrid model for supplier selection using AHP and ANN in health center settings |
| | Cosmetic (manufacturing) supplier evaluation | A locally linear neuro-fuzzy (LLNF) model to predict the performance rating of the suppliers. The model is trained by a locally linear model tree learning algorithm. The model has been tested with real-time datasets from the cosmetics industry (Vahdani et al., 2012) |
| | Cloth (manufacturing) supplier evaluation | A hybrid intelligent algorithm combining fuzzy neural network and GA to artificially enhance supplier selection and inventory control decision-making processes in manufacturing facility settings |
| **SCOR-Make** | Cycle time estimation | A multilayer network employing Bayesian regularization to achieve efficient learning and improved accuracy that can be applied to assembly tasks in the printed circuit board industry |
| | Quality inspection of soldering joints | A visual inspection system supported by ANN and a learning algorithm for accurate judgment of defective samples of solder joints. The model has been tested for inspection of solder joints in microelectronic devices (Matsushima et al., 2010) |
| | Automated failure classification | A radial basis neural network for monitoring threaded insertions, identifying and categorizing faulty insertions |
| | Manufacturing data analysis | An analysis system based on a multilayer perceptron network to accurately identify and classify the machine-operating states. The system has been successfully tested in a simulated production plant environment (Küfner et al., 2018) |
| **SCOR-Deliver** | Inventory management of railway logistics park | A hybrid model using ANN and GA for inventory management of railway logistics park. The model has been experimentally tested with historical data (Gao & Dou, 2020) |

(continued)

**Table 1** (continued)

| SCOR | Supply chain function | Implementation use-case |
|---|---|---|
| | Automated navigation within a warehouse | An ANN-based model to optimize routes for automated guided vehicles within a warehouse |
| | Route planning | A route-planning model integrating Google maps with multilayer ANN and Dijkstra's algorithm |
| **SCOR-Return** | Customer satisfaction measurement | A fuzzy neural network model to measure customer satisfaction using both qualitative and quantitative inputs for providing automation services |
| | Customer churn prediction | A hybrid model using rough set theory, ML (Adam's learning algorithm), and ANN (Back propagation neural network) to predict customer churn in the logistics industry |
| | Online shoppers' purchasing intention prediction | An online shopper behavior analysis system using ANN (recurrent LSTM and multilayer perceptron) and ML (support vector machine classifier, decision tree algorithm). The system has been tested experimentally using real-time online retailer data (Sakar et al., 2019) |

algorithms such as Dijkstra's algorithm, multilayer ANNs, and Google maps for visual representation.

In customer service scope (SCOR-Return), customer satisfaction measurement and customer behaviors related to churn and buying intent can be predicted using ANN tools. For example, a fuzzy neural network model can be deployed to measure customer satisfaction that is capable of processing both qualitative and quantitative customer feedback. Such models would automate the firm-level customer servicing aspects to a great extent. Similarly, ANN in combination with RST can be applied to predict customer churn in the logistics industry. Further, ANN (with recurrent long-/short-term memory and a multilayer perceptron) when coupled with ML (through a support vector machine classifier and decision tree algorithm) can be applied to real-time online retail records to conduct online shopper behavior analysis and prediction (Sakar et al., 2019).

## 3.2 Expert Systems (ES) in SCM

ES is applied to simulate possibilities to solve domain-specific complex problems iteratively using from past experiences or human reasonings as human expert knowledge (DeTore, 1989). Such pieces of knowledge include useful facts and relationships about the problem and applied rules of thumb as a starting point to effectively search for an answer to the problem.

Modern-day businesses (ranging from healthcare to mineral extraction) leverage on expert's prior knowledge and decision-making thought processes to solve complex problems. Problems include drug selection steps to diagnose and prescribe medicine for a disease and the logical flow of discovering new mineral deposits in a

**Table 2** Expert systems (ES) applications across SCOR activities and functions

| SCOR | Function | Implementation use-case |
|---|---|---|
| **SCOR-Plan** | Inventory management | A rule-based expert system to assist decision-making that involves complex inventory management scenarios |
| **SCOR-Source** | Supplier evaluation | A hybrid model comprising of expert system and agent-based system for online bidding and supplier evaluation processes. The system was implemented at a multinational manufacturer, Kaz (Far East) Limited, Hong Kong (Cheung et al., 2004) |
| **SCOR-Make** | Programming of industrial robots | A robot-programming platform using case-based reasoning and explanation-based learning |
| **SCOR-Deliver** | Logistics strategy | A knowledge-based logistics strategy system for freight service providers |
| | Warehouse operations management | A case-based logistics resource management system integrated with RFID technology for effectively managing warehouse operations. The system has been tested at GSL Limited, a Hong Kong-based electronic device manufacturer (Poon et al., 2009) |
| | International freight forwarder selection | An expert system tool to support evaluation and selection of international freight forwarders |
| **SCOR-Return** | Product maintenance and troubleshooting | An expert system to support troubleshooting of page-printing system |
| | Product configuration based on customer requirements | An expert system to translate the customer requirements into product configurations |

vast land. It is completed by simulating those conditions as an ES. A typical ES is visualized as a knowledge base containing domain-specific knowledge, the knowledge representation algorithms for searching, reasoning, and inferring in the form of an engine, and the user-interface (Lucas & van der Gaag, 1991).

Table 2 highlights a few SCOR-based examples of ES use-cases across supply chain functions. In demand planning (SCOR-Plan), backward and forward search rule-based ES is used to solve complicated inventory management-related decision-making problems, such as service parts ordering for an aircraft manufacturer's maintenance contracts. In purchasing concerns (SCOR-Source), ES may be extended to support bidding and supplier evaluation and selection processes-related complexities (SCOR-Source) for firms, such as in home appliance manufacturing (Cheung et al., 2004).

ES has been deployed to create a robot-programming platform using case-based reasoning and explanation-based learning to solve industrial complexities during the production (SCOR-Make) stage. Further, freight providers can apply ES tools to advance routing strategies for improving their logistical (SCOR-Deliver) efficiencies. In warehouse operations management, ES tools can be developed as case-based logistics resource management systems with integrating radio frequency identification (RFID) technology for effectively managing warehouse operations (Poon et al., 2009). Likewise, the international freight forwarder selection process can be enhanced using ES tools to support the evaluation and selection of international freight forwarders.

In customer service scope (SCOR-Return), ES tools can solve product maintenance and troubleshooting issues in simple and complex systems, such as large-scale networked printing and messaging systems. Further, ES can bring both efficiency and effectiveness to digital equipment providers to translate the customer requirements into product configurations before setting up their inventory requirements and assembling tasks.

### 3.3 Machine Learning (ML) in SCM

ML is an automated analytical modeling approach for making a system continuously learn by observing data and creating/identifying patterns such that it can artificially decide without or with little human interventions. Machine-learning techniques are commonly seen in several business activities, such as digital voice language processors (e.g., Siri by Apple, Alexa in Amazon), diagnosis applications in healthcare through pattern recognition, personalization, and recommendations tools (e.g., Spotify song, YouTube videos), recognizing customer satisfaction/dissatisfaction to manage subscriptions, pricing, and segmentations, for detecting fraudulent activities, and inventory management and operational tasks.

Table 3 highlights a few SCOR-based examples of deployed ML use cases in different supply chain functional areas. In demand planning (SCOR-Plan), ML-based classifiers such as Gamma classifier can be coupled with multilayer feedforward neural networks to perform production forecasting in highly dynamic production environments such as oil and gas, and electricity sectors (Sheremetov et al., 2013) and scenarios alike. Similarly, in purchasing concerns (SCOR-Source), ML can support activities such as performance rating of the suppliers of manufacturing firms using a locally linear neuro-fuzzy (LLNF) model that is trained through a tree-learning algorithm (Vahdani et al., 2012).

In the manufacturing context (SCOR-Make), ML can be applied in various operational functions, such as safety planning, productivity, quality specification building, and prediction. For example, as an ML-based tool with natural language processing (NLP), extreme gradient boosting (XGBoost), and linear support vector machine (SVM) capability, injury severities and safety planning can be assessed in construction and other production/manufacturing setting where the possibility of health hazard is high (Baker et al., 2020).

ML can also be used for automated production ramp-up using intelligent agents with reinforcement-learning algorithm support in production setup, such as automobile assembly lines. Likewise, using a gradient boosting ML algorithm, it can be exploited for quality prediction in a traditional manufacturing setup, such as aluminum die-casting. Further, various formats of classification toolsets using random forest ML algorithms can be developed for pattern recognition (visual or numeric) to identify good and defective elements of production outputs.

**Table 3** Machine-learning (ML) applications across SCOR activities and functions

| SCOR | Function | Implementation use case |
|---|---|---|
| **SCOR-Plan** | Production forecasting | A two-layer feedforward network ANN model using a Gamma classifier to perform production forecasting tool. The tool is applied in the real scenario of oil and gas production (Sheremetov et al., 2013) |
| **SCOR-Source** | Supplier evaluation | A model known as locally linear neuro-fuzzy (LLNF) to predict the performance rating of the suppliers. The model is trained by a locally linear model tree-learning algorithm. The model has been tested with real-time datasets from the cosmetics industry (Vahdani et al., 2012) |
| **SCOR-Make** | Construction safety planning | A tool using natural language processing (NLP), extreme gradient boosting (XGBoost), and linear support vector machine (SVM) to predict injury severity of construction safety outcomes. The tool has applied for safety planning in the construction industry (Baker et al., 2020) |
| | Production ramp-up | A cyberphysical production system for automated production ramp-up of assembly lines using intelligent agents that learn using a reinforcement-learning algorithm |
| | Quality prediction in the die-casting process | A learning tool to predict the quality of a casted part using a gradient boosting algorithm for an aluminum die-casting system |
| | Classification of welding specimens | A classification tool for identifying good parts and defective parts using a random forest algorithm |
| **SCOR-Deliver** | Social and environmental evaluation of transport activities | A model based on supervised ML methods to assess the level of sustainability of transport activities of road freight transport companies. The model has been tested at a European freight transport company (Castaneda et al., 2021) |
| **SCOR-Return** | Customer churn prediction | A customer churn prediction models using AdaBoost.M1 boosting algorithm. The model has been tested with real-time customer churn data set in the telecommunication industry (Vafeiadis et al., 2015) |
| | Disassembly line balancing | A reinforcement-learning framework to optimize the disassembly process to recover components from end-of-life products |
| | Customer purchase segmentation | A model using ML to classify customers of small-sized online shopping malls and identify sequential patterns in the purchasing systems |
| | Customer requirements management | A customer requirement management system using supervised learning algorithms and automatic text comparison to identify changes in requirements and assign the corresponding department for the changes. The system has been tested in the logistics department of a global automotive industry supplier. The system performed well with both |

(continued)

**Table 3** (continued)

| SCOR | Function | Implementation use case |
|---|---|---|
| | | English and German languages (Lyutov et al., 2019) |
| | Customer purchase prediction | An analytics tool using gradient tree-boosting ML method to predict customer behavior in the noncontractual setting. The tool has been tested using a B2B transactional dataset of a large manufacturer in Central Europe (Martínez et al., 2020) |
| | Online shoppers' purchasing intention prediction | An online shopper behavior analysis system using ANN (recurrent LSTM and multilayer perceptron) and ML (support vector machine classifier, decision tree algorithm). The system has been tested experimentally using real-time online retailer data (Sakar et al., 2019) |

In logistical functions (SCOR-Deliver), supervised ML methods are useful to assess the social and environmental sustainability of transport activities of road freight transport companies (Castaneda et al., 2021). In customer service scope (SCOR-Return), ML can be applied to tackle data intelligence requirements, such as customer segmentation, customer anticipation, and their churn and purchase intent prediction as well as for product's end-of-life return management. For example, telecommunication firms use real-time data to train ML tools (e.g., AdaBoost.M1 boosting algorithm) for customer churn prediction (Vafeiadis et al., 2015).

ML can be applied to classify customers in small-sized online shopping malls and identify the sequential patterns in their purchasing behavior. Through supervised learning algorithms and automatic text comparison, ML tools can be applied in shopping scenarios to identify customer requirement fluctuations and make necessary reorganizations in shop floors (Lyutov et al., 2019). Further, analytics tools using the gradient tree boosting ML method can be modeled to predict business-to-business transactional behaviors of customers in noncontractual settings of manufacturing firms (Martínez et al., 2020). Lastly, businesses can apply reinforcement learning methods within an ML framework to optimize disassembly processes to recover components from end-of-life products, such as PC and cell phones.

## 3.4 Genetic Algorithms (GA) in Supply Chain Management

GA is applied to iteratively solve problems through search and optimization. GA techniques, as adaptive search heuristics, are recommended for solving complex and unknown problems by making subspaces into large datasets that have undefined boundaries and biases. GA is generally good at finding *acceptably good* solutions to problems *acceptably quickly* (Amma, 2012). In the business world, data complexities related to numerical function optimization, image processing, and problems

**Table 4** Genetic algorithm (GA) applications across SCOR activities and functions

| SCOR | Function | Implementation use case |
|---|---|---|
| **SCOR-Plan** | Demand forecasting | A guided GA that feeds accurate coefficients to a linear causal forecasting model of manufacturing firms |
| **SCOR-Source** | Supplier evaluation | A hybrid intelligent algorithm combining fuzzy neural network and GA for supporting supplier selection and inventory control decisions. The algorithm has been tested at a sewing manufacturing facility in Iran (Moghadam et al., 2008) |
| **SCOR-Make** | Assembly line balancing | A GA-based optimization approach to solve two-sided assembly line balancing problems relevant to manufacturing large-sized products like trucks and buses (Kucukkoc & Zhang, 2015) |
| **SCOR-Deliver** | Network planning | A hybrid approach using GA, aggregation function, and multicriteria analysis to solve bus network optimization problems. The approach involves computing the optimal values of fitness function using the mentioned AI methods. The approach has been tested for bus network planning for a small city in Italy (Bielli et al., 2002) |
| | Customer allocation to warehouses | A GA-based tool to solve balanced allocation problem using star-spanning forest algorithm. Tested the tool using real data of a chain-link fence manufacturer (Zhou et al., 2002) |
| | Transportation planning for SMEs | An easy method for engineers to modify the standard traveling sales person algorithm for solving transportation problems in SMEs |
| | Logistics network planning | A hybrid model using GA and mixed integer nonlinear programming for integrated logistic network planning including forward and reverse logistic flows |
| | Logistics network planning | A model for reverse logistics network planning using a GA with a weight-mapping crossover operator |
| | Logistics network planning | A model for location-allocation optimization of reverse logistics for E-commerce, using GA. The model incorporates storing, reprocessing, and remanufacturing facilities and new module suppliers. The model has been tested with a sample electronic corporation (Liu, 2014) |
| | Logistic center location planning | A model for determining the number and location of reverse consolidation points, using mixed-integer programming and GA |
| **SCOR-Return** | Warehouse optimization | A model using multiple genetic algorithms to optimize product placement and material flow within a warehouse. The models were tested experimentally (Kordos et al., 2020) |

involving combinatorial optimization (e.g., traveling salesperson problem, bin packing, job shop scheduling, and design problems) can be solved through GA.

Table 4 highlights a few SCOR-based examples of applied GA use-cases in different supply chain functional areas. In demand planning (SCOR-Plan), GA can be applied to improve the accuracy of forecasting models, in terms of searching the supply and demand variability factors from past data records. Presently, such models are utilized in different industries, such as glass-manufacturing lines and residential construction companies. In purchasing concerns (SCOR-Source), GA can be combined with other exploitation techniques – such as fuzzy neural networks to support supplier selection, inventory control decisions, and activities in a traditional manufacturing setting such as sewing manufacturing facilities (Moghadam et al., 2008). In the manufacturing context (SCOR-Make), GA is useful in solving two-sided assembly line balancing problems in large-sized automobile production setting such as trucks and buses (Kucukkoc & Zhang, 2015).

In logistical functions (SCOR-Deliver), GA, as a guided search heuristic, can be applied to the planning of efficient routing networks that may be dependent on socio-geographic factors, such as small cities with twisting roads during peak traffic hours in Italy (Bielli et al., 2002). Using a star-spanning forest algorithm, GA based tools can be modeled to solve customer allocation problems by studying real-time data chain linkages of customer deliveries (Zhou et al., 2002). Further, GA is widely applied in independently solving transportation routing problems using the traveling salesperson algorithm in small firms and combined with mixed-integer nonlinear programming for integrated logistic network planning including forward and reverse logistic flows in large complex situations.

Lastly, in the customer service scope (SCOR-Return), GA can also be applied to model reverse logistics network and center location-planning requirements and location-allocation optimization of reverse logistics for e-commerce service providers (Liu, 2014). Additional customer service activities including warehousing optimization can be achieved through GA algorithms to augment product placement and material flow within a warehouse (Kordos et al., 2020).

### 3.5 Agent-Based Systems (ABS) in Supply Chain Management

ABS are a collection of well-defined, well-controlled, goal-oriented problem decomposing agents that are designed to flexibly and autonomously act – making decisions on behalf of humans – based on a set of rules in applied complex scientific scenarios. ABS are typically suited for problem-solving in digital environments (e.g., telecommunication and static optimization), electromechanical environments (e.g., robotics, intelligent highway systems), and social environments (e.g., electronic commerce, computer-supported collaborative work) (Parunak, 2000).

Table 5 highlights a few SCOR-based examples of existing ABS use-cases in different supply chain functional areas. In demand planning (SCOR-Plan), beer game simulation is an offshoot of ABS technique that managers and consultants widely use to contextualize demand forecast scenarios (Liang & Huang, 2006). In purchasing concerns (SCOR-Source), ABS is also applied to control real-world inventory disruptions of complex supply chains. ABS, as a multiagent system using Agent Building Shell and coordinating language COOL, is applied to forecast unexpected events that may affect production planning, materials ordering, delivery, and reception processes (Fox et al., 2001).

**Table 5** Agent-based systems (ABS) applications across SCOR activities and functions

| SCOR | Function | Implementation use case |
|---|---|---|
| **SCOR-Plan** | Demand forecasting | A beer game using an agent-based system, rough set theory, and GA. The beer game simulation is popularly used in graduate supply chain management courses (Liang & Huang, 2006) |
| | Inventory control | An agent-based system for addressing problems related to inventory control |
| | Inventory control | A multiagent system using Agent Building Shell and coordinating language COOL for production planning, materials ordering, delivery, and reception. The system can cope with unexpected events affecting the target processes. The system has been tested and used by Perfect Minicomputer Corporation in Toronto (Fox et al., 2001) |
| **SCOR-Source** | Supplier evaluation | A hybrid model comprising of expert system and agent-based system for online bidding and supplier evaluation processes. The system was implemented at a multinational manufacturer, Kaz (Far East) Limited, Hong Kong (Cheung et al., 2004) |
| | Global sourcing | An agent-based framework to support global sourcing of generic goods and parts manufacturers |
| | Raw material supply planning | A multiagent system that includes a normative agent for raw material supply planning in regulated sectors, such as biodiesel producers |
| **SCOR-Make** | Production ramp-up | A cyberphysical production system for automated production ramp-up using intelligent agents that learn using a reinforcement-learning algorithm. The system has been tested successfully for windscreen assembly on a moving truck assembly line (Ennen et al., 2016) |
| | 2-sided assembly line balancing | An agent-based ant colony optimization approach to solve two-sided assembly line balancing problems relevant to manufacturing large-sized products like trucks and buses (Kucukkoc & Zhang, 2016) |
| | Intelligent maintenance | An agent-based condition-monitoring system using a case-based reasoning approach. The system has been tested in a large facility that manufactures industrial robots (Olsson & Funk, 2009) |
| | Manufacturing problem-solving | A software system for manufacturing problem-solving process, using an agent-based distributed architecture incorporating 8D problem-solving method with cased-based reasoning for industrial manufacturing plants |
| **SCOR-Deliver** | Order picking | An intelligent agent-based system to dynamically manage order picking using individual, cell, and system agents interacting in real-time through hierarchical and heterarchical modeling frameworks |
| | Route planning | An agent-based system called SafeTrack for automatic delivery management of cargo loads. The system was supported by a Brazilian transportation company and |

(continued)

**Table 5** (continued)

| SCOR | Function | Implementation use case |
|---|---|---|
| | | has been tested for various scenarios (Oliveira et al., 2015) |
| **SCOR-Return** | Agent-based warehouse management system | An agent-based warehouse management system that includes entity agents, mentor agents, and service agents to manage warehouse operations. The system has been tested with simulated scenarios for order receiving, product replenishment, product picking, and congestion management (Binos et al., 2021) |

In the manufacturing context (SCOR-Make), ABS with ES algorithms enables online bidding and supplier evaluation processes (Cheung et al., 2004). Also, ABS frameworks are applied to support decision-making in global sourcing activities by large manufacturers. As a multi-ABS, it solves material planning issues in regulated sectors, such as biodiesel producers. In logistical functions (SCOR-Deliver), ABS, through hierarchical and heterarchical modeling framework, is capable of dynamically managing order-picking activities by devising individual, cell, and system agents to interact in real time with warehouses. Further, ABS can be extended to automate the delivery management systems of cargo loads of transport logistics firms (Oliveira et al., 2015). In customer service scope (SCOR-Return), the ABS technique is used to model entity agents, mentor agents, and service agents to manage warehouse operations for order receiving, product replenishment, product picking, and congestion management (Binos et al., 2021).

## 3.6 Fuzzy Logic (FL) in SCM

Fuzzy logic techniques are typically used to enable formalizing and solving uncertainty and imprecise real-world problems using the linguistic approach of inserting a degree of acceptance and denial, to the confusion of acceptance or denial conditions (Celikyilmaz & Turksen, 2009). FL is widely used in business situations to understand complex and unclear systems, where the relationship between the causes and effects is generally not understood, but often can be observed. FL can also be useful to solve problems that do not necessarily require exact solutions, but rather require useful and fast approximations.

Table 6 highlights a few SCOR-based examples of FL-based use cases in different supply chain functional areas. In demand planning (SCOR-Plan), FL can be hybridized with GA to determine the optimal lot size planning and time-scheduling. Such implementation would improve the overall material flow planning aspects of the production of single commodity or complex products such as electronics. In purchasing concerns (SCOR-Source), FL has wide applicability in supplier evaluation activities. For example, as an adaptive neuro-fuzzy inference system (ANFIS), FL can be exploited for supplier selection processes using real-time sourcing data of input materials in traditional manufacturing settings, such as textile firms

**Table 6** Fuzzy logic (FL) applications across SCOR activities and functions

| SCOR | Function | Implementation use case |
|---|---|---|
| **SCOR-Plan** | Lot size determination | A hybrid model using GA and fuzzy logic to determine the optimal lot size to order in discrete periods |
| **SCOR-Source** | Supplier evaluation | An adaptive neuro-fuzzy inference system (ANFIS)-based model for supplier selection. The model has been tested with real-time data from a textile firm in Istanbul (Güneri et al., 2011) |
| | Supplier evaluation | A fuzzy AHP model based on data inputs from purchasing managers of a white good manufacturer |
| **SCOR-Make** | Single-sided assembly line balancing | A rank position weight tool for single line assembly line balancing. The tool has been tested at a ceiling fan motor assembly line in Nigeria (Imaguike et al., 2020) |
| | Automated guided vehicle navigation for material transport | An automated navigation system using fuzzy grid maps. The system has been tested successfully in a real industrial environment (Martinez-Barbera & Herrero-Perez, 2010) |
| | Quality management | Fuzzy control charts to standardize quality control techniques |
| **SCOR-Deliver** | Automated Guided Vehicle (AGV) for flexible in-house material transport | Fuzzy logic and ANN techniques in designing AGV (Martinez-Barbera & Herrero-Perez, 2010) |
| | Logistic center location selection | A methodology using axiomatic fuzzy set-clustering method to evaluate logistics' center locations and using TOPSIS method for final selection of logistic center locations |
| | Evaluation of logistics operations | A model using fuzzy cognitive maps and GAs to evaluate RFID-enabled reverse logistic operations. The model has been demonstrated using a case of cold food container recycle management (Trappey et al., 2010) |
| | Logistic center location planning | A hybrid model using fuzzy logic and GA to forecast return quantity from different cities to be used for planning recycling center extension. The model was applied for an e-recycling facility in Turkey (Temur et al., 2014) |
| **SCOR-Return** | Customer satisfaction assessment | A customer satisfaction model on the dimensions of quality and reliability of the passenger vehicles using fuzzy logic. The model uses field failure data maintained by original equipment manufacturers |
| | Customer satisfaction assessment | A fuzzy decision-making model to evaluate the customer satisfaction level of banking service providers |

(continued)

**Table 6** (continued)

| SCOR | Function | Implementation use case |
|---|---|---|
| | Customer satisfaction assessment | A methodology based on SERVQUAL and fuzzy TOPSIS methods to assess customer satisfaction with public transport systems. The methodology has been tested with the public transport systems in Istanbul, Turkey (Erdoğan et al., 2013) |

(Güneri et al., 2011). Further, within a fuzzy analytical hierarchy process (AHP) model, fuzzy algorithms can be deployed over real-time sourcing material variables to generate tactical inputs for managers in high-value goods-manufacturing settings.

In the manufacturing context (SCOR-Make), FL, as a rank-position weight tool, can be used for single-line assembly line-balancing activities (Imaguike et al., 2020). It can be applied to automate and trace production movements per stage in factory settings by creating fuzzy grid maps (Martinez-Barbera & Herrero-Perez, 2010). Also, FL can be applied to transform manual control charts to fuzzy control charts for quality control purposes in production floors.

In logistical functions (SCOR-Deliver), FL and ANN techniques may be combined to design automated Guided Vehicle (AGV) for flexible in-house material transportation in factory settings (Martinez-Barbera & Herrero-Perez, 2010). Similarly, FL, with axiomatic fuzzy set clustering and TOPSIS methods, can be applied for choosing the most optimal logistics center located in the case of logistically intense supply chains. Further, fuzzy cognitive maps with GA as hybrid models are appropriate for enabling RFID-enabled reverse logistic operations, such as cold food container recycle management (Trappey et al., 2010) and for return quantity forecasting from various locations for recyclers and e-recyclers (Temur et al., 2014).

In the customer service scope (SCOR-Return), various customer satisfaction models can be developed using FL techniques based on failure records (i.e., quality and reliability feedback from customers) of high-value goods, such as the automotive industry. Even in the service industries, such as the banking and financial sector, FL is widely applied to evaluate the customer satisfaction level of banking products and offerings. Using fuzzy TOPSIS methods, transportation service agencies can assess customer satisfaction levels of their public transport systems (Erdoğan et al., 2013).

## 3.7 Rough Set Theory (RST) in SCM

RST is applied to perform exhaustive computations based on a vague idea as the given dataset (i.e., rough sets) by setting lower and upper approximation levels (Hossain et al., 2020). Key benefits of applying the RST technique include the following: (a) identifying invisible patterns as objects within a vague data set, (b) demonstrating the relevance of a vague dataset by condensing the data variations, and (c) supporting in the setting of significant decision rule sets or decision tables through its feature reduction and relevance analysis properties. Rough set theory-based models are primarily used for knowledge discovery, data mining, and classification within specific tasks such as supply chain risk assessment (Han, 2012).

Table 7 highlights a few SCOR-based examples of RST use cases in different supply chain functional areas. In the demand-planning activity (SCOR-Plan), RST may be deployed to identify conclusive patterns within abnormal input-output data sets for forecasting purposes, such as in energy production at a solar power plant (Yang et al., 2016). In purchasing concerns (SCOR-Source), supplier selection is a major hurdle that can be resolved by combining RST with multicriteria decision-making approaches while incorporating various economic, environmental, and social performance factors as decision criteria. Gray system theory is yet another closely associated technique that combines with RST to sustainability factors into the supplier evaluation process (Bai & Sarkis, 2010).

In the manufacturing context (SCOR-Make), more than having access to data, its vagueness leads firms to make broken quality predictions and wrong machine status diagnoses. In this regard, RST can be applied to conduct data-mining and create knowledge fusion models for quality predictions in production activities, such as milling of large hydraulic turbine blades and defect detection in backlight manufacturing (Lee & Vachtsevanos, 2002). RST is useful in handling uncertainties in setting diagnostic rules from data obtained by sensors and statistical process control to diagnose manufacturing faults, such as flagging valve defects in diesel engines or electromagnetic interferences in circuit boards manufactured (Huang et al., 2005). Further, RST can be applied to pinpoint the causal conditions for defective products, such as solder ball defects in printed circuit boards.

In logistical functions (SCOR-Deliver), RST can be applied in different scenarios, such as dealing with flexibility factors in third-party services-related reverse logistics scenarios (Bai & Sarkis, 2013). In the customer-servicing realm (SCOR-Return), RST can be applied not only to predict customer churn (Gong et al., 2018) but also to predict product demand forecasts and for distribution selection. For example, automotive distributors can develop an RST-based prediction toolset for spare-parts ordering based on the number of sold cars and their mileage (Mehdizadeh, 2020). The same RST logic can be extended to establish distributor evaluation and selection rules based on the past performance of the distributors.

## 4 A *What-Where-How* AI Implementation Framework for Supply Chain Managers

Human decision processes mainly hinge upon known domain knowledge and/or intuition that involves recognizing "clues" and learning from their environment (Frantz, 2003; Simon, 1995). In a similar vein, AI programs perform tasks related to decision-making either by (1) taking support of existing scientific knowledge or expert knowledge, (2) recognizing the associations and learning from the datasets, or (3) using a combination of both methods. Alternatively, the tasks performed by AI could be associated with knowledge exploration by recognizing the critical decision

**Table 7** Rough set theory (RST) applications across SCOR activities and functions

| SCOR | Function | Implementation use case |
|---|---|---|
| **SCOR-Plan** | Energy production forecasting | A rough-set-based energy production-forecasting model. The model has been tested at a solar plant in China (Yang et al., 2016) |
| **SCOR-Source** | Supplier evaluation | A hybrid model for supplier selection using the rough set and multicriteria decision-making approaches. The model incorporates sustainability factors along with the standard business and economic factors. The model may be applied for selection of, say, photovoltaic supplier evaluation by a solar energy company |
| | Supplier evaluation | A model based on rough set theory and gray system theory for supplier selection. The model integrates sustainability factors into evaluation. The model has been tested on a use-case (Bai & Sarkis, 2010) |
| **SCOR-Make** | Quality prediction | A knowledge fusion model based on rough set theory for mining data to predict surface quality. The model may be applied for roughness prediction in the milling of large hydraulic turbine blades |
| | Detection of defects | A rough-set theory-based technique to detect defects in the manufacturing of backlights. The proposed system has been tested in an experimental setup and can be integrated with other quality inspection systems (Lee & Vachtsevanos, 2002) |
| | Fault identification | A tool based on rough-set theory to flag valve failures in the manufacturing of diesel engines |
| | Fault diagnosis | A hybrid fault diagnosis system using rough-set theory for handling uncertainty and GA for searching and classification of electromagnetic interference faults. The system has been tested successfully with the manufacturing data of motherboards (Huang et al., 2005) |
| | Fault diagnosis | A fault-diagnostic system using rough-set theory to effectively extract a minimal set of diagnostic rules from data obtained by sensors and statistical process control charts |
| | Quality control | A quality control tool using rough-set theory to effectively identify the causal conditions of solder ball defects of printed circuit boards |
| **SCOR-Deliver** | Logistics provider evaluation | A rough-set theory-based framework for evaluation of third-party reverse logistics providers incorporating flexibility factors, using rough-set theory. The framework is tested using illustrative data (Bai & Sarkis, 2013) |
| **SCOR-Return** | Customer churn prediction | A hybrid model using ANN and rough set theory to predict customer churn in the logistics industry. The model has been tested using experimental data (Gong et al., 2018) |

(continued)

**Table 7** (continued)

| SCOR | Function | Implementation use case |
|---|---|---|
| | Spare part demand forecasting for distributors | A tool using ABC analysis and rough-set theory to predict the demand for spare parts based on the number of sold cars and their mileage. The tool was implemented in Arian Motor, an Iranian distributor for Mitsubishi Motors Corporation (Mehdizadeh, 2020) |
| | Distributor selection | A methodology using rough-set theory to generate rules for distributor evaluation |

variables. AI can extend from knowledge exploration to knowledge exploitation to offer solution alternatives to the problem at hand. Based on *the AI task context* (exploration and exploitation), *the AI knowledge source context* (Expert / Existing knowledge-based and data-based), and *the supply chain process type* (SCOR activity), we present a *what-where-how* applicability framework for SCM practitioners. This framework covers the processes for which the AI techniques are successfully applied so far and is anticipated to serve as guidance to SCM practitioners for AI implementation in their respective areas of SCM.

In the realm of SCOR-Plan, AI can be utilized for inventory management and demand/production forecasting. The area of inventory management is mature in terms of existing scientific knowledge and expert knowledge. This knowledge can very well be exploited by using expert systems. Alternatively, problems related to demand or production forecasting are characterized by a complex and dynamic environment, with a large number of influencing variables that are constantly changing. These problems are characterized as NP-hard problems and can be effectively solved by knowledge exploration from large-sized historical datasets and subsequent exploitation of the knowledge gained.

Historical datasets can be explored to identify the critical influencing factors and their level of influence. For example, rough set theory-based AI models can be used to explore the data and identify the critical decision attributes along with their weights. These decision attributes can later be used by human experts in their decision-making process or can be further exploited by other AI techniques such as ANNs or traditional time-series forecasting methods, to generate approximate solutions for the problem at hand. No AI application models were found for inventory management and demand/production forecasting in the category of knowledge exploration using existing scientific or expert-based domain knowledge. A plausible reason for this could be that the other enumerative analytical techniques are more apt for this category, which were not covered as a part of this chapter.

In the area of SCOR–Source, AI techniques are predominantly used for decision processes surrounding supplier evaluation. Supplier evaluation in each organization is a unique and subjective process that hinges upon several transactional, relational, and regulatory parameters such as performance, quality, sustainability indices, organizational structure, and supplier relations. Due to the subjectivity associated with these parameters, supplier evaluation processes tend to be heavily dependent on expert knowledge. AI tools based on FL and RST can come in handy to capture and standardize the subjective knowledge from the experts in terms of decision-critical attributes and their relative significance. These factors may then be incorporated into other AI models such as neuro-fuzzy networks to conduct the supplier evaluation processes similar to human experts.

Hybrid models can also be used leveraging on both expert knowledge and learning from past experiences to carry out the supplier evaluation processes. Alternatively, in business scenarios where selection criteria are standardized and objectively used for supplier evaluation, data-based knowledge exploitation AI models can be used. For example, the neuro-fuzzy networks trained by GAs or ML algorithms can be used to automate supplier evaluation processes. No AI applications were found for supplier evaluation in the category of knowledge exploration from data. As previously mentioned, supplier evaluation processes are typically characterized as business-critical decisions, requiring causal explanations of the decision attributes to some extent. These decision attributes, therefore, require human interpretation and judgment and cannot be merely based on patterns and correlations observed in the data sets.

AI applications in the SCOR-Make function are predominantly used for processes related to quality management. Quality management in a production environment is a complex phenomenon requiring expert interventions from different functions and/or intensive data processing, to identify the causal factors for defective products. Neural networks integrated with data input systems such as camera systems, electrical signal inputs, or RFID can be used for quality inspection processes. The neural network models can also be integrated with RST and fuzzy inference systems to deal with uncertainty associated with dynamic production environments and predict the quality outcomes. Agent-based systems may be used to integrate expert knowledge and support in quality problem-solving processes.

In the areas of SCOR-Deliver and SCOR-Return, AI tools are predominantly used for network and route planning, and customer management. Network optimization is one of the extensively researched areas spanning several disciplines. AI techniques are a natural extension of this vast body of knowledge. As can be seen in Table 8, AI solutions can be applied to all the categories of AI task context and knowledge source context for network/route planning problems. On the customer management side, AI solutions with their capability of including qualitative customer feedback can be used to manage customer requirements, assess customer satisfaction, discover purchase patterns, and predict customer churn.

## 5 Summary and Conclusion

Over the past few decades, the topic of AI applications to the practical business environment has garnered attention in organizations and academia. This increased attention has occurred in convergence with developments in statistical models, systems and data engineering, cybernetics, and industry use cases. Currently, businesses are approaching AI as a decision support tool rather than as a replacement for human intelligence and ingenuity (Uzialko, 2022).

**Table 8** The What-Where-How Model – AI implementation framework for supply chain managers

| WHAT? (*the AI task context: the AI knowledge source context*) | ←WHERE? (*In the SCOR activities, can AI techniques be deployed?*)→ | | | | |
|---|---|---|---|---|---|
| | Plan | Source | Make | Deliver | Return |
| **Knowledge exploration: expert/existing knowledge-based** | **Scenario:** <Unestablished> **Solution:** *No applications were found in the survey for this category. Probably other enumerative analytical techniques are more apt for this category. Cannot state with certainty though, since we have not included those papers in our survey* | **Scenario:** Supplier evaluation **Solution:** Use fuzzy analytic hierarchy process to formalize and standardize the qualitative decision attributes based on relative judgments of multiple decision-makers (FL) | **Scenario:** *<Unestablished>* **Solution:** *Study did not come across any applications for this scenario. Probably standard analytical and problem-solving procedures without AI are used* | **Scenario:** Network/Route planning **Solution:** Expert system integrating case-based reasoning, OLAP technologies, and a data warehouse, encoding expert knowledge, and historical case experiences. For each new case of network planning, the system can retrieve similar cases and offer solution alternatives (ES) | **Scenario:** Customer requirements management **Solution:** A hybrid model that utilizes experts' knowledge, preprocessed textual data, and classification algorithms such as Naïve Bayes, Decision tree, Maximum Entropy, and Support Vector Machine can be used to detect changes in the customer requirement documents and alert the corresponding department (ML) |
| **Knowledge exploitation: expert/existing knowledge-based** | **Scenario:** Inventory management **Solution:** An expert system can be developed using experts' knowledge and used to effectively | **Scenario:** Supplier evaluation **Solution:** A gray-based rough set methodology that incorporates decision-maker inputs, their | **Scenario:** Quality inspection/ prediction **Solution:** Visual inspection system with a multilayer neural | **Scenario:** Network/Route planning **Solution:** Multilayer feedforward neural network using real-time data of | **Scenario:** Customer requirements management **Solution:** An expert system can be used to translate the digital product |

(continued)

**Table 8** (continued)

| WHAT? (*the AI task context: the AI knowledge source context*) | ←WHERE? (*In the SCOR activities, can AI techniques be deployed?*)→ | | | | |
|---|---|---|---|---|---|
| | Plan | Source | Make | Deliver | Return |
| | support decisions for inventory management problems | impact on the decision, and relative importance of decision attribute to determine the most preferred suppliers (RST) | network using the principal component analysis learning method (ANN) | obstacles and established route optimization algorithms such as A-star or Djikshtra's algorithm for within-facility route planning of automated guided vehicles (AGVs) for route planning in general (ANN) | customer requirements into product configurations (ES) |
| **Knowledge exploration: data-based** | **Scenario:** Demand/Production forecasting **Solution:** Rough set combination prediction model to generate accurate weights for decision attributes (RST) | **Scenario:** *<Unestablished>* **Solution:** *Evaluation of suppliers requires expert intervention to prioritize the decision criteria that align to their organization context – there are elements of relation and transaction* | **Scenario:** Quality inspection/ prediction **Solution:** A multilayer neural network model to classify the operating state of the machines based on electrical current profiles can be used to discover the electrical profiles and operating states associated with worn-out machine components and | **Scenario:** Network/Route planning **Solution:** A hybrid model using GA along with aggregation function and multicriteria analysis incorporating the required route performance criteria can be used to calculate the fitness function for all the routes in the network and aid in network planning (GA) | **Scenario:** Customer satisfaction pattern discovery **Solution:** The fuzzy logic approach can be used to identify temporally changing patterns in customer satisfaction concerning the quality and reliability of individual automotive vehicle models based on available data such as the number of reported vehicle |

| | | | | | |
|---|---|---|---|---|---|
| | | | defective parts produced (ANN) | | failures, the severity of failures, and the number of visits to the dealer (FL) |
| **Knowledge exploitation: data-based** | **Scenario:**<br>Production forecasting<br>**Solution:**<br>Multilayered feedforward or recurrent neural networks with unsupervised or reinforced training algorithms (ANN)<br>Gamma classifier for time-series-based production forecasting (ML) | **Scenario:**<br>Supplier evaluation<br>**Solution:**<br>Neuro-fuzzy neural networks integrating fuzzy inference systems and trained by GA or ML (e.g., locally linear model tree learning algorithm) (ANN, FL, and ML/GA) | **Scenario:**<br>Quality inspection/ prediction<br>**Solution:**<br>1. Knowledge fusion models using rough set theory, which construct rule base from rough sets generated from preprocessed production/simulation/ visual data. The quality outcome can be predicted based on the generated and set-quality thresholds using GA or other mathematical models (RST)<br>2. Neuro-fuzzy neural networks integrating fuzzy inference systems can also be used (ANN, FL) | **Scenario:**<br>Network/Route planning<br>**Solution:**<br>A hybrid system using fuzzy cognitive maps, weight-training algorithms, and RFID technologies can be used to alert for inefficiencies in reverse logistics (FL, GA) | **Scenario:**<br>Customer purchase segmentation<br>**Solution:**<br>Data-mining tools like Weka 3.6 – that use multiple ML algorithms and ANN to discover associations and sequential patterns in customers' purchase behavior (ANN, ML) |
| **Knowledge exploitation –** | **Scenario:**<br>Inventory control | **Scenario:**<br>Supplier evaluation | **Scenario:**<br>Quality inspection/ | **Scenario:**<br>Network/Route | **Scenario:**<br>Customer churn |

(continued)

**Table 8** (continued)

| WHAT? (*the AI task context: the AI knowledge source context*) | ←WHERE? (*In the SCOR activities, can AI techniques be deployed?*)→ | | | | |
|---|---|---|---|---|---|
| | Plan | Source | Make | Deliver | Return |
| **expert/existing knowledge-based and data-based** | **Solution:** A multiagent system modeled with supply chain agents such as manufacturer agents, transportation agents, supplier agents, distributor agents, retailer agents, and end-customer agents can be developed incorporating policy rules for different events that can be used for automating inventory management decision processes (ABS) | **Solution:** Use the analytical hierarchy process to identify important decision variables and their weights. These weights are fed into a multilayered neural network, which further ranks the suppliers (AHP-ANN) | prediction **Solution:** An agent-based system integrating case-based reasoning can be used for conducting process failure mode and effect analysis and as a platform for knowledge exchange and reuse (ABS) | planning **Solution:** An agent-based system integrated with radio frequency identification (RFID) technologies and geofencing algorithms can be used for dynamic route planning (ABS) | prediction **Solution:** A hybrid system using rough set theory to extract rules from normal and abnormal customers and a multilayered feedforward neural network trained by Adam algorithm/ decision tree/support vector machine can be used to predict customer churn (RST, ML, and ANN) |
| | ←**HOW?** (*to apply the AI technique in the given supply chain scenario*)→ | | | | |

While academic and professional literature is rife with AI technique descriptions and their potential usefulness for decision support in real-time business scenarios, supply chain practitioners must bear in mind some important factors related to AI adoption to real-time supply chain process scenarios. The first factor is the cost associated with the development of AI systems. Design and development of AI systems are associated with significant investment and costs including the need for specialized expertise to code the programs, the digital infrastructure required to process large amounts of data, and integration with other business systems. Supply chain practitioners, therefore, must consider using the AI applications in processes that have the most economic impact and are mature enough to leverage on AI.

The second factor is the scalability of the AI applications. To reap the intended benefits, AI applications need to be designed for scalability, which in turn requires collaboration between the business users and the AI experts. In an AI-intensive supply chain, the required skillsets of the business users might shift to a more advanced technical skill set, to be able to comprehend the basic tenets of AI applications and utilize them in regular business processes (Uzialko, 2022).

The third factor is the complexity associated with building and maintaining AI applications. AI applications can have varying complexity based on the scope of applicable tasks, required level of automation, the expected level of precision in the results, and level of integration with other systems (Klubnikin, 2021). The development of AI systems requires complex coding of programs, building a knowledge base, and processing large amounts of data for learning. Efforts by technological firms in developing toward no-code or low-code AI platforms can help in easing the development efforts shortly (Tsymbal, 2022).

Efforts in making the AI tools more efficient can help in saving time and energy required for data-processing. For example, the development of the third-generation generative pretrained transformer, known as GPT-3, is expected to cut down the required step of a backward pass, which is a bottleneck for backpropagation neural networks and other machine-learning algorithms. This development is expected to greatly boost the performance of the algorithms in terms of time and energy required for the same level of accuracy in the results (Gent, 2022). These future developments are expected to ease the efforts and costs associated with designing and maintaining the AI applications in the coming years – and supply chain managers and actors need to be aware of older and newer AI considerations. This chapter provided this review. Further, the chapter proposed a framework that enables SCM practitioners to evaluate a particular AI task scope against the available AI possibilities (the *What) as a* SCOR activity (the *Where*) and to provide an algorithmic description (the *How*) of the AI objective in supply chain context.

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# Supply Chain Analytics: Overview, Emerging Issues, and Research Outlook

M. Ali Ülkü and Bahareh Mansouri

## Contents




**Abstract**

Supply chains (SCs) produce vast amounts of data from sourcing raw materials to manufacturing to consumption to returns. Supply chain analytics (SCA) helps organizations (profit or non-profit) to make faster, smarter, and more effective and



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efficient decisions. However, SCA requires advanced technology adoption, an organizational skill set, and a culture that embraces data-driven decision-making. In contemporary SC operations, a highly sought-after approach, analytics provides description, prediction, and prescription of the problems faced. Emerging intelligent technologies, such as the internet of things, blockchain, physical internet, and artificial intelligence that support SCA, can be utilized in almost every sector, including humanitarian and business logistics, procurement, marketing, pricing, and sustainable supply chain management. This chapter overviews the scaffolding concepts behind SCA. It offers a framework for bringing various stages of an SC to collaborate in data sharing, planning, and executing SC decisions at the operational, tactical, and strategic levels. It offers findings and managerial implications from the state-of-the-art literature and best industrial practices while focusing on SCA's current concerns and research opportunities.

**Keywords**

Supply chains · Big data · Analytics · Intelligent technologies · Circular economy · Sustainability

## 1 Introduction

Business runs on supply chains. A supply chain (SC) comprises all the stages of fulfilling a customer's request. SCs are at the heart of the economy and development. Almost all products and services emerge from productive transformation through a network of interdependent processes. In short, an SC consists of all parties involved in fulfilling a customer request.

Efficient integration of suppliers, manufacturers, distribution, logistics, retailers, and customers is vital in managing SCs so that the right products with the right information are delivered to the right place or customer at the right quantity, the right price, the right condition, and at the right time. Good management of an SC facilitates levers to pull to improve SC performance and create a competitive advantage sustainably.

Companies work with many international partners and face escalating pressure to deliver their products quickly, economically, and sustainably. Supply chain analytics (SCA) enables organizations to turn an overwhelming amount of data into digestible dashboards, reports, and visualizations that guide them through critical decisions and lead to better results. The growing popularity of the internet, coupled with the availability of several means to access it, has enhanced traditional SC practices and increased corporate sales. This situation is especially relevant as SCs have evolved into more complex systems. Companies can now collect massive amounts of data from various SC segments, including operations, logistics, sales, marketing, workforce, and risk management, to improve efficiency.

The use of "analytics" continues to be a leading trend. In 2018, analytics was recognized as by far the most significant technology for managing the supply chain

(Grover et al., 2018). In 2023, a report by the American Productivity & Quality Center (APQC, 2023) recognized "big data and analytics," along with "global trade/tariff uncertainties" and "sustainability," as the top three leading trends anticipated to impact supply chains by 2026.

SCA has now been a prominent tool in increasing the effectiveness of supply chain management (SCM): The market for SCA is forecasted to account for almost one-third of the SCM revenue worldwide, which is expected to be around $21.87 billion in 2023. It is forecast to more than double – $49.21 billion – by 2030 (SCM Market Report, 2023), with SCA market size expected to grow from $7.15 billion in 2023 to $22.46 billion in 2030 (SCA Market Report, 2023).

This chapter is organized as follows: Sect. 2 provides background info on analytics and SCM into which SCA can be integrated. Section 3 focuses on the current issues and developments, such as the SCA technologies and circularity and sustainability in SCM. In Sect. 4, emerging concerns and future research directions are discussed. Section 5 offers some managerial implications of SCA, and Sect. 6 concludes.

## 2 Background

### 2.1 An Overview of (Big Data) Analytics

*Analytics* refers to a method of logical analysis. The etymology of the word analytics borrowed from Late Latin Analytica, the title of two of Aristotle's works on logic, borrowed from Greek analytiká, a noun derivative from the neuter plural of analytikós, i.e., analytic (Defn1). Its precedent word is "analysis" – a Medieval Latin word borrowed from Greek análysis (Defn2). With the advent of scholarly knowledge and technology, analytics can be defined as "applying scientific methods to analyze complex problems to gain insights for better decision-making." Therefore, analytics call for "a detailed examination of anything complex to understand its nature or to determine its essential features; a thorough study; separation of a whole into its parts."

Analytics has four stages – descriptive, predictive, prescriptive, and cognitive – in its continuum (Fig. 1). *Descriptive analytics* is an essential first step to understanding and defining the problem. Descriptive analytics utilizes data collection,

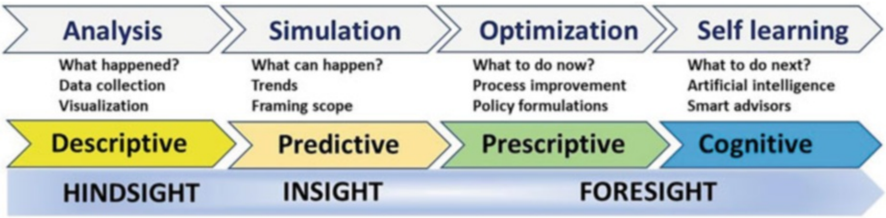


**Fig. 1** Analytics continuum (Source: Ülkü & Engau, 2021)

visualization, and analysis to provide hindsight as to what happened. To gain insight and minimize risks with decisions, *predictive analytics* mainly employs simulation techniques and statistical tools to forecast what can happen. Prescriptive analytics is where mathematical or simulation-based optimization models are developed to improve processes and formulate policies to answer what should be done now. In the final stage, *cognitive analytics,* based on advanced technologies and self-learning (e.g., data training in artificial intelligence), aims to provide solutions for what to do next. Accordingly, both prescriptive and cognitive analytics offer foresight to the optimal solution and future actions on the problem.

Soaring digitization, social media, financial transactions, and production and logistics in global supply chains produce massive amounts of data. The challenge with such *big data* (BD) is to make sense of it – turn it into information – and then utilize it for better decision-making. BD is almost unmanageable using traditional software or internet-based platforms and surpasses the traditionally used amount of storage, processing, and analytical power.

As a seminal definition, Laney (2001) asserted that data grow "big" in three dimensions: volume, velocity, and variety. As the use of BD increases, more issues and barriers appear. Therefore, new factors that help characterize BD have emerged. Figure 2 displays the *ten* Vs of BD.

Because SCA mainly offers its benefits from data-rich, complex SC problems, it is crucial to understand those factors that make BD. Figure 2 exhibits the attributes of BD, how it informs various SC sustainability metrics, and how it then enables optimal supply chain solutions – context-specific, short-term and robust policies, long term. BD may relate to any data with at least one of the ten following characteristics:

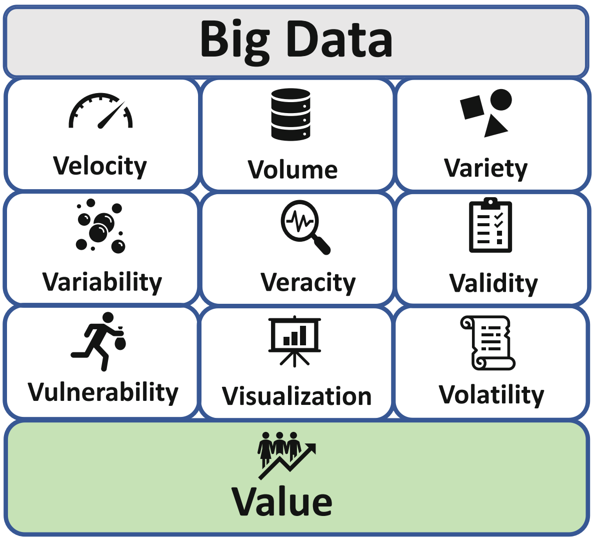


**Fig. 2** The 10 Vs of big data

- Velocity – the speed at which data is generated, produced, created, or refreshed
- Volume – the amount of data from myriad sources or the scale of data
- Variety – the types of data (structured, semi−/unstructured) in varying forms (e.g., texts, numbers, sounds, pictures, videos)
- Variability – the variance of the data (the level of inconsistencies in data, variable speed of data loading)
- Veracity – the degree to which data can be trusted or the uncertainty of data
- Validity – the data's accuracy and correctness for its intended use
- Vulnerability – the degree to which the data can be breached
- Visualization – the challenge of visualizing enormous amounts of data (data clustering, tree maps, parallel coordinates, etc., that will enable plotting millions of data points)
- Volatility – the time to keep data before it becomes irrelevant or obsolete
- Value – the business value derived from the data collected

Arguably, the value of BD – emphasized as a support characteristic in Fig. 2 – is very important. Knowing BD characteristics makes its planning, computing, and analysis more tractable. The other attributes of BD do not mean much if the BD at hand does not provide business value.

Big data analytics (BDA) is the science of collecting, organizing, visualizing, and analyzing massive amounts of data to create information and insights into solutions to data-intensive, complex problems. With advances in hardware technologies, computing software, and information systems in the last two decades, management has regarded BDA as a revolution (e.g., McAfee & Brynjolfsson, 2012). BDA has become imperative to gain a competitive advantage from supply chain decisions (e.g., Waller & Fawcett, 2013; Sanders, 2016; Rahimi et al., 2021).

Organizations gain a competitive edge in identifying new opportunities and making quick and informed business decisions using BDA. BDA is often referred to as the complex process of using advanced analytics techniques against data sets characterized as big data to discover information – such as hidden patterns, correlations, market trends, and customer preferences – that can help organizations enhance their overall business intelligence. The BDA process encompasses several steps that generally include the following:

1. **Data collection.** Organizations gather data – structured, semi-structured, and unstructured – from a variety of different sources. Some common data sources include cloud storage, mobile applications, mobile phone records, social media content, and customer feedback – messages, emails, survey responses, web server logs, internet clickstream data, and data captured by the internet of things (IoT) sensors.
2. **Data processing**. Data preparation and processing make for more accurate results from analytical queries. After data is collected and stored, it must be organized, configured, and partitioned properly for analytical queries.
3. **Data cleansing.** Data cleansing improves its quality and promotes more robust results. Data must be formatted correctly using scripting tools or data quality

software. Inconsistencies, such as duplications or formatting mistakes, can create flawed results.

4. **Data analysis.** The collected, processed, and cleaned data is then ready to be analyzed using big data analytics tools. Some tools commonly used to analyze data include data mining, text mining, machine learning, deep learning, predictive analytics, artificial intelligence, and data visualization tools.

There are several critical tools used to support BDA processes, including Hadoop, predictive analytics, **s**tream analytics, distributed storage, NoSQL databases**,** data lake, data warehouse, knowledge discovery/big data mining, in-memory data fabric, data virtualization**, d**ata integration software, data quality software, data pre-processing software, Spark, MongoDB, Talend, Cassandr, STORM, and Kafka.

Big data analytics techniques and tools have increasingly been utilized in supply chain analytics to enhance decision-making processes across the supply chain. They go beyond the traditional internal data and implement highly effective statistical methods on expanded data sources.

There exists an increasing amount of research on integrating BD into SCA. For instance, Nguyen et al. (2018) offer a literature review of BDA in SCM, while Ogbuke et al. (2022) focus on BDA's ethical, privacy, and security challenges. Moreover, research on frameworks and applications of BDA to SCA is rampant and spans almost all industries and organizations. For example, Papadopoulos et al. (2017) argue that BD is an enabler for increasing resilience in disaster SC networks, albeit the data collected needs to be more structured. Applications of BDA range from finance (Goldstein et al., 2021) to marketing (Erevelles et al., 2016; Currie et al., 2021) to healthcare (Dash et al., 2019) to service operations (Zhong et al., 2016) and to SC logistics (Wang et al., 2016; Witkowski, 2017; Mansouri et al., 2023).

## 2.2 Understanding Supply Chain (Analytics)

In essence, SCA refers to a collection of analytical tools and applications to inform better decision-making along all stages of an SC to improve SC performance (Trkman et al., 2010; Souza, 2014). Understanding SCA and its applications (enablers and barriers) along the stages of an SC requires knowledge of basic terminology. Figure 3 presents a pictorial of a typical closed-loop supply chain (CLSC) framework. In a conventional SC, the flow of materials is from the suppliers to the end customers in one direction. Therefore, it is termed *forward* logistics or SC. However, in a CLSC, the end-of-life, end-of-use, or simply the returned products – for various reasons, such as misfit or poor quality or no longer needed – are brought back into *reverse* logistics or SC. Products may be revalorized in multiple ways, for example, by reselling, remanufacturing, or recycling. Hence, adding a reverse SC to a forward one closes and makes it more sustainable.

Typical SC members include suppliers, manufacturers, distributors, wholesalers, retailers, and consumers. Directly or indirectly, all SC members are customers of raw

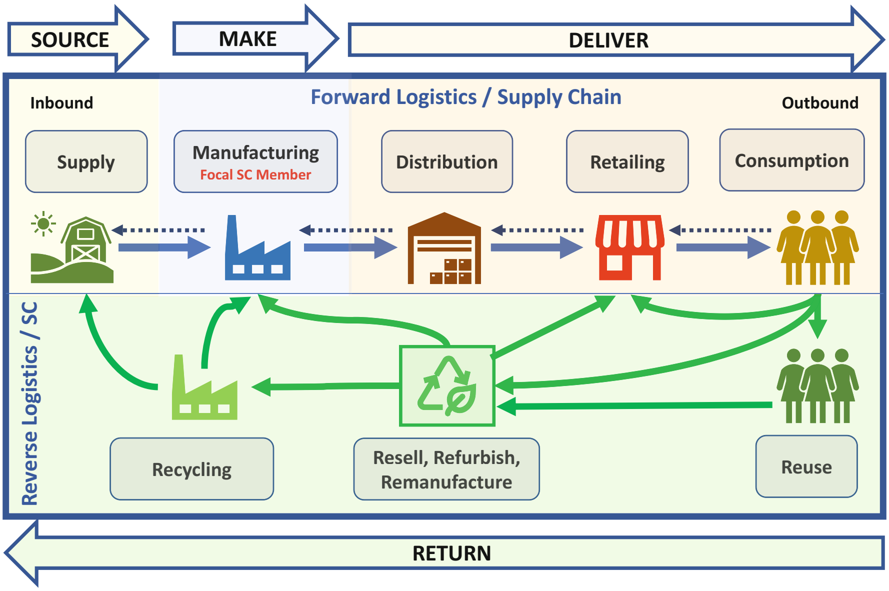


**Fig. 3** Schematization of a closed-loop supply chain

material suppliers. The consumer can be considered the *end customer*, who buys the product and derives value from its usage. It is crucial in SC modelling and analysis to determine for whom the problem is solved. The company for which the problem is analyzed is the "focal SC member" or "focal company."

In Fig. 3, the focal SC is chosen to be the manufacturer. All the storing and moving activities related to raw and semi-finished products going into the manufacturer's plant are termed *inbound logistics*. Once the product is finalized and ready for selling, it is shipped out from the manufacturer through various marketing channels – for example, via a retailer or from the manufacturer's outlet. The product eventually reaches consumers.

Logistics related to the finished good is the *outbound logistics* function. Companies from which the focal company receives materials are termed *upstream* SC members. All those receiving orders from the focal company are *downstream* SC members. For example, if the focal SC member were a retailer, the manufacturer from which it directly purchases would be a Tier-1 upstream SC member. Then, the supplier from which that manufacturer procures would be a Tier-2 upstream SC member from the retailer's relational position in the SC.

Many upstream suppliers and tiers make it a long supply chain. Regarding this construct, Yang et al. (2009, p.192) stated that "as supply chains are extended by outsourcing and stretched by globalization, disruption risks and lack of visibility into the supplier's status can both worsen." Shortening the supply chain, if possible, has the advantage of having fewer impacts of double marginalization – additional markups imposed by the intermediary agents in the supply chain that increase the purchase price as seen by the consumers. The bullwhip effect – increasing variability in order sizes further up in the SC – are also more likely.

The Supply Chain Operations Reference (SCOR) Model – maintained by the Association of Supply Chain Management – helps understand the SC holistically. Figure 3, using the SCOR model, identifies the SC activities within the set of suppliers as *source*, the manufacturing process as *make*, all the activities in outbound logistics as *deliver*, and the collection of products injected back into the CLSC via a reverse SC for revalorization simply as *return*. These aggregations of the activities through the SCOR model help provide better design and utilize SC performance metrics (e.g., Maestrini et al., 2017; Dissanayake & Cross, 2018; Ben-Daya et al., 2019; Chehbi-Gamoura et al., 2020).

SCA includes collecting data and information that provide insights into logistics performance. SCA gives organizations a comprehensive view of their logistics network and enables them to understand the impact of a specific disruption on the entire supply chain and for them to respond quickly. Such a comprehensive insight allows businesses to draw long-term strategic adjustments to gain a competitive advantage.

Examples of SCA include demand planning using historical data to predict what customers will order, sales and operations planning based on manufacturing and procurement requirements to satisfy forecasted demand, and inventory management tracking sell-through of the products. Each of these activities can contribute to helping an organization make more intelligent, quicker, and more efficient decisions. The benefits of SCA-supported decisions may include reduced costs and improved margins, better risk assessments, increased planning accuracy, and robust future preparedness. As technology becomes more commonplace in SCA, companies realize broader benefits. Information not previously processed can now be analyzed in real-time, providing companies with increased SC intelligence.

## 3 Current Concerns

### 3.1 Sustainability and SCA

In the face of diminishing resources and environmental challenges, concern for sustainable development (SD) is rising. With increasing concerns for climate change, population growth, and social instability, sustainability has been at the front and center of emerging SC research and practices. Instilling sustainability in all stages of SCs is currently very relevant and urgently calls for attention from both the academic and practitioner communities.

SD necessitates a holistic approach to the long-term coexistence of humankind and the biosphere. The Brundtland Report (1987, p. 54) defines SD as ". . . development that meets the needs of the present without compromising the ability of future generations to meet their own needs." The logic is simple: Be it on local or global scales, the economy is part of a society which is a part of the biosphere. That is, if the environment is degraded to the level that society cannot function, then an economy derived from the collective actions of humankind (see Clark & Munn, 1986) is not viable.

A rush to industrialization has resulted in the fast depletion of nonrenewable resources and social malpractices such as child labor and poor working conditions. Evidently, an unsustainable rate of human development activities (e.g., population, consumption) causes environmental damage (Nordhaus, 2017) directly impacting human lives. In recent decades, increased visibility of social and ecological malpractices has propelled pressure on companies to reduce their industrial waste and carbon or water footprints while improving the safety and health conditions of their employees and contributing to enhancing the quality of life of the communities they serve.

Production and consumption activities form the basis of humankind's impact on the environment and the biosphere. SCs directly impact the economy, environment, society, and culture – i.e., the quadruple bottom line (QBL), as depicted in Fig. 4. A typical SC is built on sourcing, production – whether in the form of "tangible" goods or "intangible" services – and distribution processes. Therefore, understanding, measuring the sustainability performance, and charting actionable courses for the betterment of the SCs for each industry, both supply and demand sides, are good starting points toward sustainable development and industrial infrastructure

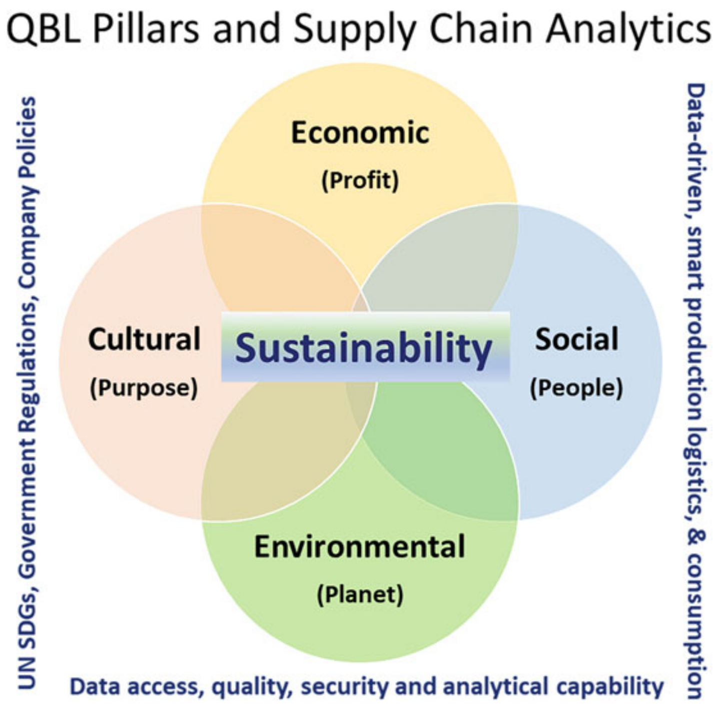


**Fig. 4** The quandruple bottom line (QBL) approach to Sustainability and Supply Chain Analytics

(c.f., Azapagic & Perdan, 2000) and require a holistic and interdisciplinary approach (see Kaufman & Ülkü, 2018).

Of particular concern is how SCA can support companies' corporate social responsibility (CSR) efforts. CSR is defined as a company's environmental, social, and economic performance in which the company's expected actions include not only producing a reliable product, charging a fair price with fair profit margins, and paying a fair wage to employees, but also caring for the environment and acting on other social concerns. When conducted in good faith, CSR benefits corporations and their stakeholders (Fig. 5).

CSR in SC has attracted recent attention from businesses and stakeholders. A corporation's SC is the process by which several organizations, including suppliers, customers, and logistics providers, work together to provide a value package of products and services to the end user, who is the customer.

As companies use SCA to draw information from several applications tied to their supply chain – such as supply chain execution systems for procurement, inventory management, order management, warehouse management and fulfillment, and transportation management – they need to be aware of social responsibilities by introducing codes of conduct. Areas relevant to SC include human rights – working conditions, slave labor, and child labor – occupational health and safety, as well as sustainable production and environmental practices (Fig. 6).

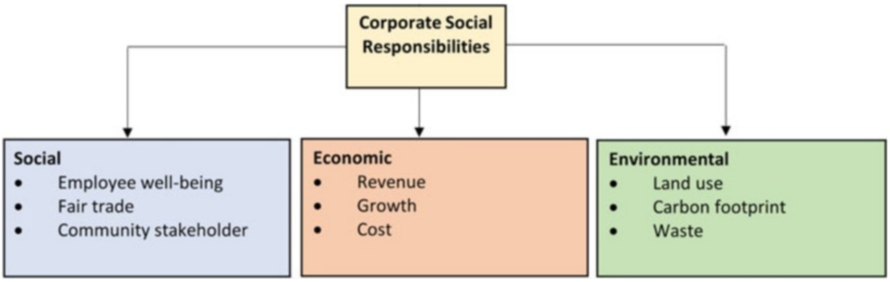


**Fig. 5** Instances of corporate social responsibility (CSR) of a firm

| Source | Make | Deliver |
|---|---|---|
| • Child labour<br>• Discrimination<br>• Long working hours<br>• Abuse of union rights<br>• Pollution | • Corruption<br>• No freedom of speech<br>• Unsafe working conditions<br>• Social inequality in the local community | • Wholesale discrimination<br>• Bribery<br>• Unfair competition<br>• Unethical investment |

**Fig. 6** Instances of corporate social responsibility (CSR) concerns within the supply chains of a firm

Wang et al. (2016) show that firms benefit from higher SCA capability to sense market changes, competitive pressures, and external stakeholder demands, which contribute to advancing CSRs. As such, corporate social irresponsibility from both the suppliers and retailers has greatly affected the stakeholders who lost trust in the affected business entities: For example, the horsemeat scandal of 2013 in the United Kingdom that affected many food retailers led to the dismissal of the supplier. These surrounding issues have prompted SCA to manage CSR.

### 3.2 Investing in and Adopting Supply Chain Analytics Technology

In contemporary SC operations, BDA plays an instrumental role in SCA by creating an additional "data-sharing" connection between the SC players. Employing BDA may help coordinate decisions between the SC stages to improve operational performance, sustainability imperatives, and consumer satisfaction.

Big data tools available for SCA are mainly utilized to organize and integrate and store data, produce visualization from them to describe the trends, and see the patterns for potential problems. Problem identification may include demand for an innovative product. Those tools can also help perform mathematical analysis and optimization, such as in the prescription stage of analytics.

Integration of SCA requires infrastructure costs, a supportive organizational culture, and transformative leadership. The SC world is evolving, and SCA is a crucial enabler, more so for SCs that compete in a turbulent business world. For example, intelligent communication technologies may eliminate administrative assistants; smart sensors may make data-logging employees obsolete. Besides some workforce frictions, companies may be coerced to invest in and utilize SCA technology within the SC where it resides strategically.

## 4 Emergent Concerns, Outstanding Research, and Future Directions

### 4.1 Data Privacy and Security, Ethics, and Artificial Intelligence for SCM

The main issue with BDA, and thereby SCA, relates to data privacy, security, and veracity. Without proper definitions and regulations of data ownership and its control of flow, IoT's potential will fail – for example, the "data generators," such as the consumers, will feel deceived, vulnerable, and revolt.

Berinato (2014, p.100) probes the issue: "Big Data and the IoT- in which everyday objects can send and receive data - promise revolutionary change to management and society. But their success rests on an assumption: that all the data being generated by internet companies and devices scattered across the planet belongs to the organizations collecting it. What if it does not?"

Integrating data-intensive, intelligent technologies like BDA does not come for free. For example, Kusi-Sarpong et al. (2021) identify technological, human, and organizational risks as the most prevailing ones in SCA implementation.

## 4.2 Emerging Technologies for Supply Chain Analytics: AI, BCT, IoT, and PI

Emerging digital technologies such as blockchain technology (BCT), IoT, the physical internet (PI), and artificial intelligence (AI) have been regarded as promising to enhance SC performance – efficiency, structure, sustainability, and innovation (Yang et al., 2021). These digital technologies are finding applications in SC functions such as procurement, logistics, scheduling, and planning, among others (e.g., Arunachalam et al., 2018). The data collected from the IoT devices (sensors) coupled with the data collected from traditional SC processes have a great potential to generate sustainable business value through AI and BDA (e.g., Liu et al., 2020). More descriptions of emerging SCA technologies follow.

A revolutionizing technology that can mimic human intelligence in creating knowledge and in solving problems, AI refers to "a new generation of machines capable of (a) interacting with the environment, gathering information from outside (including from natural language) or from other computer systems; (b) interpreting this information, recognizing patterns, inducing rules, or predicting events; (c) generating results, answering questions, or giving instructions to other systems; and (d) evaluating the results of their actions and improving their decision systems to achieve specific objectives" (Ferràs-Hernández, 2018, p. 260).

AI can provide analytics and automation, from financial transactions to health diagnostics to tracing criminal activities. Particularly for SCM, AI has immense potential for purchasing, marketing, production and quality control, demand forecasting and inventory management, SC risk analysis, inventory management, pricing and revenue management, and sustainable humanitarian logistics, among others (e.g., Min, 2010; Huang & Van Mieghem, 2014; Choi et al., 2018; Rodríguez-Espíndola et al., 2020; Toorajipour et al., 2021; Pournader et al., 2021).

Emanating from peer-to-peer payment systems and cryptocurrencies (Nakamoto, 2008), BCT is a disruptive, decentralized, and distributed digital ledger technology that ensures the secrecy, reliability, and accessibility of all data and transactions (Wamba & Queiroz, 2020). It is named "blockchain" because the successive transactions form "blocks" that become a part of earlier blocks after validation, constructing an immutable chain in which the transactions are chronologically recorded on a network of interconnected computers, all without the need for a third party (e.g., a bank) for verification (Treiblmaier, 2018; Chang et al., 2019). BCT employs a real-time cloud storage architecture that allows transactions to be completed in minutes via digital platforms. As a peer-to-peer (P2P) distributed data infrastructure, BCT has enormous potential to impact all SC processes and decision quality from purchasing to delivery to return by generating decentralized currencies and digitally automated "smart" contracts, among others. BCT enhances the authenticity, legality, transparency, traceability, visibility, integrity, and security of data and information, helping efficiency, compliance, customization, sustainability, and risk management in SCM (e.g., Saberi et al., 2019; Dutta et al., 2020; Murray et al., 2021; Nabipour & Ülkü, 2021).

IoT is a network of physical objects that are digitally connected to sense, monitor, and interact within and between SC members. IoT impacts the everyday life and behavior of potential users. IoT heralds a vision of the future wherein connecting through a network of physical things, from cellphones to bank cards to refrigerators to smart bicycles, will enable immediate access to information about the physical world with its objects to maximize SC performance (Atzori et al., 2010; Bandyopadhyay & Sen, 2011; Ben-Daya et al. 2019). IoT is posed to enhance SC sustainability (Manavalan & Jayakrishna, 2019) and help better mitigate SC risks (Birkel & Hartmann, 2020). Research on IoT and SCM has been piqued; see Rejeb et al. (2020) for a review.

PI, or symbolically "π," is a contemporary conceptualization of a highly modular logistics network that mimics the routing of packets over a network of hubs in the virtual internet (Montreuil, 2011). A novel supply chain and logistics paradigm, PI enables innovative changes to how containerized products are moved in a supply chain.

PI logistics can significantly impact transportation, inventory costs, and consolidation policies, among others (e.g., Ülkü, 2012; Venkatadri et al., 2016). The goal is to optimize the transportation cost of freight delivery for an SC comprising multiple suppliers and buyers (customers). PI may pose great opportunities for scale economies in freight transportation and warehousing and for improving the environmental performance of shipper or carrier companies (Lin et al., 2022).

In this flourishing field of study, Chadha et al. (2021) goes beyond the extant comprehension of PI confined in logistics and offer a comprehensive definition of PI-Supply Chain ($\pi$-SC) as "... a collective set of suppliers, customers, and value recovery (e.g., reverse logistics) companies with the common goal of achieving sustainable production, delivery, and consumption, by maximizing economic, environmental, social, and cultural shared-value of their business eco-system on a global scale, and by collaboratively devising and utilizing smart technologies, modular resources (e.g., π-containers, π-movers) and infrastructures (e.g., π-nodes) on a π-network."

Figure 7 depicts a conceptual model of a $\pi$-SC. The PI concept is evolving, especially with the support of other SCA technologies like the IoT and BCT. Some recent literature reviews on PI include Chen et al. (2022) and Treiblmaier et al. (2020).

In summary, the most potentially disruptive SCA technologies described above have different intrinsic properties. AI can help provide foresight and make operational level (e.g., product order quantities) optimal SCA decisions, especially those relating to cognitive analytics. BCT enables information decentralization and immutability, and IoT's properties afford device coordination and smart sensing (Sodhi et al., 2022). On the other hand, the PI concept will collectively require the former SCA technologies for the successful planning and execution of π-SC operations.

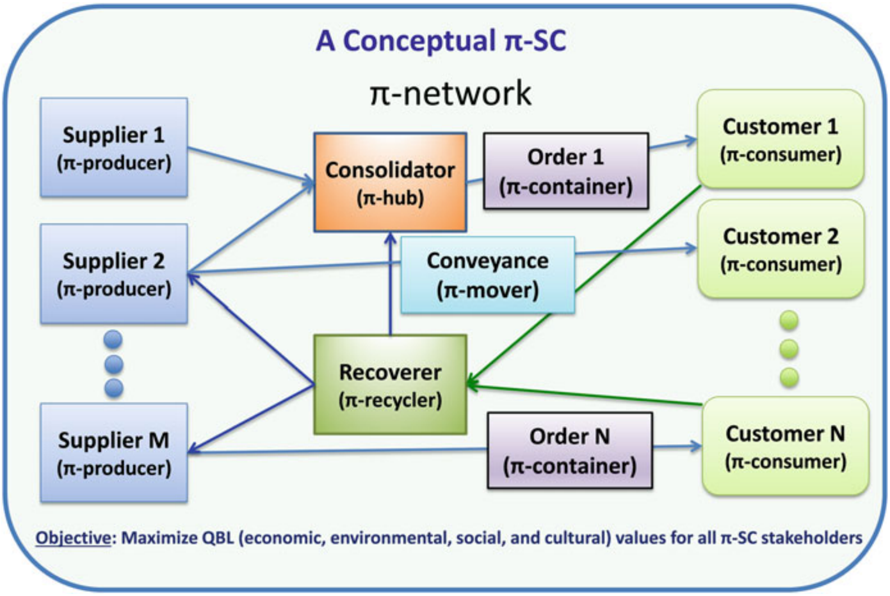


**Fig. 7** A conceptual depiction of a physical internet supply chain (π-SC)

## 4.3 Circularity and Supply Chain Analytics

Unlike today's linear "take-make-dispose" economy (LE), the circular economy (CE) "...is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles" (EMF, 2015).

CE aims to keep the added value of a product through its life cycle while enabling the processes that allow for a product at its end-of-life (EoL) or end-of-use (EoU) to be reutilized as a resource for the manufacture of another product (European Commission, 2014). Environmental imperatives due to climate change, unsustainable resource depletion, and social awareness of a "better and just" world force businesses to rethink their product offerings and processes. For instance, as many companies use, recycling strategies are all but one approach circumventing the drawbacks of wasteful production in LE. A mind and cultural shift are required, not only by the producers but also by the consumers, to create the conditions for implementing CE. Products (i.e., manufactured goods, services, and product + service options) should still meet the strict regulations and standards of safety and quality. In an increasingly "sharing economy" wherein the concept of "leasing" is replacing ownership, more products need to be modularly designed to last and facilitate reusing, refurbishing, remanufacturing, and recycling (Gao et al., 2016; Ülkü & Hsuan, 2017).

Geng et al. (2019) identify four levels on which the CE operates: products, companies, networks, and policies. Companies must develop new CE business models that create value for customers and society. Products need to be sourced and designed sustainably and manufactured with clean technology to be reused and recycled. Networks of companies such as SCs and customers (e.g., neighboring countries) have to be linked and coordinated in manufacturing key products such as transport vehicles. Of course, policies at the governmental level should support these new CE markets.

Alhawari et al. (2021) suggest the following definition of circular economy (p.13) "CE is the set of organizational planning processes for creating, delivering products, components, and materials at their highest utility for customers and society through effective and efficient utilization of ecosystem, economic, and product cycles by closing loops for all the related resource flows."

Ülkü et al. (2022, p. 217) define a *circular supply chain* (CSC) as "a sustainable and resilient supply chain designed to end waste by valorizing any material flows in shortened loops and slowing down consumption. Within a circular economy, which requires systems-thinking and compliance with quadruple bottom-line imperatives (cultural, economic, environmental, and societal long-term well-being), a CSC creates restorative and regenerative products and processes while co-creating with stakeholders (across multiple industries, public sectors, and consumer markets) a shared-value via the circulation of resources (raw materials, by-products, end-of-life and end-of-use products, waste disposed of, process capabilities), and timely and transparent information."

A CSC has both an open and closed loop (see Fig. 8). The materials – raw, by-product, EoL, or EoU – and process capabilities, such as idle manufacturing capacity recovered during the fundamental stages of an SC (source, make, and deliver), are fed back into the system as "circular resource flows." These circular

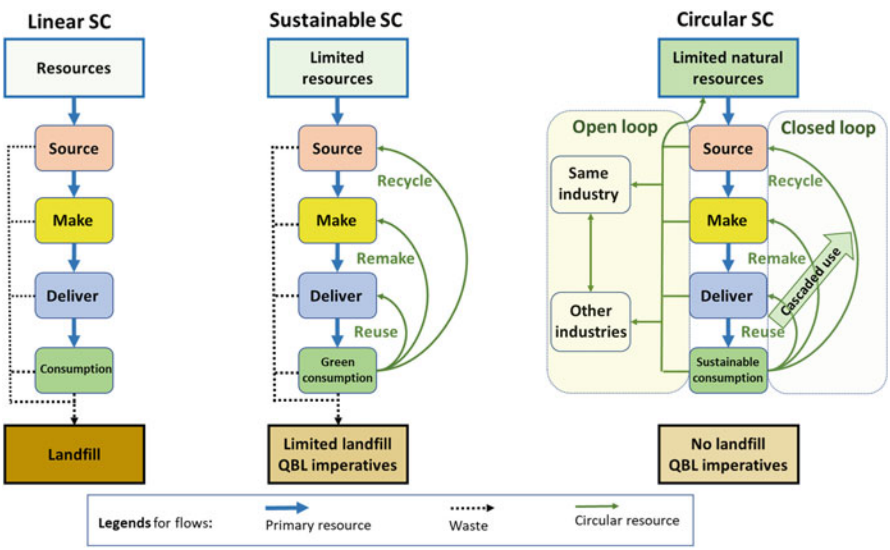


**Fig. 8** Evolution of circular supply chains (Ülkü et al., 2022)

resource flows can be restored in CSC's closed-loop end of the CSC by reusing, remaking (refurbish, remanufacture, repurpose), and recycling components and can be used in the same or other industries as an input. The latter usage happens in the open loop.

Any biological waste that could have otherwise been dumped in landfills is regenerated (i.e., turned into biological nutrients) and fed into the biosphere as natural capital for reuse. Such a representation of CSC also provides some biomimicry opportunities to realize better ways to use natural resources sustainably. For instance, in the SC setting, producers, such as manufacturing companies; consumers including retailers and households; scavengers, such as off-price sellers; and decomposers, including recycling facilities, would be the main actors in a balanced, symbiotic relationship in the natural ecosystem (Geng & Côté, 2002; Tate et al., 2019). Kristoffersen et al. (2021) provide empirical evidence of a business analytics capability for CE and its effect on firm performance.

In recent years, SCA and CE have prevailed as highly essential industrial concepts. Especially within the domain of CSC, and with the advents toward Industry 4.0 (e.g., Taddei et al., 2022), SCA provides significant opportunities for an integrated, synergistic impact. Whether in the open- or closed-loop ends of CSC (recall Fig. 8), intelligent technologies such as IoT, blockchain, PI, AI, and cloud computing may increase the quality and quantity of data to help optimize decision-making over the spectrum of all involved parties in the CSC. For instance, a comprehensive data monitoring and decision support tool that includes all related financial and environmental impacts of a product – from sourcing to manufacturing to delivery to revalorization in the CSC – would be the next big thing in SCM. Indeed, those supply chains with SCA capabilities are at an advantage in achieving collaboration toward sustainability in the CE.

## 4.4 Future Research Opportunities for Supply Chain Analytics

The interest and need for research on SCA for SC sustainability are rampant. While Ülkü and Engau (2021) have given a working definition and overarching view on issues, concerns, and future research on Sustainable Supply Chain Analytics (SSCA), Hazen et al. (2016) set a theory-driven research agenda. The authors highlight the importance and appropriateness of several management theories that can be used to study, among others, the relationships between analytics at large and SC sustainability.

Widely used theories include Actor-Network Theory, developed by Callon (1990) and Latour (1996), who argue that events should not be considered in a vacuum but rather are impacted by surrounding factors. The Institutional Theory seeks to explain how an organization's external environment affects its structures and processes and adds value when the organization meaningfully interacts beyond its isolated circle (March & Olsen, 1983; Scott, 1987). Social Capital Theory (e.g., Lin, 2002) contends that social relationships are resources that can lead to the development and accumulation of human capital. Min et al. (2008) found that the more active (e.g., in data sharing) the members of the SC, the more likely they will accept the norms and values of that SC.

Another theory that has proven helpful across a broad spectrum of applications in SCA research is Resource Dependence Theory (e.g., Ulrich & Barney, 1984), which proposes that organizations lacking resources will develop relationships with other organizations to obtain those needed resources. It is a well-established finding that to ameliorate dependencies and uncertainty, organizations may be forced to establish relationships and coordinate planning based on shared information (Cooper & Ellram, 1993). Other widely used and applicable theories to SCA, technology, and sustainability relationships include the resource-based view (see Defee et al., 2010), transaction cost economics (Coase, 1937; Ketokivi & Mahoney, 2020), Ecological Modernization Theory (e.g., Mol et al., 2013), and Agency Theory (Jensen & Meckling, 1976; Eisenhardt, 1989; Zsidisin & Ellram, 2003). This latter theory builds on a contract as the unit of analysis between the relationships of an agent to whom the work is assigned and the principal who delegates the work. Based on the dearth of extant management theories, future work to study SCA and its implementation for the whole or various stages of SCs for different industries and localities and for different types of SCs depending on their supply, demand, and product characteristics are needed (Lee, 2002).

Although some proven-to-work examples of CE exist, its acceptance and execution require a significant consensus between consumers, the SCs, governments, trade regulations, and infrastructures. One of the focuses of the CE framework is closing the loop for durable and biological products to maximize the value extracted from materials and minimize waste. Mimicking the nutrient cycle in ecosystems, natural nutrients, such as food waste, are cascaded through the biological process to extract embodied energy and nutrients before being returned to the biosphere in a nontoxic form. Cycling technical nutrients, such as metals, involves maintenance, refurbishment, remanufacturing, and recycling to the maximum extent possible before the materials become too degraded and require disposal. SCA, particularly for the water-energy-food (WEF) nexus (e.g., Zhang et al., 2018), can be pivotal in describing the current status, predicting operational variables, and prescribing solutions for intertwined complex SC problems. For instance, Deng et al. (2020) study, utilizing sample-path analysis, the WEF nexus from the consumption side to the production side along the relevant SCs. Oguntola et al. (2023) explicitly included water footprint, besides accounting for carbon emissions and cost considerations, in designing a multimodal logistics SC network and devised machine-learning techniques for enhancing demand and supply accuracy and optimality results. Another example relates to unsustainable food consumption, an emerging global issue. Baysal and Ülkü (2021) approach food loss and waste through the lens of sustainable SCA. Among their suggestions for developing sustainable food SCs, they propose using consumer analytics whereby the product and purchasing big data could be employed to draw insights and behavioral patterns to better inform consumers of the QBL impacts of their consumption.

New business and management models that require investment in technological infrastructure first must have the buy-in for acceptance, implementation feasibility, and long-term result-oriented commitment by the top management. SCA technologies are no exception to this: Sodhi et al. (2022), for example, building on the Gartner Hype Cycle (Linden & Fenn, 2003), which relates the expectations of innovation over time, offer empirical evidence that unrealistic expectations for emerging technologies precede a period of disappointment. There remains much room for transdisciplinary research on the sustainable adoption of current and emerging SC technologies (e.g., Autry et al., 2010; Wang et al., 2021; Yang et al., 2021).

There is considerable overlap between data science and SC chain research. As the SCs are being digitally transformed, future SC leaders must be well tooled with analytical and quantitative skills. Accordingly, the study of SCA has thrust its way into business and engineering SCM curricula that push the curve in higher education. Therefore, pedagogical work on SCA integration into curricula and its disciplinary nature (e.g., computer science, engineering etc.) warrants further research.

SCA opens many other doors to exciting research venues. While there are some emerging conceptual inroads (e.g., Liu et al., 2018) and encouraging practical examples of CE (e.g., Stahel, 2019), there remain many questions and concerns related to how CE indeed is the pathway to sustainability (e.g., Hofstetter et al., 2021; Corvellec et al., 2022). A many-faceted problem that requires transdisciplinary methodologies (and, thus, quite a formidable task), achieving circularity with QBL through the concept of "industrial symbiosis" (see Chertow, 2000) is a promising first step. To that end, SCA has tremendous potential to support both circularity and sustainability: Because almost every industrial organization is part of an SC, the tools of SCA – from advanced demand prediction methods to intelligent manufacturing technologies to life-cycle analysis embedded in product design to returns management – can help make optimal, comprehensive and informed, decisions in the source-make-deliver-revalorize stages of products (inflows of materials and outflows of EoL or EoU products). SCA could also improve response and relief in humanitarian SCs (e.g., Oguntola & Ülkü, 2023). Another timely research would be on SCA and FinTech relationships. Last but not the least, it would be a timely research to examine how SCA can support the United Nations Sustainable Development Goals from an SCM perspective.

## 5 Managerial Implications

Companies employing SCA capabilities in source-make-deliver-return stages (recall Fig. 3) may increase the transparency requirements for trustworthy relationships in SCs (Zhu et al., 2018). In addition to its capability to measure and improve those SC metrics, SCA could be used to enhance accessibility for affordable and sustainable consumption through pricing.

With the emergence of e-commerce, the retail and consumer service sectors face a strategic challenge of significant complexity and uncertainty. Specifically, the globalization of e-commerce has led to rapid fluctuations in market prices. To keep a competitive edge, many industry leaders find that traditional pricing tactics no longer hold up and have started adopting cutting-edge pricing tools to remain competitive. These tools utilize, curate, and synthesize present and historical data from various channels within an organization (i.e., operations, marketing, social media platforms) about different aspects of the marketplace, such as consumers' predicted demand and shopping behavior, competitors' moves, large-scale market conditions, and latest trends.

The intelligence obtained by synchronized pricing analytics provides essential information that helps better perceive, interpret, and predict market prices; control potential factors contributing to revenue losses due to supply chain inefficiencies; and position product prices accordingly.

Pricing analytics accommodates fluidity and versatility essential in today's marketplaces and allows for real-time flexibility. If products are overpriced, underpriced, or otherwise positioned poorly, pricing analytics assists with quick fixes to optimize revenue. Pricing gaps identified by pricing analytics also provide an opportunity to evaluate the effectiveness of strategies such as offering promotions and discounts that promote the products and boost revenue.

Some misconceptions about BDA and SCA may inhibit their use. Managers should understand that only some influential data should be captured and stored. More data may not help for more accurate predictions: the cost of storing and processing excess (garbage) data could be material. At the same time, there are challenges in using BCT such as the insecurity of execution, lack of standardization, inflexibility, obduracy, black-box effect, and an "oracle" problem (Babich & Hilary, 2020; Murray et al., 2021).

As the study of SCA matures, business graduates with strong analytical skills are in high demand. Curriculum revisions to grow more SC professions comfortable with SCA technologies are crucial for the viability and higher performance of the SCs.

## 6 Summary and Conclusion

This chapter provides an overview of SCA, an emerging interdisciplinary and applied field of research and practice. Included are discussions on emerging SCA technologies such as blockchain, IoT, and AI. In the face of changing business environments, good management of SCs is critical, and SCA may be an excellent enabler to achieving these goals. Besides efficiencies in SC operations, SCA has significant potential for applications in a circular economy toward a more sustainable world.

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# Big Data Applications in Supply Chain Management

Emel Aktas

## Contents




**Abstract**

This chapter overviews emerging applications of big data analytics in supply chain management. The academic attention on big data applications and their practitioner uptake is growing. Many recent papers showcase descriptive, predictive, and prescriptive analytics applications where multiple benefits emerge from applying big data analytics to managerial problems. Such benefits include cost



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reduction, increases in revenues and profits, and minimization of the environmental impact of operations. Current concerns include the transition from traditional to digital supply chains and what can realistically be achieved over the next two decades. While we evidence excellent applications of big data analytics for supply chain planning and management problems, the issue of working in silos persists. For an organization to fully exploit big data applications, data should be perceived as an asset. When deploying novel artificial intelligence algorithms, the explainability of these algorithms should be at the forefront of an implementation strategy. Future research directions should be aimed at devising a connected and coordinated analytics approach that will enable the benefits of big data applications to go beyond what is currently realized.

**Keywords**

Data capture · Descriptive analytics · Predictive analytics · Prescriptive analytics · Logistics · Distribution · Warehousing · Retail

## 1 Introduction

Together with the fourth industrial revolution, big data and analytics have entered our everyday conversations with great potential to improve how we run our operations in terms of costs, environmental impact, and social implications. One of the contributing factors to big data being the conversation topic from marketing to supply chain is the digitalization of our supply chains; relocation of our enterprise data to cloud servers, so they are accurate and accessible real time; and an astonishing increase of connected devices, mobiles, and wearables as well as sensors deployed on physical networks. All these developments are exciting for supply chain planning and operation purposes. This chapter aims to outline existing and future applications of big data and analytics.

IBM defines big data as "data sets whose size or type is beyond the ability of traditional relational databases to capture, manage, and process the data with low-latency" (https://www.ibm.com/uk-en/analytics/hadoop/big-data-analytics). Big data are digitally and passively produced, automatically collected, geographically and temporally traceable, and available in real time or almost real time. Sensors, connected devices, social media posts, and mobile apps make supply chain management a relevant testbed for big data tools and applications.

Big data are typically characterized by 5Vs: volume, velocity, variety, variability/veracity, and value. Volume refers to the size of the data sets. Velocity represents the speed of data generation. Variety indicates the diversity of data. Variability/veracity is concerned with the value or the meaning of a variable depending on the context. Value, which has recently started to be explicitly mentioned, highlights the benefits that could be achieved from using big data to address a strategic, tactical, or operational decision problem. Since handling big data requires hardware, software, and users with data science skills, applications should generate a value higher than the costs of collecting and analyzing data.

With the advent of computers in the 1960s, data were stored without structure, and many efforts were needed to create value from them. Relational databases that followed structured the data, making it easier to organize and elicit value. As the volume of structured data grew faster than the computing power, data warehouses and data marts came into place to manage the data and generate insights. Everything has changed with the Internet, as the volume of unstructured data started to grow exponentially, and data format was no longer limited to data tables. In addition to the web content, data started to flow from connected devices, sensors, cameras, and GPS transceivers, leading to only a tiny amount of data collected being purposefully analyzed. With the costs of collecting, storing, processing, and analyzing data decreasing, distributed and cloud computing allowed massive amounts of data to be analyzed almost in real time.

## 1.1 Popularity of Big Data and Supply Chain

Figure 1 shows a Google Trend chart comparing the terms "big data" and "supply chain" from the beginning of 2004 onward. While the "supply chain" term was at its highest popularity in 2004, the "big data" did not appear in searches on a regular basis until after the end of 2010. The significant growth in the interest in "big data" is visible until the end of 2016 and stable until the beginning of the pandemic in March 2020. While there is a slowing of searches on big data from March 2020 onward, the growth in supply chain searches continues to date.

The growth in big data applications can be attributed to the growth of data collected by the companies through the Internet (e.g., web searches, social media, electronic documents), mobile phones, wearable devices, and the Internet of things (IoT) (sensors). With the disruptions caused by the COVID-19 pandemic, the

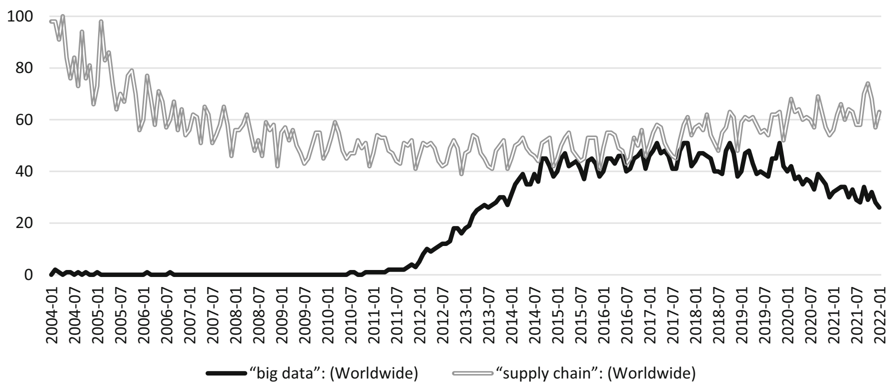


**Fig. 1** Comparison of "big data" and "supply chain" terms on Google Trends (https://trends.google.com/) date: Jan 2022

US-China trade war, and Brexit, many companies are already investing or expected to invest soon in digital tracking of data along the supply chain using sensors and other connected devices, analyzing supply chain interdependencies, and developing contingency plans.

According to Research and Markets (2022), the big data market size is projected to grow from USD 162.6 billion in 2021 to USD 273.4 billion in 2026. This growth corresponds to a compound annual growth rate (CAGR) of 11.0%. Big data is perceived to have the potential to improve many supply chain operations such as order picking and stock-taking. Operational efficiency and revenue growth are expected to rely heavily on data-driven decisions at strategic, tactical, and operational levels. Many of the big data solution providers are located in the Asia Pacific with expertise in India, China, and Japan.

Cloud platforms such as Microsoft Azure, Amazon Web Services, and Snowflake are the go-to platforms for storing data for many organizations. New terms such as “data fabric” and “data mesh” represent emerging architectures that access, manage, and integrate data across multiple platforms and technologies. While in traditional supply chains information flows in a linear fashion and is usually shared by the two sides (originator and receiver), the idea behind data fabric is to connect all entities in the supply chain so questions such as “who are the suppliers and the raw materials they provide for the finished good X?” can be queried within seconds (Megarbane, 2020).

## 1.2 Innovation Potential

Anyone studying supply chain management or conducting research in supply chain management cannot ignore the increasing relevance and significance of big data applications to innovation. Figure 2 shows the linear growth in patents issued with big data and supply chain focus, with an additional 200 patents every year over the past years. The topics of these patents include logistics storage bin allocation based on big data, intelligent information management systems for logistics transportation data, supply chain big data service systems, and computer architectures for big data calculations, to name a few. Many of the patents are focusing on big data acquisition and increasing visibility of product flows across the supply chain, which then lends itself to higher-level analytical approaches such as prediction and optimization.

The United States has one of the most innovative economies in the world, with innovations emerging from US-based companies affecting people’s lives globally. Since 2018, Innovation Roundtables have been held by the Bureau of Economic and Business Affairs with the US private sector to explore challenges and opportunities emerging in the information and communication technology sector. Among these roundtables, the IoT is perceived as an increasingly high-profile area of technological development with software, devices, and operating systems. Similarly, cloud computing is recognized as the enabler of many services and technologies. The US

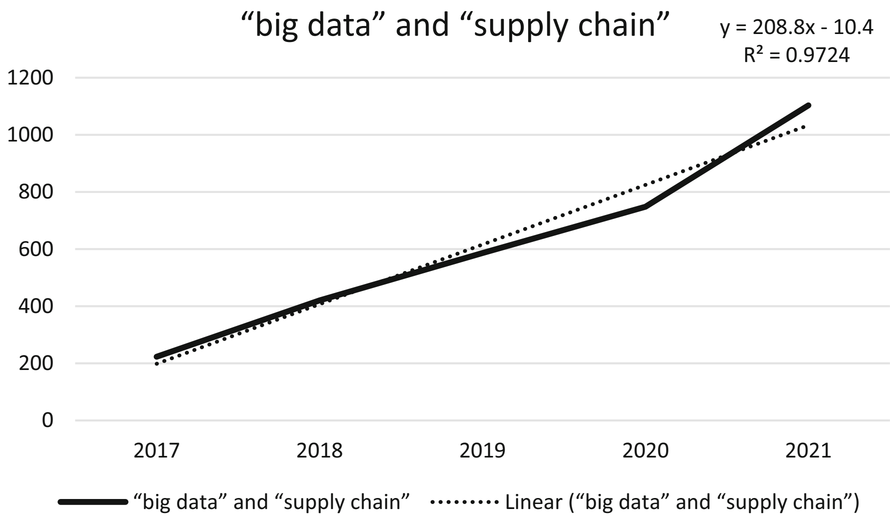


**Fig. 2** Patents published with big data and supply chain keywords over the past 5 years. (Data source: European Patent Office)

Department of State is working on creating policy environments and regulatory frameworks that support the adoption of blockchain and distributed ledger technologies in manufacturing supply chains (US Department of State, 2022).

Digital transformation is at the heart of the European Union's research and innovation strategy, which strives to move the society toward a sustainable and prosperous future faster and in a way that is respecting European values (European Union, 2022). In the Strategic Plan for 2020–2024, making Europe fit for the digital age is recognized as one of the seven specific research and innovation objectives. Ethical use of artificial intelligence is highlighted along with data governance. Data-driven manufacturing of tailor-made products and the delivery of personalized services emphasize the need for big data applications in supply chains.

The UK government has the vision to make the United Kingdom a global hub for innovation by 2035 (UK Department for Business, Energy, and Industrial Strategy, 2022). For this purpose, annual public investment in research and development is set at around £22 billion. There is a strong emphasis on protecting data, research, and intellectual property to maintain competitiveness. Specific technologies related to big data and underlined in the national data strategy are artificial intelligence, computing, and augmented and virtual reality. The National Cyber Security Centre provides guidance on secure innovation to startups and companies growing with emerging technologies. Cybersecurity company Darktrace is mentioned as the most innovative cyber defense company globally. Darktrace investigates defensive and adversarial artificial intelligence, social engineering, natural language processing, and graph theory to fight back against ransomware that disrupts businesses.

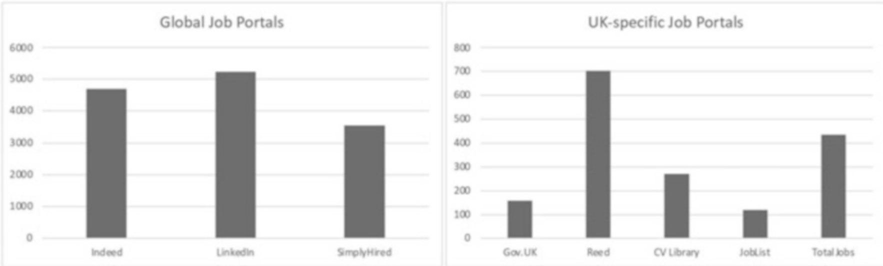


**Fig. 3** Jobs with "big data" skills in the United Kingdom. Author's search on Jan 20, 2022

## 1.3 Job Prospects

Similar observations can be made for the job market. With a naïve search of "big data" terms in the query database, thousands of jobs were identified in top job portals such as Indeed, LinkedIn, and SimplyHired (Fig. 3). The number of hits is lower but still in the order of hundreds in more UK-specific job portals such as the Gov.UK's job search engine, Reed, or CV Library. The search identified jobs in the United Kingdom that have "big data" in the title or the description. Job titles included "big data engineer," "big data architect," "big data developer," and "big data solution designer."

According to the Masters Portal (2022), there are 385 live data science and big data masters programs in the United Kingdom and 429 programs in the United States as of February 2022. On the other hand, Germany has 56 degrees, France has 51, and Canada has 31. Many of these programs offer online learning as an alternative. Typical modules taught involve machine learning, neural networks and deep learning, big data processing, data mining, and natural language processing. Electives offered highlight sustainability and how data and models could help improve the environmental and social impacts of businesses.

Among the largest private companies in the United Kingdom, British Petrol is looking for big data engineers, data scientists, and cybersecurity experts. There are tens of open positions in HSBC UK that are related to big data expertise. Similarly, Unilever is recruiting hundreds of big data professionals globally. Typical roles involve business insight analyst, product data scientist, consumer data scientist, tax data operations manager, and data lake engineer. In the pharmaceutical sector, GlaxoSmithKline has tens of vacancies that are broadly categorized under digital data and analytics, with a specific focus on artificial intelligence and machine learning.

## 1.4 Chapter Outline

The rest of the chapter is organized as follows. The background section provides an overview of the key successes in supporting supply chain management with big data applications, commenting on their links with other Industry 4.0 technologies such as the IoT, cloud technologies, and artificial intelligence. The current concerns section highlights the state-of-the-art big data applications to typical supply chain problems strategic, tactical, and operational decision levels. The emergent concerns section provides directions for taking big data analytics forward, exemplifying open research areas in several domains. The managerial implications section that follows provides key deliverables expected from a big data application, such as benchmarks against current status, alternative solutions to the proposed solutions, and sensitivity of results to the changes in input parameters or external factors that may not have been reflected in the application. The final section summarizes and concludes the chapter.

## 2 Background

One thing to note is the difference between "large" and "big" data: where big data implies higher complexity of data structure and technologies to process it, in addition to the size of the data (van de Klundert, 2016). Another case in point is the methodologies needed to process the data. It is unlikely that the big data can be analyzed with standard statistical methods.

The growing availability of big data has facilitated the development of new software packages and inspired new algorithms and approaches to big data analytics. R and Python are the two open-source software that are most widely used for analytics, as well as big data analytics. While for most analytics tasks each software performs reasonably well, R is preferred for statistical analysis and data visualization, whereas Python is preferred for machine learning. There is growing compatibility and sharing of tools between the two software such as Keras and TensorFlow. Keras is a library that provides a Python interface for building artificial neural networks, whereas TensorFlow is a library specifically used for the training and inference of deep neural networks.

A widely accepted terminology in big data applications refers to descriptive, predictive, and prescriptive analytics (Fig. 4). Descriptive analytics, also diagnostic analytics, is a summary of the current situation. It would inform what has happened in the past or the current level of performance across indicators of interest. For example, we may have a descriptive statistic of an "on time in full" performance as of 11:00 am today, for the last week, or the previous month. It may be used for diagnostic purposes, for example, for identifying deviations from expected performance or outliers in a set of similar units of analysis. A retailer interested in store profitability may monitor the sales performance of each store and identify those that are significantly overperforming or underperforming within hundreds of stores across the country. Descriptive analytics information is usually provided in dashboards, most often with some kind of a traffic light system that turns from green to orange for warning and from orange to red to indicate severe problems in the running of the supply chain. It is not concerned with the future or what the company needs to do to achieve a given objective, such as minimizing costs. However, it is the

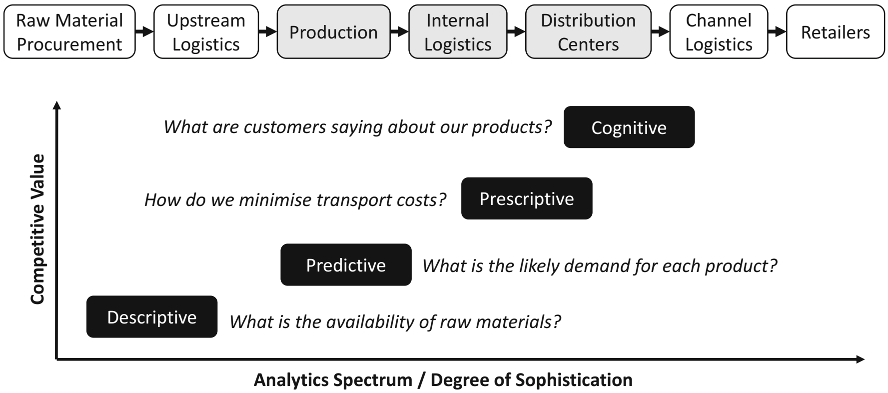


**Fig. 4** Analytics approaches applicable along the supply chain

foundation of any further data modeling that may follow in the predictive or prescriptive stages.

Predictive analytics is only concerned with producing likely future values of a variable of interest. As per the example in Fig. 4, a typical variable of interest that affects distribution and production planning, as well as procurement activities, is the demand or sales of the products and services offered by the supply chain. Other typical variables on which predictive models are used to produce forecasts are the number of customers arriving at a store or the number of patients admitted to a hospital, the number of wind turbines that are likely to fail in the next few weeks to inform preventive maintenance, or the expected time of arrival for logistics operations. A vast range of methods and models are available from simple time series to neural networks, some of which are better at handling big data.

Prescriptive analytics is the gold standard that provides decision support to reach the decision-maker's objectives. Prescriptive analytics approaches comprise mathematical modeling and sometimes simulation when the aim is to identify the best course of action for the company. The best course of action varies from strategic to tactical and operational decisions in the supply chain. Strategic decisions such as facility location, make or buy, or plant capacity would be difficult and costly to change in the short term. Operational decisions are those that are repeated on a daily or weekly basis, such as production and inventory routing decisions where the quantities to be produced and distributed across the network every day would be decided to minimize costs given a customer service level.

Recently, cognitive analytics has also started to appear in the discussions, which indicates the capacity of computer hardware and software to simultaneously analyze and synthesize big data flowing from a range of sources. Most user-generated data such as expert opinions, ratings, recommendations, and testimonials are readily available in an unstructured format for mining. The abundance of user-generated text data inspired new automation tools comprised of machine learning methods and deep learning algorithms that can parse and understand natural language, paving the way for sentiment analysis applications with increasing accuracy. For example, over 850,000 receipts collected over a year by a retailer were analyzed to estimate the customer's lifetime value (de Marco et al., 2021).

Cognitive analytics is capable of delivering descriptive, predictive, and prescriptive analytics based on big data collected and analyzed in real time or near-real time. Data used for cognitive analytics purposes would originate from multiple sources in a structured and unstructured way. Typical elements of a cognitive analytics platform would be a layer responsible for data acquisition, cleaning, and preprocessing, where the data are prepared for modeling. Another layer in a cognitive analytics platform would be responsible for model building and knowledge management with a range of predictive algorithms, which would serve as a repository of tools and models from which the required model could be selected and deployed to provide predictions of a variable of interest (Rousopoulou et al., 2022).

## 2.1 Description

Dashboards are where key descriptive analytics information is captured and presented to the users in a simple way. The main purpose is monitoring, and many dashboards follow an indicator to draw attention to deviations from long-term averages in the metrics. Typical information that can be found on descriptive analytics dashboards is the proportion of on-time and in-full deliveries for transportation activities. For a warehouse, the dashboard is likely to have the unit, line, and order fill proportions where unit fill monitors the proportion of items delivered, line fill monitors the proportion of order lines delivered, and the order fill monitors the proportion of orders delivered. Usually, monitoring all three is redundant, and the indicator to monitor could be selected in line with the service-level agreement. From an inventory management point of view, the relevant indicators are inventory days of supply, days sales outstanding, and inventory turnover. Procurement-related descriptive indicators could involve contract spend to date compared against the spending commitment, supplier performance indicators around delivery reliability and quality, and distribution of spend over categories. With the increasing e-commerce, the returns have also increased significantly. Therefore, a dashboard reporting the proportion of orders returned and return reasons could inform actions to reduce the returns.

## 2.2 Prediction

A typical problem in supply chain management, forecasting of demand, is increasingly using higher frequency data such as daily or weekly series. Daily or hourly data are relevant to forecasting the sales of perishable items for replenishment decisions (Makridakis et al., 2021). However, the frequency should be linked with the decision level rather than the availability of granular data. More granular data should be used

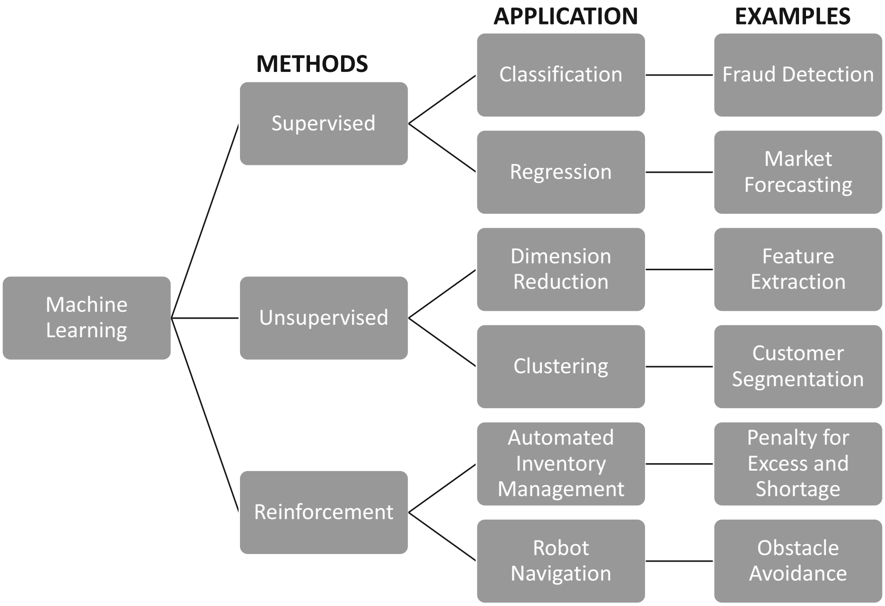


**Fig. 5** A representative categorization of machine learning methods with examples of specific applications

for operational, day-to-day decisions such as transport schedules, whereas monthly or yearly data should inform strategic decisions such as supply network design.

Figure 5 shows the broad categorization of machine learning methods. Supervised learning algorithms require matched inputs and outputs (targets), where the data are divided into training, validation, and test sets. The algorithm is trained on the training set to minimize the errors based on the matched inputs and targets. The parameters of the algorithm are tuned with the validation set, which is separate from the training set. Finally, the model performance is assessed on the test set where no further adjustments are made to the model. Typical applications are classification and regression, where the algorithm tries to detect fraudulent transactions or spam emails in the classification problem and forecasts the market size or the sales of a product in the regression problem.

In unsupervised learning, the algorithms are presented with a data structure and tasked with finding patterns in data. Typical applications are dimension reduction, for example, to identify the most useful features in a multidimensional problem to focus later on fewer features or clustering to segment customers and present them with customized marketing strategies.

Reinforcement learning is different from supervised and unsupervised learning in the sense that the algorithm learns what it needs to do based on rewards and penalties. It does not necessarily know the right answer but infers the right behavior to reach the right answer by maximizing the reward and minimizing the penalty. A typical application in the supply chain is automated inventory management decisions. The algorithm decides on the right quantities to order from penalties associated with having too much (excess stocks and possibly waste if items are perishable) and not having enough (shortages). In the warehousing context, the robot navigation application is exemplified in obstacle avoidance, i.e., the robot is rewarded for traveling on free paths.

Machine learning systems can predict service-level failures a few weeks in advance to alert the planners (Melançon et al., 2021). Service levels fall below targets due to a range of reasons, one of which is machine failures. Melançon et al. (2021) model service-level failures as binary variables and build gradient-boosted decision trees that produce a probability of failure over a prediction horizon of 14 days. Comparable other methods are artificial neural networks, logistic regression, classification and regression trees (CART), and random forests. Using the authors' model, the planners in Michelin are able to improve the service level by 10 percentage points and to recognize safety-stock calculation problems.

In a forecasting exercise with temporal big data, the least absolute shrinkage selection operator (LASSO) regression was used to predict 12 months into the future using 814,212 variables and 66 data points, which cannot be solved with conventional causal-regression predictive modeling (Sagaert et al., 2018). The authors automated the identification of key leading macroeconomic indicators from a set of 67,851 to predict tire sales. Macroeconomic indicators were considered in the tactical tire sales prediction as they drive sales across different regions and markets. The LASSO method improved the accuracy of prediction by 16.1% compared with the company's existing practice.

## 2.3 Prescription

We can find many applications of big data analytics for supply chain and operations management problems. For example, scheduling tugboats in a seaport is a common problem observed across the world in the context of seaborne cargo transportation. Many supply chains got disrupted when Ever Given ran aground in the Suez Canal on March 23, 2021. The ship did not have a tugboat and was behind two containerships that were paired with a tugboat. While the reasons for Ever Given's not being assisted by a tugboat remain unclear, the research is underway for scheduling tugboats with instances from a busy container port in Shanghai (Jia et al., 2021). In scheduling problems such as this one concerning tugboats for ports, a range of models are used (e.g., mixed integer linear programming, heuristics, and metaheuristics) where the computational complexity of the problem requires relaxation and decomposition approaches.

Production and distribution planning decisions are interdependent and difficult to solve simultaneously. A decision support system executing operations research tools on big data collected by Danone Waters to optimize production and distribution decisions is reported to have reduced the total cost of operation by 4.7%, by approximately $5.2 million (Zhang & Song, 2018). The big data application involved a mixed integer linear programming model that minimizes production, transportation, and storage costs under operating constraints. In addition to the direct economic benefits of using this decision support system, managers at Danone started making data-driven decisions with lower complexity.

## 2.4 Prediction and Prescription

The typical workflow of a big data analytics project would be from descriptive to predictive analytics, followed by prescriptive analytics depending on the needs of the business problem addressed. An exemplary execution of this flow is applied to distribution network design (Liu et al., 2021). The prediction stage leverages artificial neural networks to predict customer demand, as affected by the logistics service quality of a network and the city-level purchasing power of customers based on demographic characteristics of residential areas. The optimization in the prescriptive stage solves a mixed integer linear programming model to choose facility locations so that the total costs of transportation, facility setup, and package processing are minimized.

Four themes for big data applications in retail operations are availability, assortment, pricing, and layout planning. Interviews with experts suggest that historical sales data and loyalty schemes help obtain customer insights for operational planning, but granular sales data can be used to increase availability and facilitate assortment decisions (Aktas & Meng, 2017). Demand forecasting and pricing decisions can benefit from models that incorporate external data such as competitors' prices and weather conditions. Retailers could leverage big data to improve inventory decisions by stocking the correct kinds of products in right quantities. They could make pricing decisions for the season-end products or promotions by discounting prices at prescribed percentages.

Assortment planning is a key part of retail operations management. It involves making decisions on which products to carry (assortment breadth) and how many of each product to carry (assortment depth) in store. Big data applications have great potential to improve assortment planning decisions, as is evidenced in one of the leading outdoor fashion brands in South Korea, Kolon Sport. The company teamed up with a business analytics team to improve their distribution decisions: what set of items to pack in a box and how to allocate boxes to retail stores (Sung et al., 2017). The assort packing and distribution decisions need to be taken for more than 4000 articles sold at more than 250 stores, making the problem extremely difficult to solve for human decision-makers. The authors develop a two-stage prediction – optimization methodology, where they use multiple linear regression in the first stage to predict the demand for articles sold at stores, followed by an optimization model that assigns articles at different sizes and quantities into shipment boxes to minimize the time needed for distribution in the second stage. Their method is anticipated to increase sales by eight percent due to the increased availability of items in stores.

Equally relevant is managing and monitoring thousands of suppliers and controlling spend. Strategic sourcing teams hold lengthy, labor-intensive negotiations. In an impressive application of big data analytics, Verizon built a supplier rationalization tool based on operations research, machine learning, text mining, natural language processing, and artificial intelligence and reduced spend by millions of dollars while obtaining the lowest price per unit for the sourced products and services (Abdollahnejadbarough et al., 2020). Other benefits reported are a centralized and transparent contract and supplier relationship management, overhead cost reduction, decreased contract execution lead time, and service quality improvement for strategic sourcing teams.

Big data applications are expected to support assessing risk exposures and developing supply chain risk management practices while managing the transfer of risk along the supply chain. Zurich Insurance combined legacy claims databases with the large claims database and produced a data lake of historical claims from structured and semi-structured regional databases to understand risk exposures based on its customers' industries (Mizgier et al., 2018). Hence, Zurich Insurance is not only able to better assess risk exposure but also can offer its customers customized insurance products as well as risk mitigation strategies such as operational hedging (design of agile and flexible supply chains) and the reduction of supply chain complexity.

An award-winning implementation of predictive and prescriptive analytics in Walmart helps clear excess inventory in stores by a certain time period, improves revenue by minimizing the discounts needed to move inventory and clear shelves, and reduces the operational cost of relabeling discounted products (Chen et al., 2021). The integrated system developed by the authors first builds a forecasting model that produces the price-to-demand forecast based on items that need discounting, store demographics variables, store inventory, and discount depth. Second, the output of the forecast model is inputted into an optimization model along with operations costs, markdown period to recommend when the products should be marked down, and their corresponding prices. The benefits of the model include a 7% reduction in costs, a 21% increase in sell-through rate (the proportion of items sold by the end of the markdown period), and a store-specific price-adjustment policy.

In a comparable study, Intel increased their profitability by over $25 billion using advanced analytics in their supply chain planning and product design (Heiney et al., 2021). As can be appreciated, Intel has a complex supply chain owing to its scale, products, and capital-intensive manufacturing processes. Heiney et al. (2021) developed an integrated approach that generates and optimizes product design alternatives using genetic algorithms and mixed integer programming. The approach not only brought financial benefits by increasing revenues and reducing costs but also provided organizational benefits where the users took ownership of the solution. The users advocated for its use owing to its environmental benefits that reduced the amount of water used and the wastewater generated in the system.

## 2.5 Cognition

Cognitive analytics for supply chain management using big data is in its infancy compared with other analytics approaches. Many studies focus on text mining of customer reviews (Varudharajulu & Ma, 2018) or incorporating weather and Twitter data into predicting the estimated time of arrival for trucks delivering certain goods (ben Miled et al., 2021). For example, a market leader in fruit juice manufacturing used big data in their new product development process (Jagtap & Duong, 2019), specifically by collecting data on sugar levels (nutrition data), prices (retailer data), quality (customer reviews), cost (own data), and environmental impacts (estimates informed by research reports) of own alternatives and competitors' existing products. Incorporating big data into the new product development reduced the associated costs by 33% and the development time by 11% for this fruit juice manufacturer.

Mobile crowdsensing is an approach that collects social data from a large number of users carrying mobile devices. Such data can then be used for cognition purposes, for making near-real-time predictions that can inform industrial processes. Typical research questions involve extrapolating from sparse data collected from a few users, learning nonlinear correlations, and completing the picture where sensor or mobile data are unavailable. Once the nonlinear correlations are learned, these correlations should be preserved and used for predicting the near future (E. Wang et al., 2021).

Real-time stock information can be captured using machine-to-machine communication and inform replenishment decisions so that stock-outs can be minimized. With the advent of the IoT, sensors in vending machines can monitor the sales rate of various snacks and beverages in real time. Machine-to-machine communication allows dataflow between entities in the system without human intervention. For example, the stock position in the vending machine is communicated to a Web Application Programming Interface (Web API) via an IoT module. Web API then passes this information to an application server (AppServer), which then communicates with a mobile app used by the owner. None of these data transactions require human intervention (Dijaya et al., 2019).

# 3 Current Concerns

Using the machine-to-machine communication framework in Dijaya et al. (2019), real-time stocking information obtained by an IoT module is sent to a Web API, which is then communicated to the vendor of the products via an AppServer on the computer or on a mobile device. Hence, the user can access real-time stock positions of products in the vending machine and make timely restocking decisions for individual products. The next step in this type of exercise would be an automatic reordering of low stock by the system, eliminating human supervision on stocking decisions.

As the technology is developing, empirical and conceptual works on big data analytics and applications in logistics and supply chain management are also evolving. Big data applications for logistics and supply chain strategy decisions comprise

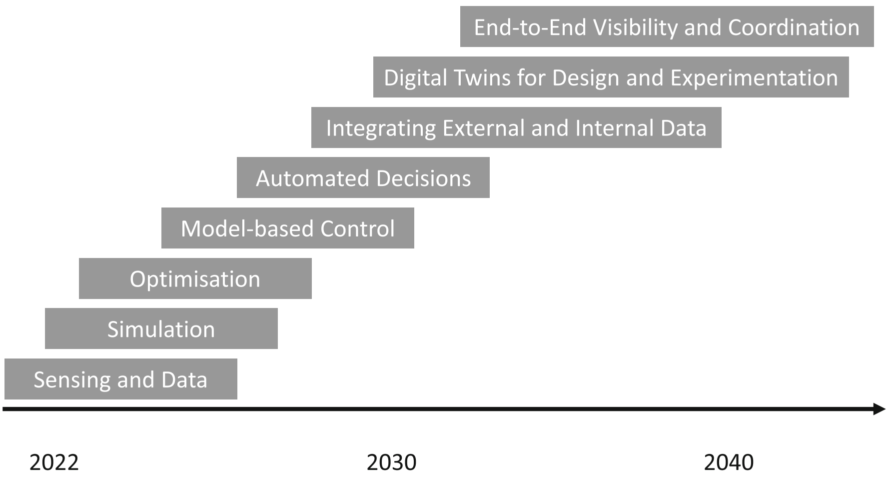


**Fig. 6** Anticipated big data analytics development over the next two decades

strategic sourcing, supply chain network design, and product design and development, while operational decisions involve demand planning, procurement, production, inventory, and logistics (G. Wang et al., 2016). We find statistical analysis, simulation, and optimization to be the driving analytical approaches, where new techniques need to be invented to cope with increasing multidimensionality and observations in data flowing from systems. Figure 6 shows the move toward simply sensing data and building individual models in the 2020s toward fully operational digital twins and the vision of end-to-end coordination of supply chains in the next two decades to come.

Today, we can build and run simulation and optimization models, but these need to be integrated with business functions and other supply chain partners using real-time data (sensing). Simulation and optimization models could provide higher value when data from external stakeholders are incorporated into the decision-making. Such external data integration is expected to facilitate dynamic replanning in case of deviations from expectations. The future of decision-making in logistics is expected to rely on model-based control, automated decisions, and the ultimate replica of the real-world operations with digital twins, which will enable experimenting with different configurations and observing the consequences of strategic, tactical, and operational decisions without changing the real-world operation.

## 4 Emergent Concerns, Outstanding Research, and Future Directions

In many of the applications reported in this chapter, the authors address a real-world case with some simplifying assumptions. The authors ignore some costs to keep the models at a practical complexity, or they consider some factors that may affect the

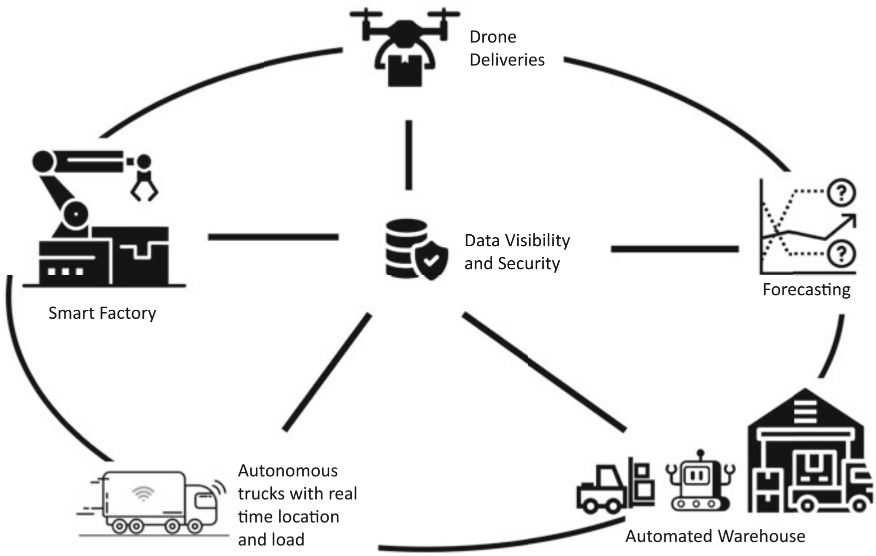


**Fig. 7** Transitioning into digital supply chains

costs out of scope. Many of the models solve a deterministic problem, and future research is expected to address the demand uncertainty as well as supply chain disruptions with stochastic modeling approaches. Figure 7 highlights the key concepts in transitioning from traditional to digital supply chains. Our factories are becoming smarter with the IoT devices, mobile and fixed robots, and automation. Visibility of machine status has increased, thanks to frequent readings from sensors which enable predictive and preventive maintenance.

We are fast approaching an age where autonomous trucks will be on the roads with real-time information on the location and the load (Simpson & Mishra, 2021; Talebian & Mishra, 2022), allowing the dynamic update of schedules in case of deviations from the expected journey (Cota et al., 2022; Nagarajan et al., 2022). However, many factors affect technology adoption, and larger organizations are likely to be slower in adopting new technologies. Having visibility of truck travel times and deviations from the plan would help minimize penalties caused by delays in fulfilling customers' orders.

Automation in warehouses is also an exciting area where we can incorporate multiple technologies, including autonomous robots. Warehouses are under increasing pressure from rapidly growing e-commerce activities, online purchasing, and same-day deliveries. Autonomous robots support human order pickers by reducing the nonproductive walking time (Žulj et al., 2022). Current concerns around incorporating autonomous mobile robots into warehouses include robot path planning and navigation, obstacle avoidance, collision avoidance, and battery/recharging management.

With the advance of machine-to-machine communication, we have higher data visibility, but we need to consider data security issues in all applications. Services for conducting data breaches are increasingly shared by criminals in online forums. These services are tools and software sold at various prices to collect financial and personal information of victims, scam websites to acquire sensitive information, and compromise computers for malicious purposes (Li et al., 2016). Online forums such as cardmafia, cardpro, or cardclub have tens of thousands of members with hundreds of thousands of threads and several hundreds of thousands of posts. Li et al. (2016) extracted service listings and their ratings by cybercriminals from these forums and proposed a text-mining approach to predict the service quality of these listings. They were able to identify key services used for data breaches. Comparably, Bayesian Belief Networks are used to detect cyberattacks and improve cybersecurity (Yeboah-Ofori et al., 2019). Categories of malware recognized are viruses, trojans, rootkit, and botnet. The Bayesian Belief Network is capable of determining the likelihood of an attack and its corresponding impact.

Blockchain and smart contracts are exciting developments in this area (Omar et al., 2022; Tolmach et al., 2022). Smart contracts reside in a blockchain and self-execute upon instructions received to exchange money, property, or any other value over transactions recorded in a blockchain (Grida & Mostafa, 2022). However, the transparency offered by smart contracts needs further digitalization of supply chains to match real-world assets with asset records in the virtual world.

Thanks to higher volumes of structured and unstructured data available, we now have many options to improve forecasting models, increase service, and reduce inventory costs. While the widely used inventory models rely on the normality assumption, new techniques such as bootstrapping, robust optimization, density forecasts, quantile estimation, and machine learning approaches exploit the increased computing power at the hands of the user and the big data flowing from enterprise information systems (Goltsos et al., 2022).

We shall not forget exciting developments in the last mile delivery process with drone deliveries and autonomous robots. Although drone deliveries are mostly in the experimental phase, they have been used to transport urgent medication during the COVID-19 pandemic (Constant, 2021). Comparably, autonomous delivery robots have been extensively used to deliver groceries when many countries in the world decided to introduce lockdowns to curb the spread of coronavirus. Using delivery robots in the last mile not only increases the delivery efficiency but also reduces the rate of infection transmission (Du, 2021) and serves those customers who cannot leave their homes to join long queues in supermarkets. COVID-19 stimulated the demand for unmanned and contactless deliveries, urging different types of autonomous e-commerce delivery vehicles and scenarios to be tested across the world (Buldeo Rai et al., 2022). The new business models developed and tested during the pandemic are promising further adoption of automation and efficiency increase in the last mile delivery problem.

While areas such as text mining and relationship network analysis have witnessed significant developments over the last decade, future research on them is still exciting and attracting many researchers and practitioners. Some of the prominent conferences where new research on text mining with supply chain applications regularly appears are as follows: IEEE International Conference on Digital Twins and Parallel Intelligence, IEEE Conference on Technologies and Applications of Artificial Intelligence, and IEEE International Conference on Big Data. These conferences provide a fresh overview of the current big data, text mining, and supply chain research, and they deserve to be regularly monitored for the most current applications of methodologies on supply chain big data.

One of the emergent concerns around big data applications for supply chain management is the need for updates and innovations in curriculum design. New academic programs are opening on big data, analytics, data science, and a few on supply chain analytics. As the availability of data increases and the companies' hunger for converting big data into insights strengthens, the gap in academia is felt both by academic institutions and their collaborating industry partners. Some organizations, such as the United States Air Force Academy, have spent significant time and effort on developing an operations research program for practitioners (Armacost et al., 2018). In the program, big data analytics is highlighted with R and Python classes and Apache Spark final projects, which require the students use parallel processing and machine learning on big data. There is a growing need for considering changes and extensions to tools used on big data; an example could be natural language processing.

Big data applications increase supply chain visibility, reduce time and resources needed for coordination, and grow revenue streams by better targeting customers or offering new products or services built on the big data capabilities of an organization (Nguyen et al., 2018). Yet, there is scope for a systematic investigation of business models leveraging big data and for empirical research on maximizing the value captured from big data and how traditional businesses can transition into an operating environment enhanced by big data flowing from internal and external systems.

However, visualizing big data is not straightforward due to the complexity of the data. Some kind of data aggregation and dimension reduction need to be executed on the data before it can be visualized clearly. Recently, visualizing big data with augmented reality has been offered as a novel and interactive approach for users to engage with data. A representative example is a 3D visualization of stock levels overlaid on a geographical map (Ramaseri Chandra et al., 2019). Augmented reality could help improve the understanding of thermal characteristics of warehouses, the computational power demand of complex calculations, or the communication of supply chain risk.

## 5 Managerial Implications

### 5.1 Preliminaries

The path to exploiting big data is not straightforward. Managers need to overcome shortages of people with the right set of data analytics skills, lack of support from other players in the supply chain, IT integration and data security issues, and physical capability to respond to real-time changes captured by big data. A data maturity profile can help businesses gauge their status and plan the way forward to embed big data analytics into their operational decision-making.

To capture benefits from big data, managers should have flexible IT resources to integrate with their company's upstream and downstream supply chain partners. The operations in many supply chains are interconnected, and investment in IT resources alone does not bring sufficient gains. Excellence depends on data-driven supply chains. Actors in the sector can adopt cloud-based applications for accurate and timely sharing of data. Technology alone won't be sufficient to reap the benefits. Appropriate change management and technology adoption processes should be put in place, and transition should be governed carefully. When a new technology is being adopted, the affected parties' views on the expected benefits and potential issues should be collected and reviewed prior to taking the decision to implement.

Data governance is a key data capability required to unlock and maximize the value captured from data. Many companies use business intelligence, digital products, analytics, and artificial intelligence to unlock the value of data. These are the most talked-about developments that feature news and presentations. However, for any of these tools to deliver value, the data that inform them must be trustable. Trusted data can only be obtained by formal data quality management, monitoring data collection, and building a data culture. Data culture entails roles and responsibilities for data owners and awareness of how data are leveraged within the business. There should be a single point of reference for everyone where data definitions, data sources, and dataflows can be found and queried.

A manager needs to reconcile the growth in big data processing capabilities of a business with its decision-making processes, which are likely to be updated to accommodate new data streams while keeping a certain level of standardization for transparency and accountability purposes. Incorporating big data analytics applications into the supply chain management decisions allows managers to observe trade-offs between different decisions such as the production and transportation costs with the appropriate tools and methodologies that can estimate them accurately (Zhang & Song, 2018). Decision support systems leveraging big data analytics applications allow managers to decide objectively, based on evidence rather than guesswork.

## 5.2 Success Factors

For any big data analysis of supply chain management problems to inform managerial decisions effectively, the data should be presented in a way that can be effortlessly followed by its audience. A sensible recommendation is to present the managerial problem first, followed by the tensions caused by this problem in the business, and conclude with a resolution of the problem with a proposed solution approach (Camm, 2018). This type of structured communication of big data problems can facilitate better engagement with the stakeholders and alleviate the anxiety generated by the jargon in the big data analytics domain.

A good big data application would not only present solutions to the given managerial problem but also provides alternative optimal solutions along with a discussion of limitations. Such a discussion should note factors external to the model that may make one of the alternative solutions preferred over the others. Since applications are built on assumptions, the limitations should acknowledge how the solution may shift from one alternative to another when factor values change within an acceptable range.

Another element of successful big data applications is the explainability and reproducibility of results. The receivers of the solutions provided by the application should be confident why the application is suggesting these specific solutions. It is unlikely for a black-box application to be widely adopted in business.

Any analytics project, irrespective of the size of the data that informs it, should start with a solid managerial problem that is identified and agreed upon by the stakeholders. The stakeholder buy-in and involvement in the project is a must for any decision support tool developed to address the problem to be accepted and implemented in the business. There is a strong aspect of change management to carry big data analytics projects in the supply chain to completion and exploitation.

### 5.3 Breaking Silos

Many of the applied research reviewed in this chapter refer to working in silos and suffering from an inability to have a holistic view of the problem. Our systems are generating big data, and we are capable of storing and processing them; there is scope for integrating various sources of data and how decisions informed by a set of data affect other decisions. While we are improving an element of the supply chain, we may be deteriorating another. The typical tension is between procurement and inventory management. Large quantities are incentivized with lower unit cost, improving the procurement performance metric while the items bought need to be stocked elsewhere in the supply chain, deteriorating days of inventory metric.

Traditionally, many of the big data applications in supply chain and operations management focus on a single or a few objectives, which makes it challenging to have a holistic approach to managerial issues. A way forward is to incorporate multi-objective decision analysis and explore the trade-offs between interdependent decisions. Any big data application on supply chain management thus shall try to incorporate stakeholders from different departments to the problem at hand and possibly produce a trade-off analysis for a range of decisions. Once the business priorities are set and understood by everybody involved in the process, the decision-making could be left to automation in cases of repeat operational decisions.

Managerial challenges comprise shortages of people with the right set of skills, the lack of support from upstream and downstream supply chain partners, issues in information technology and systems integration, concerns around information sharing and security, and physical capability of the supply chain to respond to real-time changes captured by big data. A data maturity profile for businesses is proposed in Table 1.

**Table 1** A big data analytics maturity proposal around people, supply chain, and information technology

| Indicator | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| People capabilities | People who can use the system | People who can interpret data and apply it to business | People with excellent analytical skills, using prescriptive models | People developing hypotheses for improving operations |
| Information technology and systems integration | Data handled in isolation | The system is connected but not fully integrated | IT integrated, but the user requires frequent changes | The system is fully integrated, and decisions are automated |
| Supply chain operation | Surviving | Improving performance with downstream partners | Improving performance with upstream and downstream partners | The entire supply chain is synchronized |

People's capabilities in Table 1 refer to a range of challenges that need to be overcome as organizations introduce and improve their big data applications. Organizations sometimes suffer from the lack of people who can use a big data application system effectively. At the very least, people could be trained to use the system, collect data, and produce complex analyses. However, further investment needs to be made to either develop skills to interpret analysis results and produce insights or further introduce hypotheses to improve current operations. It should be noted that people at the fourth level of maturity are difficult to find and expensive to keep. The organization needs to have in place career progression plans and both financial and nonfinancial incentives to attract and retain people with big data analytics capabilities.

Integrating the supply chain with downstream partners is relatively easy, for it is in the best interest of these partners (e.g., retailers) to improve their predictive capabilities or reduce lead times to serve the customer better and increase the supply chain surplus. Then the experience in downstream integration could be extrapolated to upstream integration in a comparable way. The vision for the supply chain is to be synchronized entirely with end-to-end visibility and coordination of decisions. Reaching end-to-end synchronization requires investments and improvements in both hardware and software, along with skills development.

## 6 Summary and Conclusion

Big data applications in supply chain management draw heavily on statistical analysis and operations research methods where deterministic and probabilistic mathematical modeling have been widely utilized. Now many companies are at a transition phase where they are investigating the availability of data in their systems and matching the data with business problems that need immediate attention. More and more, we will see an increasing demand for people who have not only supply chain management knowledge but also have a good command of data science skills so they can bridge supply chain management with analytical approaches.

Encouraging attempts to leverage big data for forecasting have been highlighted in the chapter. It is possible to include new variables into predictor sets, considering not only macroeconomic indicators but also weather temperature or other incorporating unstructured data from customer reviews of the products into the prediction model.

It is now the time to treat data as an asset and investigate how it can be effectively used to improve the efficiency of operations and resources in the supply chain. It is not a trivial exercise to determine which data assets are valuable, but this process is supported by automated algorithms that sift terabytes of big data. The key idea behind assessing the value of data focuses on the use of data in applications and business integration, monitoring, and management.

Introducing big data applications could face resistance from people within the organization. Curiosity and openness to novelty and searching for innovative ways of running the business should be encouraged. A culture of “fast fail” could help navigate the uncertain waters of big data technology adoption. Fast fail culture entails being open to new opportunities when success is not guaranteed and being able to discontinue failing endeavors swiftly without deploying further resources into them.

## 7 Limitations

While the content reported is novel at the time of publication, big data applications are expected to evolve and become more intelligent as our understanding of algorithms and computing capabilities increases. What may be new and exciting for 2021 is likely to become standard practice over the next decade.

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# Machine Learning and Supply Chain Management

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## Contents




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**Abstract**

Scholars have turned to highly capable machine learning (ML) approaches for analyzing and interpreting huge amounts of data due to the limitations of older methodologies. There has been a recent uptick in using machine learning algorithms in supply chain management (SCM). This chapter uses some literature and a bibliometric analysis to provide an overview of the field. Overall, ML is applied for supplier management, risk management, transport and distribution, and the circular economy. Some of the areas of study we review, based on a bibliometric analysis, include frameworks, performance management, and artificial intelligence (AI) challenges for supply chain management. Conversely, issues rarely discussed include the selection of ML techniques for supply chain management (SCM), sustainability issues, the future of ML in supply chain management, and system requirements for ML in supply chain management. Based on these issues, we provide insights for managers, interesting research areas for future research directions for SCM researchers, and application insight for SCM practitioners.

**Keywords**

Machine learning · Supply chain management · Literature review · Bibliometric analysis · Future research directions

## 1 Introduction

Competition across supply chains, rather than between enterprises, has become increasingly important due to the effects of the information technology revolution, economic globalization, and rising customer expectations (Yang et al., 2021). The reliability of future projections and their capacity to predict demand become problems when managing a supply chain in an uncertain environment (Y. Zhu et al., 2019). Today, tighter strategic management of the supply chain is more important than ever. Rapid growth in industrial automation across the supply chain has led to increased competition, making sustainable growth essential for long-term success.

In the era of big data, interactive data are routinely created, collected, and archived in different process industries (Dubey et al., 2019; Quayson et al., 2020). These data are important in process operation, control, and design. Intelligent data use and information and knowledge extraction can greatly benefit supply chains. The explosive growth in data from various SCM elements has forced companies to develop and implement new technologies to rapidly and intelligently interpret large data (Bai et al., 2021; Sheng et al., 2021). Traditional decision support systems cannot singly effectively integrate big data. Hence, supply chain professionals seek to handle big data to reach smart supply chains using software-enabled systems in the big data era.

Artificial intelligence (AI) methods can help cope with this big data-related challenge (Nayal et al., 2021). Machine learning (ML) techniques are a popular subdiscipline in AI. ML can identify and extract patterns among variables using large datasets. They can reduce or eliminate data interpretation difficulties, given no direct human involvement (Quayson et al., 2020, b). ML generally incorporates large datasets as input to the system and for rapid response to emergent industrial demands. ML helps recognize situations and integrate them with the system – where models use them for analysis purposes. These models are further used for decision-making.

Estimating reliable forecasts is another application of ML. Artificial intelligence (AI) systems may analyze data for hidden patterns, develop novel ideas, and point scientists in the right direction. The supply chain encompasses many industries, and ML approaches can be applied in many different contexts, such as manufacturing, operations, and healthcare (Tirkolaee et al., 2021).

ML algorithms and their applications in managing the supply chain have gained attention from researchers and practitioners (Bodendorf et al., 2021; Carbonneau et al., 2008). This interest is due to the limitations of traditional data analysis methods. Traditional methods such as moving average forecasting and autoregressive integrated moving average (ARIMA) have difficulty handling widespread nonlinear problems in real-world supply chains. Traditional methods cannot effectively use large and unstructured data from diverse areas of the supply chain. Fortunately, ML techniques can mitigate these limitations of traditional methods. For instance, ML can provide substantial insight into nonlinearities in the supply chain. ML was developed to deal with big and unstructured data. They have been shown to better recognize and predict effective factors in supply chain performance – not only for prediction but a comparative evaluation. ML is a valuable tool for analyzing supply chain-related data and its activities (Sharma et al., 2020). SCM managers can now predict future trends, leading to informed decisions in various parts of the supply chain.

Various studies have been conducted in various areas of ML in supply chains. For example, Kumar et al. (2021) analyze ML's role in green supply chain management. Kamble et al. (2021) provided a decision support system for managers to predict an organization's probability of successful blockchain adoption using ML. Malviya et al. (2021) used various machine learning models to predict the demand for transformers in various locations. One supervised ML method for dependable supplier selection was proposed by Cavalcante et al. (2019). By combining the multicriteria decision making (MCDM) with ML, Bai et al. (2017) categorized suppliers according to their environmental impact. Similarly, Tirkolaee et al. (2021) develop a framework for ML algorithms to manage different supply chain areas.

Given these situations and previous works, we focus on providing additional insights based on a comprehensive study of ML applications in the supply chain, providing observations on how these valuable techniques can effectively manage different aspects of SCM. We also provide a bibliometric analysis for a broader understanding of the issues. Therefore, this chapter seeks to:

1. Discuss the application of machine learning in the supply chain
2. Explore the importance of machine learning in the supply chain
3. Present the current state of research on machine learning in the supply chain and propose future research areas

The chapter can be used for and support:

(i) Examining and assessing recent developments in machine learning for SCM. For this reason, this article surveys state of the art in the field by discussing the most popular ML methods used in SCM research.
(ii) Understanding the most frequently used ML methods in SCM.
(iii) Using a framework to understand how ML is integrated into the supply chain.
(iv) Providing the reader with gaps in the current practice and research with guidelines for interesting future directions.

## 2 Background

### 2.1 Machine Learning

Arthur Samuel coined the term *machine learning* in 1959 (Wiederhold & McCarthy, 2010). Machine learning has been advanced across various fields of research and practice. The strength of ML lies in its ability to learn patterns in data, improve, and make decisions from the given data based on a set of performance criteria (Gambella et al., 2021). Beyond the experientialism and social learning that embodies personal learning, machines are data-driven. ML is a subset of artificial intelligence that forms the thinking ability of computers to learn and make decisions independently. Practically, every machine learning algorithm is measured based on performance metrics. Accuracy and efficiency are significant aspects of ML; it is measured by the number of times a certain computer action is modified to reach a correct result.

Machine learning cuts across disciplines and research domains. Computational statistics, optimization models, and algebra are necessary foundations for realizing the successful design and execution of ML algorithms (Sun et al., 2020). ML application spans computational design, online stock trading, fraud detection, face detection, medical diagnoses, prediction of traffic, product recommendation, forecasting, and character recognition, among many other applications. Countless use cases of ML exist, including new social innovations such as self-driving cars.

SCM is not left behind in terms of ML application. There are many potential use cases of ML in SCM. These include customer behavior prediction, demand forecasting, market situation sensing, supply selection, and segmentation (Bai et al., 2022). ML embodies different algorithms and tools that are tailored for a special purpose.

#### Main Groups of ML

Three main groups of algorithms embody ML (i.e., supervised, unsupervised, and reinforcement learning).

Supervised learning refers to training classification and prediction algorithms utilizing annotated datasets. As part of the cross-validation process, the model's weights are tweaked as new data is added to ensure a good fit (Burkart & Huber, 2021).

Unsupervised learning implements machine learning techniques to analyze and group unlabeled datasets. These algorithms automatically find clusters or hidden patterns in data without human interaction. Due to its ability to distinguish between related and unrelated data, it is well-suited for exploratory analysis, cross-selling techniques, customer segmentation, and visual recognition (Eshaghi et al., 2021).

Reinforcement learning means changing behavior to get the most out of the current situation. Many machines rely on it to determine how to respond to a scenario. The model in supervised learning is provided with the correct solution because it is part of the training data, whereas in reinforcement learning, there is no solution, and the agent chooses how to finish the job. Even without a training dataset, it will pick up knowledge through trial and error (Chen et al., 2021).

The right tool must be used for the right algorithm. The next section overviews some machine learning tools.

## Machine Learning Tools

ML is helping to shape and bridge machine-to-human interactions. It is not surprising that ML is making advances in this technological space. The ML ecosystem and AI communities provide substantial open-source libraries and tools for creating industry-specific use cases and models. Example of libraries and tools include scikit-learn, TensorFlow, Pytorch, and Natural Language Analysis with Python (NLTK). These tools are shown in Fig. 1.

## Scikit-Learn

Scikit-learn is not strictly a tool but a free and open-source library for python programming language, built on NumPy, SciPy, and Matplotlib (Jurczyk, 2021). It is specifically used for data mining and analysis. This library provides a range of supervised and unsupervised learning algorithms suitable for different tasks. These algorithms include classification, regressions, clustering algorithms, dimensionality reduction, etc. It is imperative to know scikit-learn since it is one of the basic building blocks of any machine learning project. The skeleton of scikit-learn is shown in Fig. 2.

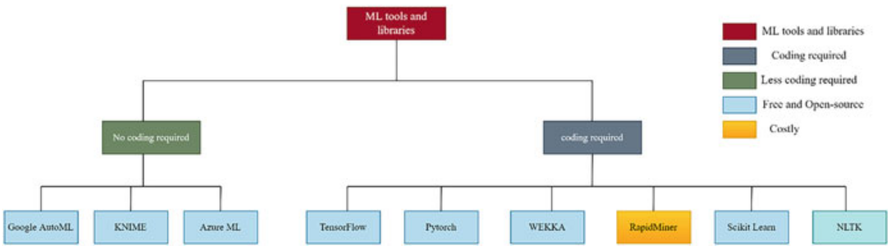


**Fig. 1** Machine learning tools and with some characteristics

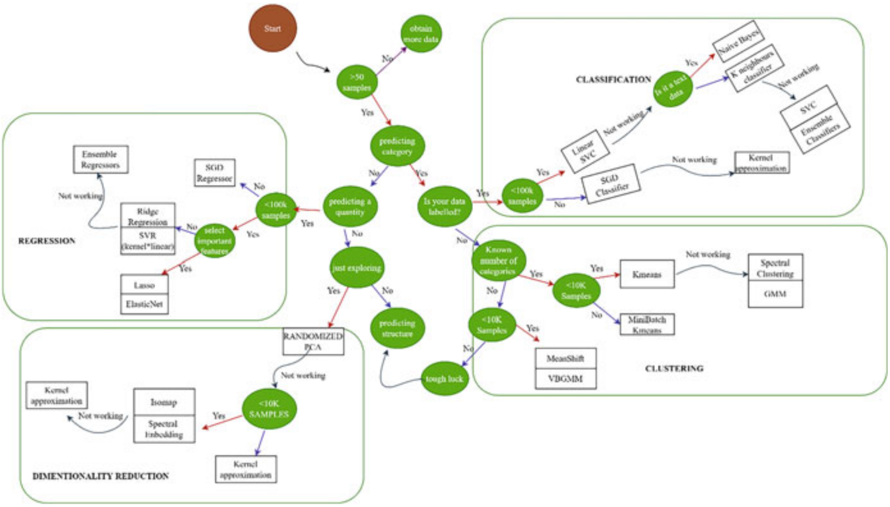


**Fig. 2** Roadmap and skeletal structure of the scikit-learn machine learning system

## KNIME (Konstanz Information Miner)

KNIME is also a free, open-source data analytics and ML system, reporting with a platform integrated with powerful analytics on a graphic user interface (GUI)-based workflow (Maraza-Quispe et al., 2022). This architecture makes it easier for beginners in programming to navigate and use the K9 – an open-source command line tool that facilitates working with Kubernetes and gaining insights into building models on the platform. It is very flexible in gathering data and creating models for deployment into production. It encompasses all the functions of workflow management. This means a user can gather, wrangle, model, visualize and optimize the program (Ninasivincha-Apfata et al., 2021). Most importantly, a user does not need to know how to code before using KNIME. This characteristic allows users without substantive technological capabilities to apply the tool to practical ML use cases.

## TensorFlow

Whenever you hear of ML, it is likely to be complemented by TensorFlow. This complementary relationship is because TensorFlow is one of the most effective libraries for machine learning. The *Google Brain team* created it. It is an open-source library suitable for numerical computation and large-scale machine learning. TensorFlow provides an accessible and readable syntax that makes it easy-to-use programming resources (Singh & Manure, 2020). It also provides flexibility and uses Keras and other high-level application programming interfaces (APIs) which makes things much smoother. TensorFlow can run on both central processing unit (CPU) and graphic processing unit (GPU) machines

(Pang et al., 2020). It is easier and smooth to deal with graphics, videos, and image data with TensorFlow.

### Pytorch

Pytorch is a competitor tool to TensorFlow, also referred to as *torch* (Imambi et al., 2021). It is a python library built to provide a flexible platform for deep learning development. Facebook uses Pytorch. The workflow of Pytorch is comparable to the scientific computing library Numpy. A major highlight of Pytorch is its dynamic computation graphs. Pytorch supports a compute unified device architecture (CUDA) environment, which ensures that the code can run on GPUs, decreasing the time needed to run the code (Ketkar & Moolayil, 2021). This capability increases the overall performance of the system. Pytorch framework is embedded with ports to iPhone Operating System (iOS) and android backends.

### WEKA

Waikato environment for knowledge analysis (WEKA) is an open-source Java software that hosts a collection of machine learning algorithms for data mining and exploration (Merlini & Rossini, 2021). It makes it possible to understand and visualize machine learning algorithms on local machine. WEKA has a graphic user interface and command-line interface. It is based on the java programing language, which provides predictive modeling and visualization (University of Waikato, 2016). It is a suitable environment for comparing learning algorithms. However, there is limited documentation or online support available.

### RapidMiner

RapidMiner integrates data preprocessing, machine learning, and predictive model deployment into a single workflow as a team data science platform. As a data science platform, its potent and intuitive graphical user interface allows for predictive analytics development, distribution, and upkeep (Javadpour, 2022). With RapidMiner, disorganized and seemingly useless data becomes very useful and valuable. This is because it structures data in a way that becomes easy to comprehend. It results in a visualization lot. Through GUI, it helps design and implement analytical workflows (RapidMiner, 2016). However, the tool is not free and open-source but rather costly to patronize.

### Google's AutoML

With Google Cloud AutoML, even individuals without experience with machine learning may take advantage of its powerful capabilities (Walker, 2018). The human labeling services by Google render models by users to be trained with high-quality data. Google AutoML has various learning tools for serving different purposes. For example, ML vision is specifically used for images. Auto video intelligence is also used for videos. AutoML natural language is used in structuring and obtaining meaning from text. Moreover, autoML translation is purposely for detecting and translating between different languages (Viswanathan et al., 2020). There are the AutoML tables that build models on structured data.

### Azure Machine Learning

Azure Machine Learning Studio by Microsoft is a collaborative drag-and-drop-machine learning tool (Barnes, 2015). This tool could be used to build tests and deploy predictive analytics. It is easy to navigate, drag, and drop plain assets into an interactive canvas and connect them to a form that will run in a machine learning studio (Milad et al., 2020). There is no need for programming requirements, just visually connecting datasets and modules in constructing the predictive modules analytic model (Joshi, 2020). Finally, the workflow could be published as a web service.

### Accord

Accord is a Net machine learning framework combined with audio and image processing libraries. Accord is written in C# (pronounced as C sharp). It is a powerful framework for building computer vision, signal processing, and statistics applications. All libraries are available from the source code, the executable installer, and the new git packet manager. It provides an algorithm for numerical analysis, linear algebra, optimization, and artificial neural networks. Also, it supports graph plotting and visual libraries. Accord contains more than 38 kernel functions and 35 hypotheses tests. These hypotheses include one-way and two-way ANOVA tests and non-parametric tests. Nevertheless, it supports Net-supported languages.

### Google COLAB

Google COLAB is a free Jupyter computational notebook that is an open-source, interactive web application that allows researchers to merge things like source code, computational output, explanatory text, and multimedia resources – that requires no local computer installation (Gunawan et al., 2020). It runs entirely in the cloud. The main motive for creating COLAB was to disseminate machine learning education and research. Since there is no need for manual installation of software and libraries, it is very important for data scientists with fewer computational resources. It already has preinstalled libraries like Pytorch, TensorFlow, Keras, and other high-level APIs required to create and deploy ML and deep learning (DL) projects.

### Natural Language Analysis with Python NLTK

Python NLTK is a natural language processing toolkit in Python that has the core package for all-natural language processing (NLP) tasks, including text processing needs (Kulkarni & Shivananda, 2021). Text processing is a significant part of any NLP task for language modeling, neural machine modeling, or named entity recognition Google's AutoML.

## 2.2 Machine Learning Applications for Supply Chain

In recent years machine learning has gained increased attention in supply chain management, although the integration of ML in SCM is still in the early stages

(Ni et al., 2020). Supply chain management (SCM) strategically coordinates all steps of a company's supply chain, from its suppliers to its customers, to boost profits and sustain a competitive edge in the market. The advances in information technology and the industrial revolution have huge potential to disrupt conventional SC. Particularly, in this era of big data, a vast amount of interactive data is frequently created, collected, and preserved in various process industries. These data are valuable assets in control, process operation, and design. The integration of ML, DL, and SC is shown in Fig. 3.

The intelligent utilization of this data and the extraction of information and knowledge from them are key to the future of current SCs. As more areas of SCM produce more data, businesses have developed and implemented new technologies to efficiently and intelligently understand big data, as conventional decision support systems cannot cope with big data (Akbari & Do, 2021).

Supply chain professionals attempt to manage big data to achieve smart supply chains. The weakness of conventional methods in analyzing big data gives an undisputed advantage to the application of ML in SC. ML techniques outperform traditional statistical methods in identifying and predicting supply chain performance (Feizabadi, 2022). We now provide examples of areas in the supply chain applying machine learning.

## Supplier Segmentation

Supplier segmentation is a key component of a supplier relationship management (SRM) strategy that categorizes suppliers into various groups to allocate limited

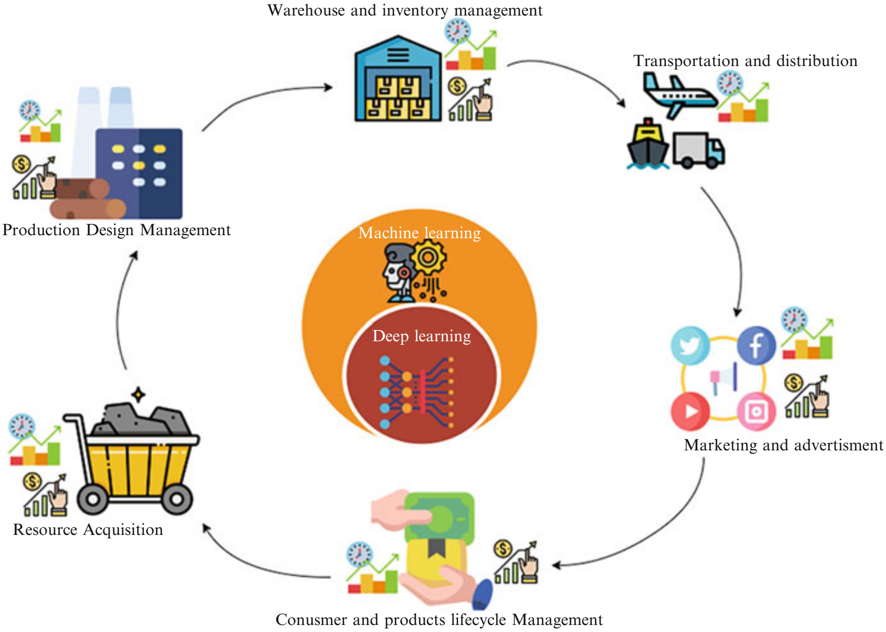


**Fig. 3** Machine learning, deep learning, and supply chain integration scenario

resources to manage them efficiently. Companies must form long-term relationships with strategic suppliers to get the best value. Conventionally, multicriteria decision-making (MCDM) methods have been applied in determining the score of suppliers to guide decisions on segmentation. However, classification algorithms such as support vector machines, decision trees, and K-means possess key characteristics in categorizing objects into partitions of similar observations (Tirkolaee et al., 2021).

**Supplier Selection**
Supplier selection refers to finding, assessing, and contacting potential suppliers. The time and money spent on finding and vetting potential suppliers are vital to the company's success. The supplier selection process's major objective is to lessen the buyer's exposure to risk, boost the purchase's overall value, and encourage the growth of a close, mutually beneficial relationship between the company and its chosen vendors. Reinforcement learning techniques such as Q learning are very useful for supply selection (Tirkolaee et al., 2021). It can reward and penalize actions. This method is essential in evaluating a supplier's ability to define requirements in measuring the quality of service.

**Supply Chain Risk Management (SCRM)**
SCRM focuses on building and adopting strategies for managing operational and exceptional risk. Machine learning techniques and algorithms were designed to mimic the environment through historical data to predict the uncertain future. The onset of big data and AI technologies has given way forward for risk assessment and prediction to aid the supply chain decision-making process. Support vector machine (SVM) methodology has been used in supply chain risk identification and Bayesian and artificial neural networks research in risk assessment (Tirkolaee et al., 2021).

**Sustainable Supply Chain Management**
Sustainable supply chain management seeks to balance environmentally, socially, and economically sound practices throughout the life cycle of a supply chain. Machine and deep learning techniques can model greenhouse gas emissions along the production line throughout a product's lifetime (Mohamed-Iliasse et al., 2020). Moreover, long short-term memory (LSTM), and a recurrent neural network (RNN), is used in forecasting time series data with high volatility and nonlinearity. There are modified and improved RNNs that advance the forecasting of sequence-to-sequence data, for example, transformer and encoder-decoder models. The ML modeling of supply chain emissions assists in designing an eco-friendlier product with fewer emissions.

**Circular Economy**
The circular economy promotes the reuse, sharing, leasing, reusing, repairing, refurbishing, and recycling of goods and material for as long as possible. Machine and deep learning could be used in life cycle assessment. These models tell the

producer when the products need refurbished, repaired, or recycled. ML and deep learning techniques are more promising for the product-as-a-service (PaaS) business model.

### Transportation and Distribution

The movement of products from one point to another, between facilities and production house to the warehouse, represents a significant proportion of logistics cost. This makes it critical to optimize the transportation and distance during the distribution of goods and services to the nearest neighbor and genetic algorithm. Particle swarm algorithms are ML models that optimize transport routes between cities to minimize cost. Convolutional neural techniques, a deep learning model, can be employed in building self-driving cars and robots for transporting goods from one point to another. Each of these tools, put together, enhances the overall supply chain.

### Marketing and Advertisement

Good marketing and advertisement strategies can boost demand and the supply chain. Here, ML techniques hold implications for analyzing customer interest in goods by modeling customer purchases. Also, ML and DL can also be applied to assess online reviews and chatbots, improving customer satisfaction. This way, marketing strategies could be tailored to customers' interests and to which platform to best advertise products and services.

### Warehouse and Inventory Management

It is critical to monitor and speed up the movement of goods from one point to another. Automating warehouses using robots to pick up goods ready to be sent to customers is key to increasing productivity and efficiency. Moreover, a human-induced error is substantially reduced by introducing artificially intelligent bots. Machine learning and deep learning allow one to predict inventory-based data on previous inventory to meet demand. This technique reduces inventory holding costs at all levels along the supply chain and boosts material planning.

### Demand Forecasting

Business supply decisions can be improved with the help of demand forecasting, which estimates expected sales and income for a specified period. Deep learning models such as long short-term memory (LSTM) and transformers – in Python, can be used to clean, reduce, expand, or generate features – are very efficient in learning from highly volatile and nonlinear data. Big data presents data pools with different data types and structures. These data are very nonlinear and difficult for conventional models such as ARIMA to handle. However, RNNs such as LSTM and transformers were built to handle nonlinearity and vanishing gradient in conventional models, which are very useful in forecasting demand and supply. Producers can meet customers' demands at all levels by partly relying on deep learning models.

Figure 4 presents a summarized flowchart of ML and DL algorithms for supply chain management.

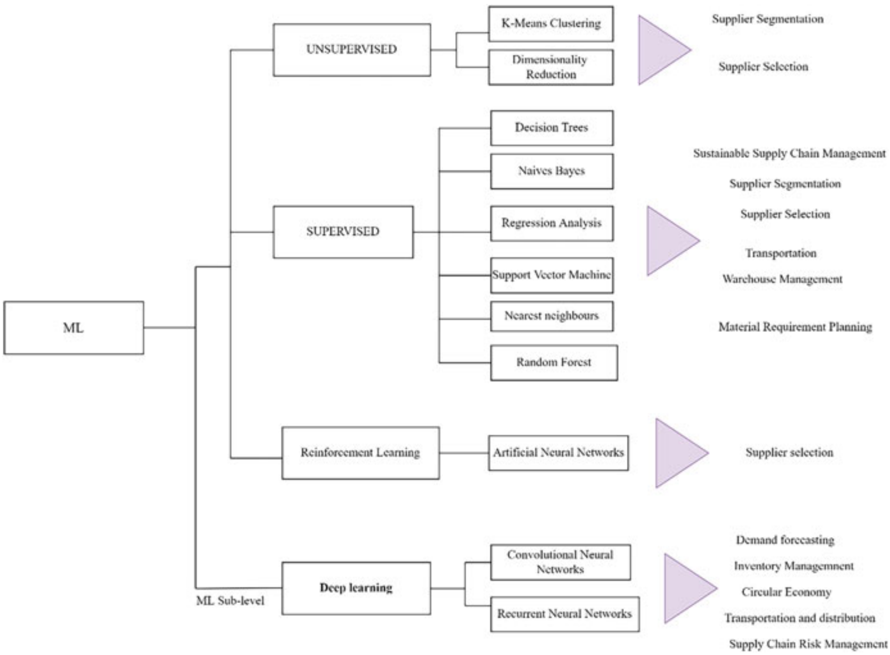


**Fig. 4** Machine learning and deep learning categorizations for supply chain applications

## 2.3 Roadmap of Prediction Model Framework

Following the above discussion on machine learning platforms and algorithms (Fig. 4), this subsection introduced the roadmap for developing an accurate machine-learning model in supply chains and beyond. These steps will serve as a roadmap for both expert and non-expert in implementing predictive models in their supply chains. As shown in Fig. 5, the steps involved in building a prediction model are detailed below:

Step 1. Data collection

Obtaining a significant sample size in training a machine learning model is highly required to achieve higher performance. The greater the sample size, the better the machine-learning model. Although real-world supply chain and industry-specific data could be collected and used for training the model, it is advised to assess publicly available datasets for the training and testing phase of the machine learning model (Ng et al., 2020). Nevertheless, the industry-specific data can be employed as a real-world use case. Assessing publicly available datasets gives some level of trust in theory and practice that support the real-world use of the designed model.

Step 2. Data preprocessing

In reality, it is unlikely to obtain perfect data to train machine learning models (C. Zhu & Gao, 2016). Mostly, these datasets come with a series of errors that can be sensor specific or human-induced. There is a need to handle missing data by

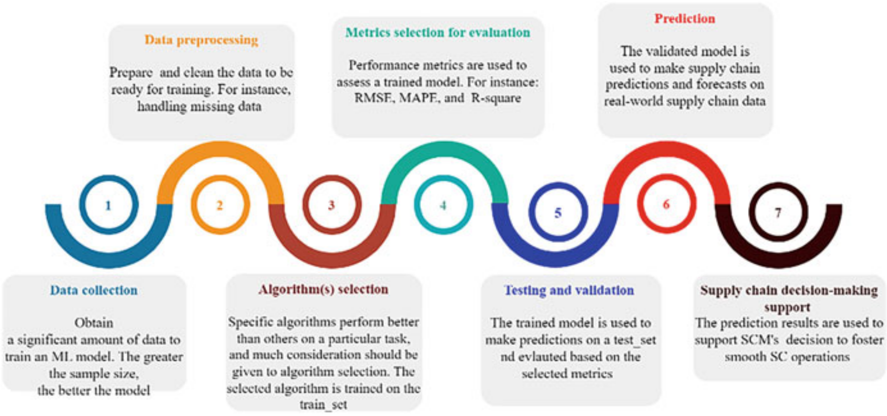


**Fig. 5** Roadmap of building a prediction model framework

elimination, filling in with the mean or median values, encoding categorical data, and feature scaling and selection. Data preprocessing is a significant aspect of data analysis and machine learning. Particularly feature selection. It is necessary to select features that match the interest of the problem at hand. Feature scaling is also relevant to achieving an accurate model. In practice, different data are measured in different scales; thus, normalizing the data before training is the crucial analysis and prediction model (Al-Taie et al., 2019). Finally, data is split into train and test sets for training ML models.

Step 3. Meta-learning

ML models are referred to here as an algorithm. In ML, the selection of an algorithm is known as meta-learning. Meta-learning is dependent on criteria such as the size of training data, accuracy, computing power, linearity of data, and the number of features. It should be noted that specific algorithms perform better than others on a particular task, and much consideration should be given to algorithm selection (Hospedales et al., 2022).

Step 4. Metric(s) selection

Metric selection for assessing the performance of machine learning models is equally important to select machine learning algorithms. Varying metrics are utilized to assess different tasks, such as classification or regression. It is fundamental to use accuracy score, AUROC(area under receiver operating characteristics curve), precision, recall, and F1-score for classification tasks (Bukhari et al., 2019). Unlike classification, mean squared error (MSE), root mean square (RMSE), mean absolute error (MAE), and R-squared ($R^2$) are used for regression tasks.

Step 5. Testing and validation

Prediction refers to the output of an algorithm trained on historical data and applied to current data. The trained model is used to make predictions on a test set. The model is validated to ensure there is no underfitting or overfitting with acceptable performance before deploying it into production (Tao et al., 2019).

Step 6. Prediction

The validated model is deployed and used to make supply chain predictions and forecasts based on real-world supply chain data (Bunker & Thabtah, 2019), for instance, predicting the likelihood of whether or not a customer would churn in 30 days and the occurrence of climate-related extreme weather events that can disrupt the supply chain process (Wang et al., 2007). Predictive models are salient to eliminating unforeseen supply chain risks. The design of ML models facilitates artificial intelligence in businesses and organizations, especially automation of tasks.

Step 7. Supply chain decision-making support

Better business decisions can be made with computer software called a decision support system (DSS). Massive amounts of data are examined, and the most effective solutions are recommended to a company. These are made possible due to machine learning and artificial intelligence in modern supply chains (Villegas & Pedregal, 2018).

## 2.4 Importance and Benefits of Machine Learning in Supply Chain Management

Machine learning applications have many benefits in supply chain management. This section touches on a few: smart workstations, decision support, cross-functionality, accelerating operations, effective supplier management, handling inventory, etc.

### Help in Designing Smart Workstations

“Smart workstations” share characteristics with other machines on the shop floor, are dependent on each other, and may be given instructions to all machines so that resource utilization can be easily enhanced (Nagar et al., 2021). Optimization work was previously carried out under the guidance of seasoned staff as an ongoing process. However, to meet the sector’s goals, sustainable practices must be matched with them.

### Help in Providing Back Support to the Decision-Making Process in an Organization

Machine learning has the feature of analytical evaluation, which helps in capacity building in an organization while making industrial operations decisions. Machine learning helps provide decision support to industry and supply chain partners.

### Helps in Increasing the Cross-Functionality Among Teams

SCM can attain better outcomes by implementing IT-enabled systems. However, industries are not integrating all SCM stakeholders with their IT-enabled systems. This lack of inclusiveness causes challenges in meeting shared goals across cross-functional teams. The emergence of machine learning in the supply chain can provide a common platform for cross-functional teams to work with greater insights/intelligence (Nagar et al., 2021). This integration will further eliminate the functional and organizational imbalances in the supply chain and with integrated activities completed more effectively.

### Helps in Accelerating Operations

The inclusion of machine learning can broadly accelerate operations performance within and outside the organizational boundaries. Prediction and utilizing recognized data related to a particular common goal is more easily completed. Automated signals generated from prediction tools then help in decision-making and improve the interconnectivity among various operations (Lee & Mangalaraj, 2022). Machine learning accelerates logistics operations through various optimization efforts with resulting optimum solutions.

### Helps in Effective Supplier Management

Machine learning in the supply chain can support managing supplier quality through pattern recognition. Patterns offer a quick insight into a supplier's quality level by helping to create a summary and history of supplier and manufacturer activities. Machine learning can more precisely examine products and materials supplied and provide confirmation of adherence to various quality criteria (Kosasih & Brintrup, 2022).

### Helps in Improving the Demand and Production Planning

Decision-maker biases and market speculations influence the traditional supply chain. The inclusion of machine learning can help in managing these aspects of demand and production planning. Machine learning can support production planning because it helps identify consumer requisitions and purchase patterns in different scenarios. The precise analytical information is provided through algorithms employed in ML, which helps neutralize and render the data for verification purposes (Nagar et al., 2021). This capability can aid organizations in building advantages over their competitors.

### Helps in Handling Inventory-Related Issues (Creating a Pull System)

Machine learning enables the industry to eliminate inventory buffers – greater leanness – by simultaneously keeping track of several attributes within and outside the organization. In the pull system, materials are acquired and fed into production in response to actual demand from customers. Maintaining a sufficient supply also contributes to the smooth running of forthcoming events. With the aid of the Internet of Things (IoT) systems, ML helps handle all-around inventory issues (Effah et al., 2022).

### Helps in Deciding the Pricing of Goods and Services

While determining the price, it is important to identify and measure determinants that generally meet customer expectations and are profitable to the manufacturer. Inappropriate pricing decisions made by the manufacturer or service provider are a common reason why items miss their intended market (Brintrup et al., 2020). A company can use ML to set prices based on real-time data, and if necessary, ML can also help set prices with additional offers and promotions to enhance market share.

#### Can Support Harnessing Uncertainty

ML receives data inputs in real time about the quantity and timing of available resources and activities. Based on this trait, ML gathers data and analyses and supplies the required inputs for dealing with circumstances and making decisions. With ML, businesses can cut back on human oversight, which introduces bias and uncertainty while increasing their processes' reliability and efficiency.

#### Helps in Improving Consumer Satisfaction

The customer experience is kept at the utmost best in the supply chain because it is directly related to the demand for products and services. Customer and stakeholder value alignment with supply chain processes is necessary for building competitive advantage (Dubey et al., 2020). A better consumer experience helps in increasing demand and vice versa. ML can help consumers to find real-time data by enabling the features within the system. It enables a quick response to consumer queries and feedback, leading to greater consumer satisfaction.

### 2.5 Challenges of Machine Learning Applications in Supply Chains

Acquiring relevant data is a common challenge for ML applications in the supply chain (Wuest et al., 2016). Data acquisition is a limitation because supply chain data's availability, quality, and composition strongly influence ML algorithm performance. Inaccurate and redundant information can harm the performance of learning algorithms. Most machine learning algorithms can only work with data with continuous and nominal values. Several factors impact the required data, including the algorithm and parameter settings.

Obtaining supply chain data and ML applications is a common problem because of security concerns or a lack of data capturing during the process. Some critical available data characteristics must be considered, even though ML allows for knowledge extraction and generates better results than most traditional methods with fewer data requirements. A clear understanding of data characteristics is important before attempting to apply ML.

Depending on the ML tool or algorithm, it may be necessary to preprocess the data after it has been secured. Data preprocessing has a significant impact on the results. Normalizing and filtering data, for example, can be accomplished with various industry-standard tools. The training data – which ML heavily relies on for learning – must also be checked for imbalances and bias. For some algorithms, this can pose a problem in their training.

It is common for some attributes to be missing or unavailable in the dataset. Because of these so-called "missing values," it is difficult to apply machine learning algorithms. Filling the gap is possible with practical induction systems. For each problem and ML algorithm, the replacement of missing values must be tailored to meet the specific needs of the problem. The original dataset is altered as new values are added to fill the gaps. The goal is to minimize bias and other negative influences on the analysis objective as much as possible. Because this is such a common problem, a wealth of information and suggestions is available (Sharma et al., 2020; Tirkolaee et al., 2021).

An additional problem is deciding on the best machine learning algorithm and technique. There have been attempts to define "general ML techniques," but because there are so many different types of problems and their requirements, the need for specialized algorithms with specific strengths and weaknesses is clear (Wuest et al., 2016). The fact that practitioners and researchers pay more attention to ML in supply chains also means many different ML algorithms, or at the very least variations of ML algorithms, to choose from to address multiple needs and attention. Many "hybrid approaches," or combinations of different algorithms that promise better results than single algorithm implementations, are becoming more common; mixing and matching are major overall concerns.

The interpretation of the results is also an issue. It is important to remember that not only the output format or illustration is important for the interpretation and specifications of the chosen algorithm but also the parameter settings, the "planned outcome," and the data, including preprocessing. Again, more identifiable constraints like immunity to overfitting, bias, and variation can significantly impact the interpretation of the results (Wuest et al., 2016).

## 3 Current and Future Concerns and Directions

We completed a bibliometric review to identify current issues and propose future research directions**.** The bibliometric overview provides publication trends and citation structure relating to machine learning in the supply chain. We highlight the major themes discussed in machine learning and the supply chain and present an overview of the content. A mapping analysis illustrates the thematic links of the major discussions in articles relating to machine learning in the supply chain by examining the co-occurrences of author-specified keywords.

### 3.1 Methodology

This study uses various measures to map the development of machine learning in the supply chain, including the total number of papers, citations, and the *h*-index, thus providing a complete demonstration of the bibliographic data (Donthu et al., 2020). The VOS viewer software is used to generate network visualizations of bibliographic coupling and co-occurrence of keywords by linking relevant items under analysis.

The data was retrieved from the Web of Science data from early 2022. The search was conducted using the source title **("supply chain" OR "value Chain") AND ("machine learning" OR "supervised learning" OR "unsupervised learning"**

**OR "artificial intelligence")** (All Fields) and **Articles** (Document Types) and **English** (Languages) and **Business Economics** or **Operations Research Management Science** (Research Areas) and **Science Citation Index Expanded (SCI-EXPANDED)** or **Social Sciences Citation Index (SSCI)**. Our refined search produced 249 research items. We then read the abstracts and selected 131 more suitable for this study. VOSviewer (Waltman et al., 2010) was used to conduct the bibliometric analysis. The results proceed as below.

**Top Cited Documents**

Table 1 lists the more influential publications relating to machine learning in the supply chain. The most cited document is by Carbonneau et al. (2008), with 200 global citations, followed by Efendigil et al. (2009) with 124 citations and Choy et al. (2003) with 97 citations. Carbonneau et al. (2008) investigates use of sophisticated machine learning methods like neural networks, recurrent neural networks, and support vector machines to anticipate bullwhip-like distortions in demand at the supply chain's tail end. They looked at these strategies next to naive forecasting, trend analysis, moving averages, and linear regression. They determined that while recurrent neural networks and support vector machines perform well, they do not significantly outperform the regression model in terms of prediction accuracy. Similarly, Efendigil et al. (2009) presented a comparative forecasting methodology using neural techniques for uncertain customer demands in a multi-level supply chain (SC) structure.

**Most Cited Journal Sources**

A bibliometric analysis of journals is valuable to give practitioners and researchers opportunities to understand the applications from a broader perspective given the topics of the journal. It also allows researchers to identify appropriate outlets for future work in this area.

Table 2 displays the most cited research sources relating to machine learning in the supply chain. The table indicates that the *International Journal of Production Research* (IJPR) is the most cited source, with 424 citations. This is followed by the *International Journal of Production Economics* (IJPE) with 400 citations, *Journal of Cleaner Production* with 218 citations, the *European Journal of Operations Research* with 211 citations, and *Expert Systems Applications* with 169 citations. An overall observation is that many of these journals have a good mixture of application and methodological developments, supporting the practical usefulness of ML for SCM.

## 3.2 Analysis of Co-Occurrence Keyword

Table 3 presents the most frequent themes discussed regarding machine learning in the supply chain. Author keywords are indications of the article's content or its connection with its research question (Strozzi et al., 2017). Ding et al. (2001) claimed that the co-occurrence of the author keywords could imply that the

**Table 1** Top cited documents

| | Document | DOI | Year | Local citations | Global citations |
|---|---|---|---|---|---|
| 1 | CARBONNEAU R, 2008, EUR J OPER RES | 10.1016/j.ejor.2006.12.004 | 2008 | 13 | 200 |
| 2 | EFENDIGIL T, 2009, EXPERT SYST APPL | 10.1016/j.eswa.2008.08.058 | 2009 | 4 | 124 |
| 3 | CHOY KL, 2003, EXPERT SYST APPL | 10.1016/S0957-4174(02)00151-3 | 2003 | 2 | 97 |
| 4 | FRAGAPANE G, 2022, ANN OPER RES | 10.1007/s10479-020-03526-7 | 2022 | 2 | 68 |
| 5 | ZHU Y, 2019, INT J PROD ECON | 10.1016/j.ijpe.2019.01.032 | 2019 | 4 | 66 |
| 6 | ZHANG XG, 2017, INT J PROD RES | 10.1080/00207543.2016.1203075 | 2017 | 1 | 63 |
| 7 | BAG S, 2021, TECHNOL FORECAST SOC | 10.1016/j.techfore.2020.120420 | 2021 | 3 | 59 |
| 8 | FERREIRA L, 2012, EXPERT SYST APPL | 10.1016/j.eswa.2012.01.068 | 2012 | 0 | 52 |
| 9 | DI VAIO A, 2020, SUSTAINABILITY-BASEL | 10.3390/su12124851 | 2020 | 3 | 48 |
| 10 | CHOD J, 2020, MANAGE SCI | 10.1287/mnsc.2019.3434 | 2020 | 0 | 47 |
| 11 | PONTRANDOLFO P, 2002, INT J PROD RES | 10.1080/00207540110118640 | 2002 | 0 | 42 |
| 12 | SAURABH S, 2021, J CLEAN PROD | 10.1016/j.jclepro.2020.124731 | 2021 | 0 | 38 |
| 13 | RODRIGUEZ-ESPINDOLA O, 2020, INT J PROD RES | 10.1080/00207543.2020.1761565 | 2020 | 4 | 37 |
| 14 | CHOY KL, 2004, INT J COMPUT INTEG M | 10.1080/0951192042000237483 | 2004 | 1 | 37 |
| 15 | DUBEY R, 2021, INT J PROD RES | 10.1080/00207543.2020.1865583 | 2021 | 1 | 33 |
| 16 | PRIORE P, 2019, INT J PROD RES | 10.1080/00207543.2018.1552369 | 2019 | 5 | 28 |
| 17 | CHIEN CF, 2020, INT J PROD RES | 10.1080/00207543.2020.1733125 | 2020 | 3 | 26 |
| 18 | BRINTRUP A, 2020, INT J PROD RES | 10.1080/00207543.2019.1685705 | 2020 | 3 | 26 |
| 19 | CHI HM, 2007, EUR J OPER RES | 10.1016/j.ejor.2006.03.040 | 2007 | 0 | 26 |
| 20 | HARTLEY JL, 2019, BUS HORIZONS | 10.1016/j.bushor.2019.07.006 | 2019 | 0 | 25 |

publications share a common theme. Author keywords were observed to analyze the research trends in machine learning in the supply chain.

The author keyword with the highest occurrences is artificial intelligence with 56 occurrences. This is followed by management with 33 occurrences, machine

**Table 2** Most cited research sources

| Id | Source | Citations |
|---|---|---|
| 1 | Int j prod res | 424 |
| 2 | int j prod econ | 400 |
| 3 | j clean prod | 218 |
| 4 | eur j oper res | 211 |
| 5 | expert syst appl | 169 |
| 6 | comput ind eng | 136 |
| 7 | prod plan control | 118 |
| 8 | manage sci | 113 |
| 9 | ann oper res | 111 |
| 10 | technol forecast soc | 107 |
| 11 | int j inform manage | 102 |
| 12 | sustainability-basel | 101 |
| 13 | j oper manag | 100 |
| 14 | supply chain manag | 99 |
| 15 | int j oper prod man | 97 |
| 16 | j bus res | 93 |
| 17 | int j logist manag | 85 |
| 18 | decis support syst | 79 |
| 19 | mis quart | 68 |
| 20 | int j phys distr log | 67 |

learning with 32 occurrences, framework with 22 occurrences, and model with 21 occurrences. The resulting visualized co-occurrence network appears in Fig. 3.

From the co-occurrence analysis, we can summarize current issues and those that have not been discussed more, proposing these concerns as further study areas. The colors of the clusters represent timelines for the keywords and co-occurrence clusters.

## 3.3 Current Research Concerns

The co-occurrence analysis reveals that many topical issues related to machine learning in the supply chain have been discussed. For instance, the issues of artificial intelligence in the supply chain are key issues in the literature.

For instance, Tirkolaee et al. (2021) state that machine learning in supply chain management is a common form of artificial intelligence. A conceptual framework was developed to determine ML techniques' role in areas such as supplier selection and segmentation, risk prediction in the supply chain, demand and sales forecasting, inventory management, transportation and distribution, sustainable development (SD), and the circular economy (CE).

Similarly, Toorajipour et al. (2021) identified the contributions of AI to SCM through a systematic review of the existing literature. They identified existing and future AI tools that can be used to advance the study and use of SCM. The following

**Table 3** Analysis of keyword occurrences

| Words | Occurrences |
|---|---|
| Artificial intelligence | 56 |
| Management | 33 |
| Machine learning | 32 |
| Framework | 22 |
| Model | 21 |
| Supply chain management | 21 |
| Performance | 17 |
| Impact | 15 |
| Supply chain | 15 |
| Design | 14 |
| Sustainability | 14 |
| Big data | 13 |
| Big data analytics | 13 |
| Information | 12 |
| Neutral networks | 11 |
| Blockchain | 11 |
| Challenges | 9 |
| Selection | 9 |
| System | 9 |
| Future | 8 |

four topics were discussed in further depth: (1) AI methods are currently used in SCM, (2) which AI methods could be used in SCM, (3) which SCM specializations are currently enhanced by AI, and (4) which SCM specializations have great potential to be enhanced by AI. However, it is possible to gain perspective by doing a literature study to assess state of the art. Their research was limited in its ability to go deeply into every sub-field because they were investigating such a broad topic. Each of these relationships and categories can be observed in Fig. 6.

Pournader et al. (2021) presented a research synthesis on AI's role in supply chain management. Through examining the articles' co-citations, we can learn about the bodies of knowledge that make up this field of study. Through development and validation, they created a taxonomy of AI that is now being utilized for analyses to help guide their conversations. There are three distinct areas of study that make up the proposed taxonomy: (a) sensing and interacting, (b) learning, and (c) decision-making. However, their review did not thoroughly explore the technical aspects of AI approaches and their implementation in SCM. Again, observations of these keywords and clusters can be seen in the co-occurrences in Fig. 6.

Dora et al. (2021) developed the rough-SWARA technique to rank and prioritize the critical success factors (CSF) for AI adoption in SCM using the relative importance weights. The study found that the most important CSFs for adopting AI in the food supply chain are technological preparedness, security, privacy, customer happiness, perceived advantages, demand volatility, regulatory compliance, competitive pressure, and information sharing among partners.

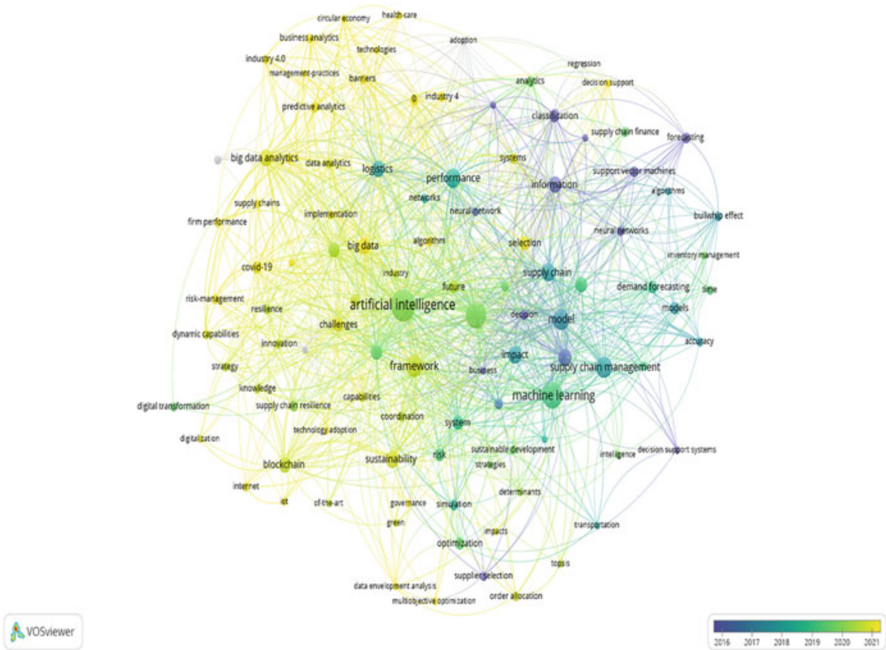


**Fig. 6** Visualization of keyword co-occurrence for SCM and ML topics

Relating to developing frameworks, the co-occurrence analysis reveals relatively many investigations. For example, Sharma et al. (2020) highlighted how agricultural supply chains (ASCs) could benefit from ML techniques leading to ASC sustainability. They proposed an ML application framework for sustainability. To facilitate proactive data-driven decision-making in ASCs, the architecture isolates the function of ML algorithms giving real-time analytic insights. It gives academics, farmers, and government officials a road map for optimizing ASCs for maximum yield and longevity in agricultural production. However, the framework presented is based on the literature review findings, which have not been tested empirically.

Baryannis et al. (2019), based on the combination of AI and supply chain expertise, established a framework for predicting risks in the supply chain. Implementing and deploying the system to anticipate delivery delays in a real-world multi-tier industrial supply chain allowed them to investigate the trade-off between prediction performance and interpretability. The experiments demonstrated the potential for sacrifices in performance when interpretability is prioritized over efficiency.

Regarding models, Malviya et al. (2021) employed a wide range of machine learning models, such as regression, random tree, logistic regression, CHAID, and Auto numeric (ensemble model) classifier models. Allocation centers were optimized using aerial distances and the standard deviation to anticipate demand for transformers in different areas. The above studies show these areas are getting much attention, and there are possible further areas for investigation.

### 3.4 Future Research Areas

Based on the literature review and co-occurrence analysis, we present areas that can be investigated to help the practice and research of ML in SCM progress.

There is a paucity of research into the specific issues of AI for distinct sectors of the supply chain, even though machine learning has been around for the last half-century and has only recently emerged in the SCM domain. Most attempts to apply AI methods to supply chain management have been confined to operational and tactical SCM challenges with a high degree of structure (definition). Some of the many supply chain management (SCM) problems that can be addressed with artificial intelligence (AI) techniques (particularly agent-based systems) include the circular economy, risk management, and the inability to implement machine learning effectively. The inherent complexity and ill-structured nature of many SCM problems, such as outsourcing relationships, supplier relationship management, supply chain coordination, and strategic alliances among supply chain partners, make it either too expensive or too difficult to provide efficient solutions for SCM problems.

Also, although some studies provide insights into ML in SCM, there are still many scientific gaps. Integrating the supply chain is only one area in which AI researchers have become interested. However, more investigation into this issue is required to learn more and enhance the quality of the scientific evidence. Agent-based social simulations (ABSs) with sophisticated complexity management skills could be used for this purpose. Supply chain risk and disaster management are two such areas where ABSs could be useful.

Research efforts frequently center on developing new models, frameworks, methods, and answers. Very few researchers have tried out their innovations in terms of usability, practicality, and generalizability. Real-world practical data might be used to test the offered solutions and close this gap. Moreover, the application of AI to difficult problems and scenarios, the use of various case study designs, and the empirical comparison of research on the same topic can enrich the current body of literature.

Since machine learning pushes traditional models to their limits in terms of accuracy and processing power, it can efficiently optimize and improve network orchestration in ways that would be impossible with human thought alone. Therefore, further investigation into interactive decision-making systems is needed to foster a more in-depth comprehension and, by extension, enhance the capabilities of AI technologies.

Current events with COVID-19 supply chain problems are receiving greater focus. As a result of the widespread disruptions created by the pandemic, there has been a call for a shift away from outsourcing in supply chains and toward increasing investments in domestic production. The complexity and interconnectedness of supply chains present a significant challenge in this regard, making it difficult to map and duplicate complete supply chain processes. Certainly, AI and ML can provide a bright future to ease these kinds of worries by enhancing supply chain transparency and adaptability. The co-occurrence analysis revealed that COVID-19 and machine learning issues had not been investigated much. This provides an important direction for future research.

More research must determine how ML can convert current production systems into data-driven smart manufacturing systems.

Lastly, most of the proposed frameworks were not tested empirically. Hence future studies may be conducted to validate these frameworks empirically with comprehensive comparative analyses.

### 3.5 Managerial Implications

This chapter and the topic provide many interesting implications for managers.

To begin, picking the right algorithm is profoundly impacted by the specifics of the industry, as well as the nature and quantity of the data at hand. Managers should exercise caution when implementing new algorithms and ensure that the chosen method is compatible with the data type and can be easily interpreted within the context of the target industry. Some sectors are already ahead in applying ML methods to supply chain management. For instance, the study and implementation of renewable energy supply chains have much-untapped potential. This is a field with a wealth of explorable information for researchers. There is a significant void in using mathematical optimizing models and machine learning capabilities in SC design and optimization; managers may benefit from both established and novel methods for gaining insight and making choices.

Considering the high cost of investment in digital technologies and developing ML capabilities, investments in digital technologies and data gathering will likely occur – making investments in ML training and development seems like a necessary and important step for ML in SCM organizational application. Here is an example. In emerging market agricultural supply chains, many farmers do not have access to the Internet, mobile phones, or new technologies and data interpretation training. Advisories must be developed to assist the farmers in understanding the information and recommend suitable mechanisms to improve farm productivity; whether or not they need to understand ML is an important aspect of the diffusion of ML in SCM.

Connecting farmers in rural areas requires policymakers to think ahead and establish plans to cooperate with governments and technology businesses to subsidize the price of data collection hardware and software. Widespread adoption of these farming practices requires widespread and cutting-edge education. Clearly, similar opportunities exist across many industries, policymakers, and major organizations, and their supply chains need to be aware of the capabilities of ML for both small and larger companies across industries and product families.

## 4 Conclusion

This chapter provides an overview of machine learning in the supply chain. It specifically discusses ML tools, ML tools used in the supply chain, ML applications in the supply chain, and challenges of ML in the supply chain. Significantly, it outlines crucial steps that serve as a roadmap for building a predictive model framework (Fig. 5) and outlines key machine learning algorithms for specific supply chain tasks (Fig. 4). To explore the current state of machine learning (ML) research in the supply chain, we performed a bibliometric review of 131 research articles.

The major issues discussed relate to AI, machine learning, framework development, sustainability, supply chain, and system design. The chapter also reveals research opportunities relating to COVID-19, empirical testing of frameworks, risks management issues, and circular economy, among others.

Considering the high cost of investment in digital technologies and developing ML capabilities, companies, supply chain partners, and policymakers may need to subsidize investments in digital technologies and tools and make them more affordable to be used widely – open access tools, which we identified could help in this area.

Overall, ML in SCM is practical and feasible and can provide great contributions and insights. The chapter provides the reader, whether they are new researchers, advanced scholars, or practitioners, a comprehensive overview of the field.

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# Blockchain and Supply Chain Management: Applications and Implications

Soode Vaezinejad and Mahtab Kouhizadeh

## Contents




**Abstract**

Blockchain has shown promise to transform supply chains due to its unique combination of features such as decentralized networks, security, smart contracts, and auditability. Numerous supply chains have examined and implemented blockchain to ease global supply chain issues such as lack of traceability and reliability and poor information management. Blockchain can address sustainability concerns such as data manipulation and fabrication, poor environmental safety, and product provenance. Despite the potential, several barriers for blockchain adoption exist. This chapter provides an overview of blockchain and its underlying features. We highlight the potential application of blockchain for supply chain management and sustainability and propose a framework that can guide successful adoption of this technology. We introduce a few use cases from different industries that adopted blockchain for their supply chain



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operations. This chapter presents several blockchain barriers that impede successful adoption of this technology. A lack of theoretical perspective provides an untapped potential for research and further practical development. We explore blockchain adoption through various lenses and provide managerial and theoretical insights for future development.

**Keywords**

Supply chain management · Blockchain · Framework · Application · Implication

## 1 Introduction

Globalization and technological advancement have unveiled many opportunities and captured the attention of supply chain researchers and managers in recent years. Global supply chain management contributes to complex supply chain structures due to the many stakeholders involved in various countries and locations (Wang et al., 2019b). More than 60% of world trade occurs with multinational companies (Gao & Zhao, 2015). Globalization is coupled with positive and negative results. The positive side highlights increased efficiency and cost-saving opportunities for supply chain operations and processes. However, the opposite side of the coin is more vulnerability of supply chain management to unexpected disruptions and traceability issues. Other challenges may include shifting duties, exchange rates, taxes, trade laws, different local cultures, and differing worker skills. In addition, some supply chains contain numerous inefficient and paper-based processes, which create delays and disrupt effective flows of goods and information (Wang et al., 2019a).

The COVID-19 pandemic was one of the most recent worldwide health crises that adversely affected global supply chains and caused massive shortages of medical supplies, food, and other essential commodities. According to the European Parliamentary Research Service, blockchain is one of the key technologies that has been identified to combat the negative effects of COVID-19 and similar disruptions in supply chains (Kritikos, 2020). Blockchain can unlock numerous opportunities for supply chain information management, offering improved reliability, traceability, and resiliency.

Blockchain is defined as digital ledgers that record transactions using a distributed and decentralized structure. Records on blockchain ledgers are secure, traceable, authenticated, and updated with the most recent data in real-time. Among new technologies, blockchain can manage cooperation among unknown parties, providing trust and dependability (Chang & Chen, 2020). Blockchain capabilities in business processes optimization can effectively improve collaborative and data integration (Parmentola et al., 2021). Blockchain can play a vital role in sharing data, transferring value, and increasing visibility (Chang & Chen, 2020). This can increase the efficiency and effectivity of the entire supply chain.

Effective supply chain management requires an urgent need for reliable and transparent flows of information. Blockchain can provide a platform for information transparency, traceability, and reliability to detect and prevent detrimental activities such as freight theft, replacement, or adulteration during transportation, and illegal or expired commodity transactions (Pundir et al., 2019). Blockchain traceability can further increase customer satisfaction by providing the opportunity to track and trace their merchandise through the entire supply chain (Saberi et al., 2019).

To address globalization and complexity issues, supply chain companies are moving toward integrating technological advancements, particularly blockchain (Seyedghorban et al., 2020). Blockchain can increase the visibility, transparency, speed, and accuracy of data shared among suppliers, manufacturers, and customers – multiple stakeholders in the supply chain. The automated flow of information removes the need for manual entry and consequently human errors, which results in a more efficient system (Korpela et al., 2017).

Digital supply chain management is defined as a data-driven, smart, globally connected mechanisms to manage supply chain processes with many innovative technologies (Büyüközkan Feyzioğlu & Gocer, 2018; Seyedghorban et al., 2020). Examples of supply chain digitalization can be radio frequency identification (RFID), big data, cloud computing, internet of things, artificial intelligence (Seyedghorban et al., 2020), and blockchain (Nakamoto, 2008).

Blockchain can effectively support supply chain management. Supply chains usually consist of numerous companies and stakeholders who can be involved in a product chain and record transactions and share information. This situation can make it exceedingly difficult to trace information from multifaceted networks with many parties from downstream to upstream supply chains. Blockchain can address this issue and collect and integrate information in real-time.

Blockchain can decrease operation lead times, increase competitive advantage, and improve flexibility in a supply chain (Korpela et al., 2017). Despite the advantages, blockchain has some drawbacks such as high adoption cost, technology immaturity (Sarkis et al., 2020), difficulty in implementation (Mishra & Venkatesan, 2021). Blockchain consumes a substantial amount of energy for its computation and operations. This can negatively affect the environment (Sarkis et al., 2020), while at the same time it can be beneficial for the environment by collecting, saving, and monitoring related data to wastes and pollution production and environmental degradation (Parmentola et al., 2021).

This chapter provides an overview of the potential of blockchain for supply chain management, proposes a framework for successful adoption, and indicates the current and future managerial and theoretical concerns. The structure of this chapter includes a background of the current literature of blockchain and its underlying features. We then propose a framework for adoption of blockchain for supply chain management. The structure also includes sections on the application of blockchain to promote sustainability, case studies of blockchain for supply chain management, and the potential challenges and limitations. Managerial and theoretical analysis and directions for future studies conclude this chapter.

## 2 Blockchain: Definition and Features

Blockchain was originally introduced as a platform to support Bitcoin, a digital cryptocurrency (Nakamoto, 2008). Although the initial application of blockchain was in finance through cryptocurrencies, a wide variety of markets and industries have examined this technology to take advantage of its unique features and benefits. These industries including healthcare management (Hussien et al., 2021), the energy sector (Teng et al., 2021), and e-government (Kassen, 2022), as well as supply chain management (Lim et al., 2021).

Blockchain is defined as distributed digital ledgers of transactions that have been executed and shared among a network of participants (Crosby et al., 2016). Blockchain is considered as part of the fourth industrial revolution (Industry 4.0) and is expected to promote economic development in the world. Blockchain is developed on a peer-to-peer network in which parties can transfer commodities, services, and data directly without the need for any central organization or intermediary to verify and approve the transactions (Parmentola et al., 2021). Blockchain structure relies on blocks that are recorded in chronological chains. Blockchain ledgers record transactions and provide an opportunity to track transactions back to their origins.

In the supply chain context, blockchain transactions can reflect the key dimensions of a product such as nature, quality, quantity, location, and ownership (Saberi et al., 2019) to guarantee the authenticity and legitimacy of the product (Wang et al., 2019a) in its journey from production to delivery. The current consumer priorities have become centered more on transparency of the production process and product provenance. A recent study shows that over 90% of food product consumers consider transparency as the key factor in their purchase (Laaper et al., 2017). Blockchain as an effective solution can provide needed visibility for both end consumers and companies (Laaper et al., 2017). Blockchain has multiple key features that differentiate it from other technologies. These features include decentralization, security, smart contract, and auditability. Each of these features is now overviewed.

*Decentralization:* Blockchain uses a decentralized structure for recording and storing information. There is no central database in the blockchain structure. The network is managed by its participants (Hackius & Petersen, 2017). Every member has the same copy of the recorded information, which will create trust among members without the need for a trustworthy intermediary (Hackius & Petersen, 2017). The decentralized structure prevents the system from bribery, hacking, crashing, and corruption. Each network participant holds the same copy of ledgers, which increases transparency, trust, and data reliability.

*Security:* Security of blockchain stems from encrypted ledgers. In a blockchain network, every member has a private key with a personal digital signature (Kouhizadeh & Sarkis, 2020). Data is stored in a set of blocks that are linked with cryptographic protocols (Biswas & Gupta, 2019) and is secure, which prevents data manipulation (Zhu et al., 2022). Once a transaction is verified through a predefined network verification algorithm, it is almost impossible to change or remove it

(Biswas & Gupta, 2019; Öztürk & Yildizbaşi, 2020). This feature is called immutability, which ensures that a transaction cannot be altered without the consensus of blockchain participants (Kouhizadeh & Sarkis, 2018). This feature boosts security and reliability of data. Decentralization can further enhance the security of a blockchain network since data is not stored in a single location or database (Kouhizadeh & Sarkis, 2020).

*Smart contracts:* One of the most crucial features of blockchain that contributes to the automation of actions and processes is smart contracts. A smart contract has agreed upon rules and conditions of an agreement among users on a digital platform (Kouhizadeh & Sarkis, 2020). After a transaction is recorded, a smart contract that stores rules and policies for each transaction automatically executes the related codes (Saberi et al., 2019). If the contractual term is met, the transaction will be added to the blockchain and saved in a network of digital blocks (Crosby et al. 2016).

*Auditability:* In a blockchain structure, each transaction is verified and executed using predefined consensus mechanisms. The consensus mechanisms are defined and agreed upon by the entire network. Each participant can review and assess a transaction and ensure the validity and authenticity of the transaction. Manual verification processes may take weeks, while blockchain can decrease the time of verification process through its smart contract and distributed ledgers (Laaper et al., 2017).

Blockchains are classified into public-open, private-closed, and consortium-federated. In a public blockchain, anyone can join the network, access the ledgers and record, and verify transactions. A public blockchain requires a prominent level of security and reliability (Kouhizadeh & Sarkis, 2018). In a private blockchain, only known and authenticated users can join the network and enjoy the features. A combination of public and private blockchains is called federated blockchains. Federated blockchains can contain public ledgers which are open to the public and, at the same time, private ledgers that only specific users can access and use.

Due to the importance of maintaining privacy and vital data, a desirable blockchain system for the supply chain can be private and closed with known and authenticated users (Kouhizadeh et al., 2020). Four main entities can play roles in a blockchain implementation for supply chain management: (1) registrars who register participants and define unique identities for users, (2) standard organizations who specify standard plans, policies, and requirements for using blockchain, (3) certifiers who access and verify blockchain transactions, and (4) supply chain participants who record and assess supply chain transactions, such as manufacturers, distributors, etc. (Saberi et al., 2019).

## 3 Current Concerns

Blockchain has the potential to revolutionize supply chain management and sustainability. However, its adoption is a slow go. In this section, we propose a framework for successful blockchain adoption and discuss the main barriers that prevent its adoption. We continue this section by reviewing blockchain benefits for sustainable supply chain management given its promising features. We then emphasize its potential by introducing a few use cases that adopted blockchain for their operations in supply chains.

### 3.1 Blockchain-Enabled Supply Chain Management: A Framework

To enable the successful implementation of blockchain for supply chain management, we introduce a framework that highlights the contributing factors for blockchain adoption in supply chain management. Figure 1 presents the framework in the form of a house, which is adapted from the lean supply chain management framework developed by Anand & Kodali (2008). In this study, the proposed framework is built on a solid foundation that includes requirements for the successful adoption of blockchain. Blockchain is a disruptive technology, and its successful implementation requires readiness for change, which is a multidimensional, multilevel, and multifaceted problem (Wang et al., 2020). The foundation of the proposed framework includes individual readiness, organizational readiness, and environmental readiness for blockchain adoption.

*Individual readiness* is grounded in the concept of unfreezing proposed by Lewin back in the 1940s (Lewin, 1946). The unfreezing concept includes processes that affect organizational member mindsets towards change to perceive it as necessary and likely to be a successful project. In many previous studies, the unfreezing stage has been considered as a warm-up or defrosting activity, which can prevent many

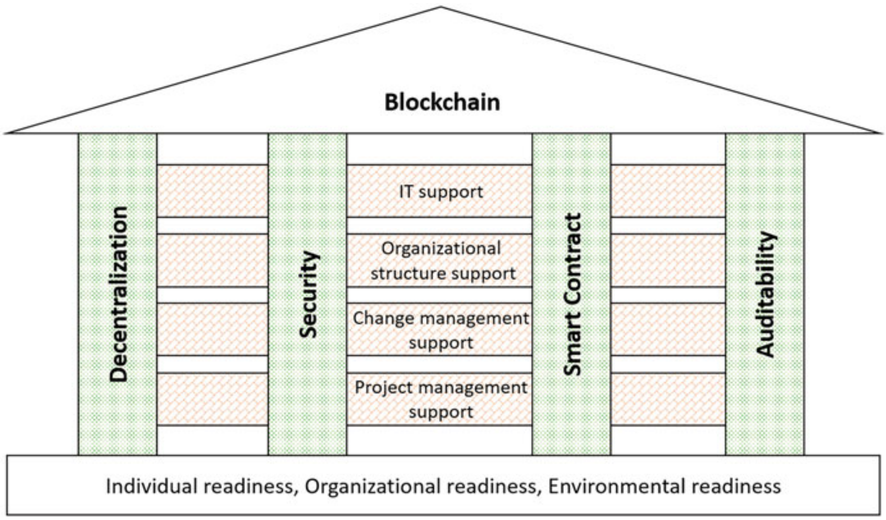


**Fig. 1** Blockchain adoption in supply chain management: A framework

failures in the change process (Choi & Ruona, 2011). Blockchain can change the current processes and require preparation and new skills and expertise.

*Organizational readiness* refers to the extent to which organizational members are prepared for the change mentally and behaviorally (Weiner et al., 2008). Organizations with an elevated level of readiness invest more in the change effort, persist greater against obstacles, and are more likely to succeed in change implementation (Weiner et al., 2008). Top management support is vital for the successful implementation of blockchain projects which includes activities such as providing financial resources, devoting time to managing the project, facilitating the project implementation processes, and solving possible conflicts. The lack of management commitment and support, such as challenges in resource allocations and financial decisions, can impede successful adoption (Kouhizadeh et al., 2021). The McKinsey influence model contains four key building blocks of change affect employee mindsets and behaviors. Change stands the most chance of success if organizations focus on these four key actions: fostering understanding and conviction, reinforcing with formal mechanisms, developing talent and skills, and role modeling (Basford & Schaninger, 2016). Top managers as role models can show their commitment to blockchain adoption as a new change in organizations to get their employees' support in the change process.

Given the novelty of blockchain, there are few experienced and trained people who are professionals in supply chains and blockchain at the same time. Organizations need to plan to employ skilled workforce and train their current employees. Blockchain awareness and organizational readiness can decrease resistance to change and guarantee successful implementation (Kouhizadeh et al., 2021). Financial resources readiness is another organizational factor that plays role in blockchain adoption. Blockchain implementation requires financial resources to adopt, maintain, and monitor the entire supply chain networks. Organizational culture is another strategic factor that can contribute to blockchain adoption. Blockchain as a disruptive technology may change current organizational cultures in terms of work culture, values, and organizational behaviors and leads to resistance to change and hesitation to adopt if no preparation is taken in advance (Saberi et al., 2019).

*Environmental readiness* includes activities that lead to increasing the readiness of external stakeholders, customers, and governments in successful blockchain adoption. Blockchain is not a single entity-held technology. All stakeholders should be well prepared and involved in blockchain implementation and take their own responsibility in the process. Different forms of stakeholder engagement such as cooperation, collaboration, and coordination are crucial for blockchain adoption since they lead to finding new opportunities and solving problems together during and after blockchain implementation (Balasubramanian et al., 2021).

Interorganizational culture readiness is another facet of environmental readiness to be considered. Cultural and geographical differences across supply chains can hamper blockchain implementation (Kouhizadeh et al., 2021). The attitude to assume information as a valuable resource that should be kept inside the organization to maintain organizational competitiveness is rooted in organizational cultures. Supply chain partners should be guaranteed security within blockchains to increase their willingness to share information. Some organizations may hesitate to share information, which casts a shadow on the successful implementation of this technology (Saberi et al., 2019). Therefore, organizations should collaborate to take full advantage of this modern technology. Governmental policies and regulations are also needed to support blockchain adoption. However, there is still a lack of blockchain-supported regulations (Kouhizadeh et al., 2021) and a lack of financial governmental aid for the use of blockchain in supply chains (Öztürk & Yildizbaşi, 2020).

Once various activities are executed to increase diverse types of readiness for blockchain adoption, there is still a major concern on whether the product or service offered by the organization is the customer's best choice. Customer readiness is another important factor that should be considered in the adoption process (Balasubramanian et al., 2021). Appropriate marketing activities should be planned and executed to increase customer excitement and readiness to demand and support this technology.

In the proposed framework (see Fig. 1), four key pillars are placed over the foundation of the house. These pillars consist of decentralization, security, smart contracts, and auditability. Each pillar denotes a feature of blockchain. To support the pillars, some tools and techniques are identified as bricks to strengthen the house. Due to blockchain complexity and advanced features, the current technological systems are not suitable to support the requirements of blockchain adoption. This is one of the key reasons for the low blockchain adoption rate. Blockchain requires ready-to-use hardware and software to be sustained (Kouhizadeh et al., 2021). Besides the need for accessibility to IT (Information Technology) infrastructure for all members across supply chains, compatibility of the different blockchain platforms with each other is another concern in blockchain-based supply chain management. Hence, appropriate IT infrastructure will help blockchain's successful implementation (Öztürk & Yildizbaşi, 2020; Kouhizadeh et al., 2021).

Organizational structure should support blockchain adoption (Öztürk & Yildizbaşi, 2020). Organizations with hierarchical and bureaucratic structures and strict managerial control may encounter difficulties in the implementation of blockchain. The reason lies in the fact that hierarchical organizations respond slowly to the fast-changing environment due to the increased bureaucracy and many authority levels. Alternatively, horizontal or flat organizational structures with open cultures can improve coordination and speed of implementing innovations such as blockchain (Kaal et al., 2018). Establishing some organizational innovation units such as research and development units in the structure of organizations can increase the speed and spread of blockchain adoption by providing state-of-the-art information for the whole organization.

In addition to IT support and organizational structure support, change management and project management can make the house stronger. Before, during, and after blockchain adoption, many difficulties and problems may arise. These problems should be addressed immediately. Otherwise, they may decrease the speed of adoption or even in some cases hinder the change. Change management is defined as a structured approach to help individuals, teams, and organizations to transition from a current state to the desired state (Adam, 2022).

According to Lewin's three-stages of change management, change includes unfreezing, changing process, and refreezing (Lewin, 1946). The unfreezing stage involves evaluation of the current state, investigating the necessity of change and identifying the obstacles (Adam, 2022). In the proposed framework, we assume that the unfreezing stage is an element of the house foundation and is a preparatory stage.

The change process phase consists of necessary activities to accomplish the change such as planning for change, communicating with stakeholders, and training the employees (Adam, 2022). The refreezing phase consists of activities that aim to ensure change is sustained and the outcomes become part of organizations. Change management can help to increase the awareness of human resources, define a bright and clear future after the change, decrease resistance, sustain change after implementation, and prevent organizations' failure to gain change.

Project management is also needed for successful blockchain adoption. Project management is defined as "the disciplined application of knowledge, skills, tools, and techniques to project activities to meet the project requirements" (Hornstein, 2015). Accurate planning, risk recognition, financial and human resource management, monitoring the implementation process, and effective communication with stakeholders are part of project management. Change management and project management use different terminologies and methods to address the change implementation process, but they are complementary (Hornstein, 2015) and supportive in the successful implementation of various projects including blockchain adoption and implementation project.

## 3.2 Blockchain Challenges and Limitations

Although blockchain can benefit and transform traditional supply chains, the blockchain adoption speed is still too low among supply chain companies. The investment in blockchain is decreasing, with some exceptions, which indicates the existence of the barriers (Kouhizadeh et al., 2021). Blockchain implementation is a challenging task and requires a collaborative effort among the various stakeholders in a supply chain (Biswas & Gupta, 2019). It is equally crucial to make managers and practitioners aware of blockchain adoption barriers to plan for successful adoption. Lack of awareness about blockchain barriers can result in a low rate of adoption (Aich et al., 2019).

Blockchain may face various barriers and challenges. It is critical to identify the barriers and plan to overcome them. One of the major barriers can be associated with the negative effect that blockchain has on the environment. Blockchain implementation increases energy consumption due to its heavy computer calculation (Astarita et al., 2020). Another negative effect of blockchain on the environment is related to the need to create large buildings and infrastructures to host the blockchain server for running operations (Parmentola et al., 2021).

Lack of regulation and lack of sufficient practical experiments about smart contract applications can also increase the risk of blockchain implementation (Astarita et al., 2020) and decrease the willingness to adopt it. Another reason that may hinder the successful implementation of blockchain is human resource barriers. Due to the fear of being fired, lack of necessary competence to align with an innovative technology (Salah et al., 2020), and lack of knowledge about the new technology's application and advantages (Astarita et al., 2020), employees may resist the new changes. The lack of skilled experts in blockchain to develop and manage blockchain solutions (Mishra & Venkatesan, 2021) is one of the most important human resource barriers. Various categories of blockchain adoption barriers in supply chain management that have been identified in the previous studies are presented in Table 1.

**Table 1** Blockchain adoption barriers and challenges

| References | Blockchain adoption barriers and challenges categories |
|---|---|
| Saberi et al. (2019) | Intraorganizational barriers<br>Interorganizational barriers<br>System-related barriers<br>External barriers |
| Wang et al. (2019a) | Organizational and user-related challenges<br>Technological challenges<br>Operational challenges |
| Ghode et al. (2020) | Interorganizational trust<br>Governance<br>Transparency<br>Immutability<br>Exchange of information<br>Selection of products<br>Societal change<br>Behavior of participants |
| Öztürk and Yildizbaşi (2020) | Technological and security barriers<br>Financial and human resources barriers<br>Organizational and individual barriers<br>Social and environmental barriers |
| Kouhizadeh et al. (2021) | Technological barriers<br>Organizational barriers<br>Environmental barriers – Supply chain interorganizational view<br>Environmental barriers – The external view |
| Vafadarnikjoo et al. (2021) | Transaction-level uncertainties<br>Usage in the underground economy<br>Challenges in scalability<br>Privacy risks<br>Managerial commitment |

### 3.3 Blockchain Applications for Sustainable Supply Chain Management

Blockchain can support sustainable supply chain management. Sustainable supply chain management involves integrating economic, social, and environmental considerations into the complete supply chain processes from the original suppliers to the end customers (Seuring & Müller, 2008).

The promising features of blockchain such as immutability, transparency, traceability, and reliability can strengthen the triple bottom line of sustainability. In terms of economic sustainability, blockchain can eliminate intermediaries that results in involving fewer tiers in a transaction. Blockchain can increase the safety and authenticity of data and reduce the cost of preventing data manipulation. The data protection capability of blockchain can build social sustainability since it prevents corrupt entities from seizing people's assets.

Every transaction is recorded on blockchain ledgers with the reliable information regarding the complete history of the transaction, the involved actors, and the time of transaction. The traceability features of blockchain allow customers to trace the history of a product and are another step toward human rights and social sustainability improvement. Blockchain can contribute to environmental sustainability. Blockchain can help reduce carbon emission by measuring the carbon footprint of product and improve recycling by offering financial rewards in the form of cryptographic tokens (Saberi et al., 2019).

Blockchain can support sustainability in each stage of supply chain management from upstream to downstream. The first step to ensure the sustainability of supply chains is through supplier selection and development. Blockchain can be beneficial for this critical activity by providing accurate data about supplier and subsupplier environmental performance. This shared reliable information provides an opportunity for the whole supply chain to carefully select sustainable suppliers. Blockchain application is not limited to supplier selection, since it can reinforce supplier performance through recording, documenting, monitoring their performance, and implementing supplier development and training programs (Kouhizadeh & Sarkis, 2018).

Blockchain can benefit material purchasing, warehousing, and inbound logistics. By recording historical data of materials and products such as the origins, quantity, quality, and owners, the sustainable journey of resources can be traceable and auditable. The transparent and accurate flow of information provided by blockchain can enhance material warehousing operations and make scheduling and planning more efficient.

Taking transportation into consideration, there is a huge need for tracing transportation activities due to their significant effects on the environment by greenhouse gas emissions and other environmental burden. Blockchain can trace transportation information and vehicle performance to detect unsustainable practices and align driver behavior with sustainable values through utilizing cryptocurrency tokens as an example (Kouhizadeh & Sarkis, 2018).

The next important stage in supply chain management is production processes. Recording life-cycle analysis data, evaluating sustainability performance, and tracking data related to eco-design of products are some exemplary applications of blockchain in production (Kouhizadeh & Sarkis, 2018).

Toward the downstream supply chain, blockchain can improve outbound logistics from a sustainability point of view. Blockchain can facilitate access to an accurate and up-to-date flow of information, and the possibility to use cryptographic tokens can prevent vehicles from exceeding freight capacity and modify the anti-sustainability behavioral habits of vehicles drivers. Smart packaging as part of outbound logistics can record reliable information on blockchain regarding the recyclability and the end-of-life cycle processes.

Smart packages enable monitoring packaging materials through the life cycle and increase recycling and reusability of the materials. Blockchain can further facilitate reverse logistics by providing accurate information on the owner and location of the used materials to be returned to the consumption cycle (Kouhizadeh & Sarkis, 2018).

## 4 Use Cases for Blockchain-Enabled Supply Chain Management

Blockchain includes several capabilities such as security, immutability, real-time tracking, and transparency. These capabilities can be beneficial for a wide variety of industries in the entire supply chain (Kouhizadeh et al., 2020). Figure 2 summarizes blockchain adoption in different industries in the supply chain.

Within the manufacturing sector, the automotive industry has an urgent need to implement many Industry 4.0 technologies due to its complexity, technological

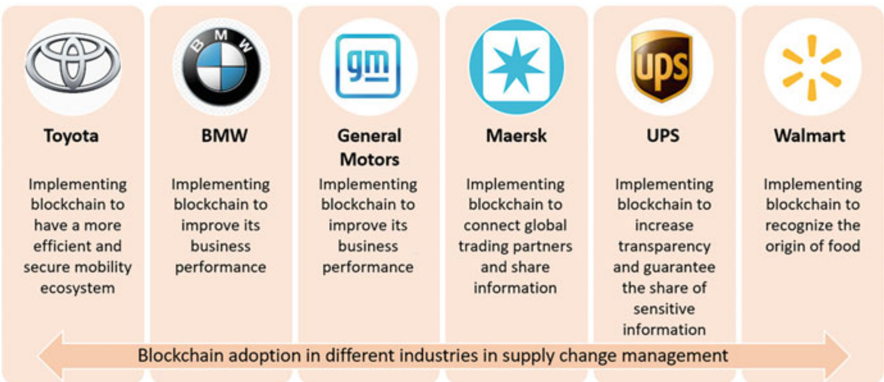


**Fig. 2** Blockchain use cases for supply chain management

advancement (Fraga-Lamas & Fernández-Caramés, 2019), and wide-ranging ecosystem (Sharma et al., 2018). The power of blockchain can solve many problems in the automotive industry such as using counterfeit spare products (Sharma et al., 2018). In this regard, since 2017 blockchain has been implemented in Toyota's supply chain network, which results in a more efficient and secure mobility ecosystem (Kouhizadeh et al., 2020). Other leading automotive companies such as General Motors and BMW have also applied blockchain to improve their business performance (Kouhizadeh et al., 2020). The giant automotive manufacturers have formed several consortiums to regulate blockchain implementation in the automotive industry (Powell et al., 2021).

Blockchain can greatly affect the performance of the transportation industry. Transportation cost is a major concern of the supply chain and logistics sector, and it constitutes a considerable amount of total logistics cost. Also, due to the growth in globalization, transferring goods in a multiagent supply chain is complicated. The transportation processes are not efficient and still involve extensive paperwork which results in loss, fraud, and tampering (Hackius & Petersen, 2017). To overcome these problems, a sufficient and accurate information system is vital (Astarita et al., 2020). Blockchain can guarantee the reliable flow of information across the whole ecosystem (Kouhizadeh et al., 2020) and facilitate tracing the products through their transportation journey (Astarita et al., 2020).

Maersk, one of the largest container shipping companies and vessel operators in the world, joined IBM to implement blockchain to benefit from blockchain advantages and tackle transportation inefficiencies (Hackius & Petersen, 2017). Using blockchain, Maersk connected a wide variety of global trading partners such as shippers, freight forwarders, customs, ports, and shared the most updated, detailed, and accurate information with its network. All members can access real-time information about container condition, temperature, weight, location, etc. (Kouhizadeh et al., 2020).

Another transportation cooperative use case utilized blockchain capabilities between UPS, which is one of the world's largest shipping carriers, and Inxeption, which is an e-commerce tech firm. They developed a blockchain-based platform for business-to-business sales, which increases transparency and guarantees the share of sensitive information like contract-specific pricing and rates among the authorized members (Kouhizadeh et al., 2020).

Blockchain can effectively support the retail industry. Blockchain can help companies manage product inventories more accurately and efficiently and improve their offered services to customers. Blockchain acts as an enabler to assist retailers to enhance their business processes and strengthen their business growth. For example, Walmart collaborated with IBM to implement blockchain in 2016. The goal of this collaboration was to use blockchain capabilities in tracing food back to the origin. When a foodborne disease outbreak occurs, Walmart can immediately identify the origin of the disease since all related information in the food supply chain management such as the origin, involved actors and factories, expiration date, and transportation processes is stored in blockchain ledgers (Hackius & Petersen, 2017).

## 5 Emergent Concerns

In this section, managerial, practical, and theoretical insights are presented. We describe the issues that help organizations and managers to adopt blockchain in supply chains. The research implications highlight the critical outcomes of the review and present future research studies.

### 5.1 Managerial Issues and Directions

Managers and organizations need to understand the applications of blockchain in supporting their businesses and supply chains. Blockchain can improve the supply chain performance by reducing the paperwork, recognizing counterfeit products, easing provenance tracking, and facilitating internet of things operations (Hackius & Petersen, 2017). Blockchain can provide a platform to support transaction visibility and traceability, remove intermediaries, build data security, and use smart contracts to elevate automation and flexibility for a large network of different parties and stakeholders (Wang et al., 2019a; Laaper et al., 2017).

The traceability capability of blockchain is more instrumental for industries in which tracking a product is critical such as food, pharmaceutical, and luxury products industries. In these industries, tracking is essential, since the customers can be aware of product status throughout the entire supply chain which increases their level of satisfaction and builds or maintains customer loyalty. In the healthcare industry, the traceability capability of blockchain can enhance patient safety by ensuring whether they received the original drugs (Hackius & Petersen, 2017). Tracking is also valuable for the food industry since it prevents product loss, breakdown, expiration, and keeping conditions.

Fake commodities result in a large amount of profit loss in trade annually (Laaper et al., 2017). Blockchain can create visibility of information for users in the digital platform in a way that each user has access to updated and real-time information. This will decrease communication costs and errors (Laaper et al., 2017). Enhanced transparency and traceability created by blockchain can improve supply chain processes (Kouhizadeh & Sarkis, 2020).

Despite the potential, investments in blockchain need to be carefully examined, due to the existence of barriers and challenges. Sufficient awareness for managers and practitioners is vital to tackle blockchain adoption barriers. Blockchain barriers can range from the lack of management commitment support to energy-intensive operations of blockchain to the lack of regulations that support blockchain adoption.

Although several use cases have been reported, they are mainly in the pilot stage, far from full adoption. The uncertainties about the actual outcomes of blockchain implementation and the shortage of literature on the postimplementation data can contribute to a low adoption rate and make individuals and organizations hesitant for broader adoption. Formal data analysis and theory development can alleviate the risks and uncertainties of blockchain adoption.

## 5.2 Practical Implications

The decentralized structure of blockchain makes it a promising solution for operating in a multistakeholder setting like supply chains (Bai et al., 2021). Blockchain enables a wide variety of members to collaborate in a peer-to-peer network without the need for a trusted intermediary. What synchronizes supply chain partners on this trustless network is embedded in smart contracts. For successful blockchain adoption, supply chain partners need to agree upon data sharing, confidentiality, and network governance (Agi & Jha, 2022), which can be challenging tasks. For example, to facilitate blockchain adoption in supply chains, at least one organization is required to act as the network owner to manage the probable conflicts. Not only is finding this central authority difficult but also this can cast a shadow on the blockchain decentralization feature (Hunt et al., 2021). Another source of conflict among supply chain partners can be data sharing issues. Blockchain gives the ownership right to members. This may allow supply chain partners not to share their critical data, which can affect data availability in the network. Although to increase involvement in the network, monetary and nonmonetary mechanisms can be beneficial, more research is needed to address these problems.

Blockchain can create a paradigm shift in collaboration between supply chain partners. However, it is not a one-size-fits-all solution. For highly customized transactions, blockchain may not be the optimal option due to the need for verifying each transaction. In addition, as discussed in this chapter, the high cost of adoption and its negative impact on environments can make organizations hesitant to adopt this technology. Supply chain partners may also face some problems after blockchain implementation such as high blockchain maintenance costs and training costs. According to the Deloitte report, the mortality rate of blockchain projects developed by organizations is near 85% (Deloitte, 2017), which reveals the necessity of conducting a cost-benefit analysis before blockchain adoption.

## 5.3 Theoretical Issues and Directions

Creating and advancing theory is a key to expanding any scientific field and providing insights into any phenomena (Treiblmaier, 2018). Blockchain is a novel technology, and the theoretical underpinning is limited to blockchain studies in supply chain management. In this section, we review two groups of research that have used theories in blockchain literature. The first group includes those studies that focus on the benefits of blockchain for supply chain management through theoretical lenses. The second group contains those studies that theoretically examine the process of blockchain adoption in supply chain management.

The first group of research denotes the studies that address how blockchain as a disruptive technology can benefit supply chain management from different theoretical perspectives. Table 2 presents the theories, definitions, level of analysis, the supply chain challenges, and the application of blockchain through the theoretical lenses. These studies have examined the popular supply chain management theories

**Table 2** Blockchain benefits in supply chain through the theoretical lenses

| Theory | Definition | Level | What are the current challenges in supply chain management? | How can blockchain improve supply chain management? |
|---|---|---|---|---|
| Principal-agent theory | Principal agent theory occurs when one party (the principal) delegates authority to another party (the agent) to control or manage certain tasks (Fayezi et al., 2012). | Organizational and individual level | The principal-agent problems arise when:<br>The principal has lack awareness of the task nature done by the agent<br>The principal has a lack of awareness of the agent's capabilities.<br>The principal has a lack of awareness of the agent capabilities to complete the task.<br>The principal has a lack of awareness of and difficulty on how to select the right agent to build a trustable relationship. | Principal-agent challenges mostly occur due to information asymmetry which can be omitted or alleviated by smart contracts (Treiblmaier, 2018). Thus, blockchain can provide the proper flow of information to decrease the unbalanced power of one side and improve the interaction between two sides. |
| Transaction cost theory | Transaction cost theory refers to the required effort and cost for two parties, for example, supplier and manufacturer, to complete an activity (Sarkis et al., 2011). | Organizational level | There is a lack of information access to fully understand the transaction (Sarkis et al., 2011).<br>Under uncertainty, both parties need to spend considerable transaction costs related to ongoing negotiations on specifications and prices (Grover & Malhotra, 2003).<br>Due to the nature of opportunistic behavior hidden in the theory or shirking the agreed responsibilities from either side, monitoring and safeguarding behaviors are needed which increase the transaction cost (Grover & Malhotra, 2003). | Blockchain can optimize transaction costs (Treiblmaier, 2018) by reducing search and information cost to understand buyer or supplier reputation as an example, reducing negotiation and agreement cost, and reducing after-contract control due to the imitability feature of blockchain in storing records (Schmidt & Wagner, 2019). |

| | | | | |
|---|---|---|---|---|
| Resource-based view | Resource-based view refers to valuable, rare, difficult to imitate, and nonsubstitutable resources (Sarkis et al., 2011) and their capabilities that an organization already must create competitive advantages (Nandi et al., 2020). | Organizational level | Valuable and rare resources may not necessarily build competitive advantages. Other factors such as the global economy, rules, and regulations may also have a profound impact under some circumstances. | Blockchain helps to create and improve collaboration capabilities between partners by building long-term strategic relationships between partners. This results in jointly dealing with market demand and sharing market risks (Nandi et al., 2020). Hence, firms have the most accurate and updated information about the market which helps them to review and if it is needed to realign their strategies based on. This strategy redefinition may result in reviewing what valuable resources in firms are and ignoring some resources despite their uniqueness and inimitability. As an example, a firm that has unique and rare software may not necessarily provide competitive advantages since customers may still prefer less-advanced products with lower prices. Blockchain provides this opportunity for firms to define what resources create competitiveness for them in the market. |
| Resource dependence theory | Resource dependence theory refers to how external factors affect organizational behavior (Hillman et al., 2009). | Organizational level | Too much dependency on external factors creates uncertainty and vulnerability for firms. Firms engage in mergers, acquisitions, and joint ventures to decrease competition by absorbing critical competitors, | Blockchain can provide a transparent, traceable, trustable, and visible flow of information which helps organizations to reduce their dependency on other organizations and in some cases survive in the market without a need |

(continued)

**Table 2** (continued)

| Theory | Definition | Level | What are the current challenges in supply chain management? | How can blockchain improve supply chain management? |
|---|---|---|---|---|
| | | | managing interdependence, extending operations, and reducing dependence on other organizations (Hillman et al., 2009). | for merge, acquisitions, and joint ventures. |
| Network theory | Network theory refers to mechanisms and processes that interact with networks to gain specific goals for members (Borgatti & Halgin, 2011).<br>Network theory focuses on personal relationships between the members and the creation of trust created through cooperation (Treiblmaier, 2018). | Organizational level | Due to the lack of transparency and traceability, trust among supply chain members is low (Wang et al., 2019b).<br>To build trust within supply chain networks, there is a need for intermediaries like banks to control transactions or often to create long-term relationships and financial commitments (Wang et al., 2019b). | Blockchain eliminates a trusted central organization that controls and maintains the network (Saberi et al., 2019). Hence, blockchain removes the need for trust for intermediary organizations or other members in the network since trust is embedded into its technological platform.<br>BTCs can enhance the efficiency and effectiveness of supply chain collaboration processes within their network by supporting connectivity and reliability in the network (Kim and Shin, 2019). |

such as principal-agent theory (Treiblmaier, 2018), transaction cost theory (Treiblmaier, 2018; Schmidt & Wagner, 2019; Loklindt et al., 2018), the resource-based view (Treiblmaier, 2018; Nandi et al., 2020; Kim and Shin, 2019), resource dependence theory (Nandi et al., 2020), and network theory (Treiblmaier, 2018).

The second group of studies highlights notable studies in the current literature on blockchain adoption in supply chain management from theoretical perspectives. Table 3 outlines the theories, definitions, level of analysis, relevance, and the theory roles in addressing blockchain adoption in supply chains. This group examines theories that deal with blockchain implementation in supply chains. The theories include sense-making theory (Wang et al., 2019b), diffusion of innovation theory (Loklindt et al., 2018; Agi & Jha, 2022), theory of planned behavior (Kamble et al., 2019), technology readiness index theory (Kamble et al., 2019), technology acceptance model theory (Kamble et al., 2019), force field theory (Kouhizadeh et al., 2021), and technology organization and environment theory (Malik et al., 2021; Kouhizadeh et al., 2021). These notable studies have addressed blockchain adoption requirements during the preadoption and implementation phases. These studies can shed light on blockchain implementation processes. Researchers and practitioners can take these theories as guidelines for blockchain implementation in supply chains.

Reviewing the previous studies illustrates the limited attention to theoretical perspectives on blockchain in supply chain management. Several important results from the literature review can be summarized: First, most of the previous studies have focused on theory application in blockchain in supply chain management in the implementation phase. There is a lack of articles that investigate blockchain adoption in the preadoption and postadoption phases. Preadoption is vital since it ensures the required resources are in place, increases the awareness of organizations on technological innovation, makes organizations conduct research on whether they are well-prepared for the technological changes, and helps organizations in decision-making processes (Wang et al., 2019b). The postadoption phase also helps organizations to ensure that change is sustained, and the desired outcomes are achieved.

Second, there is a need for a more detailed investigation and comparison between the applied theories and their best scopes of pertinence. It is mostly beneficial for practitioners to understand how to start and successfully complete blockchain adoption using the most relevant theories. Third, human resources can play a role in the successful adoption of blockchain. However, there is a lack of theoretical views on human resources in blockchain adoption in supply chain management. Fourth, among previous research studies, some theories such as transaction cost theory, resource-based view, diffusion of innovation theory, and technology organization and environment theory have received more attention from the researchers, while there is a lack of research on other theories such as stakeholder theory (Freeman et al., 2010), complexity theory (Byrne, 2002), information asymmetry and signaling theory (Mavlanova et al., 2012), and network effect theory (Uzzi, 1996). Future studies need to focus on various theories to develop and advance blockchain research and application in supply chain management.

**Table 3** Theories application to blockchain adoption

| Theory | Definition | Level | Relevance | How can the theory facilitate blockchain adoption in supply chain management? |
|---|---|---|---|---|
| Sensemaking theory | Sensemaking focuses on organizational actors' perception of modern technology in terms of suppositions, expectations, and knowledge of recent technology and then their actions towards it based on the perception (Wang et al., 2019b). | Organizational and individual levels | Preadoption phase | Sensemaking theory can be helpful in the appropriate decision-making process when organizations should decide whether to take or ignore the innovative technology during the preadoption phase, specifically when the benefits of taking a modern technology like blockchain are in an aura of ambiguity (Wang et al., 2019b).<br>Sensemaking theory can create a deeper understanding of how executives and experts recognize blockchain symptoms, develop their knowledge of blockchain, and shape their future actions based on their assumptions and perception of the potential impact of blockchain on their organizations (Wang et al., 2019b). |
| Diffusion of innovation theory | Diffusion of innovation theory explains how an idea diffuses through a specific population over time. It illustrates a technology innovation distinguished in five phases by users: innovators, early adopters, early majority, late majority, and laggards (Rogers, 2010). | Organizational and individual levels | Implementation phase | Diffusion of innovation theory helps executives to understand and assess how blockchain adoption occurs over time in their organizations to define and execute appropriate change plans for each target group during the implementation period. |

| | | | | |
|---|---|---|---|---|
| | Diffusion of innovation theory examines the adoption process from technology and organizational aspects (Malik et al., 2021). | | | |
| Theory of planned behavior | Theory of planned behavior suggests that attitude towards behavior, subjective norms, and perceived behavior control are factors that determine people's behaviors (Kamble et al., 2019). | Individual level | Implementation phase | Theory of planned behavior helps executives to understand the behavior of individuals toward blockchain adoption. |
| Technology readiness index theory | Technology readiness index theory proposes people's tendency to accept and use modern technologies and includes four dimensions: optimism meaning a positive belief about the outcome of using innovative technology, innovativeness meaning the willingness to be a pioneer, discomfort meaning feeling worried while using recent technology, and insecurity meaning a feeling of suspicion towards its capability to secure data (Kamble et al., 2019). | Individual level | Implementation phase | Technology readiness index theory focuses on the influence of innovative technology adoption by individuals (Wahyuni et al., 2021). Using this theory can show individual perceptions of blockchain. |
| Technology acceptance model theory | Technology acceptance model theory investigates how end-users accept and use technology by considering variables such as usefulness and perceived ease of use (Kamble et al., 2019). | Individual level | Implementation phase | Technology acceptance model theory predicts individuals' acceptance of modern technology (Wahyuni et al., 2021). Using this technology relates the individuals' perception gained by other theories like technology readiness index to users' acceptance of blockchain. |

(continued)

**Table 3** (continued)

| Theory | Definition | Level | Relevance | How can the theory facilitate blockchain adoption in supply chain management? |
|---|---|---|---|---|
| Forced field theory | Forced field theory is used for implementing changes in structure, technology, and people and it is used to identify and evaluate forces affecting change (Thomas, 1985). This theory can explain challenges that firms may encounter when they are adopting new technological innovations (Kouhizadeh et al., 2021). | Organizational and individual levels | Implementation phase | Force field theory can be considered as a valuable theoretical backbone to identify and analyze challenges firms face during blockchain implementation (Kouhizadeh et al., 2021). |
| Technology organization and environment theory | Technology organization and environment theory proposes that technology adoption in organizations is influenced by three key elements: technological context which presents technological features, organizational contexts which refers to resources, structure and communication within a firm, and environmental context which proposes market features (Kouhizadeh et al., 2021). | Organizational level | Implementation phase | Technology organization and environment theory is the most validated theory to investigate modern technology adoption. It can create a useful starting point to examine blockchain adoption processes (Malik et al., 2021). |

## 6 Conclusion

This chapter describes the application of blockchain in supply chain management. Blockchain can be a disruptive technology that changes the current organizational and interorganizational processes, and its successful adoption requires preparation. We reviewed blockchain features and applications and proposed a framework that contains the contributing factors and tools for successful adoption.

We further explored the potential of blockchain for building a sustainable supply chain management. We provided several exemplary practices and real-world use cases that implemented blockchain to improve supply chain processes and performance. We outlined some of the barriers and challenges that have reduced the blockchain adoption rate among the supply chain companies. The discussion continued by reviewing the managerial implications and the previous theoretical studies that guide the future development and theoretical directions.

Given the novelty of blockchain and the existence of barriers, its broader real-world application for supply chain management has been limited and requires further investigation. We reviewed the potential of blockchain and provided some exemplary practices.

More research is needed to theoretically and practically analyze blockchain adoption for supply chain management and preadoption and postadoption information to examine the effectiveness of blockchain for supply chain management.

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# Additive Manufacturing in the Supply Chain

Pourya Pourhejazy

## Contents



**Abstract**

Additive manufacturing (AM) is replacing traditional manufacturing approaches – such as subtractive and molding – in some industries. The product and supply chain impacts of AM continue to extend its industrial reach, improve engineer-to-order manufacturing, and pave the way to mass customization. This study explores the supply chain changes that may arise from a full or partial transition to AM-based production. Supply chain factors and dimensions that are greatly impacted are initially identified. Management and operational issues pertinent to each factor are discussed next. The interrelationships between these factors are then investigated considering the disruptive impact of AM on supply chain management. Next, the supply chain change matrix is presented for identifying the areas in that supply chains are expected to be impacted. Finally, the current literature and the future of AM-based supply chains are discussed. This chapter is concluded by providing a summary of the findings and insights into AM-based supply chain transition.

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Additive manufacturing · 3D printing · Supply chain management · SCOR · Decision analysis

## 1 Introduction

The concept of disruptive technologies refers to a new technology that triggers serious changes in a system's routines and state (Bower & Christensen, 1995). A disruptive technology discourages users from continuing with conventional methods. Disruptive technology remains a central idea both in academia and practice as well as in various contexts, only a few have resulted in revolution-like changes. The Internet is a prime example of a truly disruptive technology that altered business operations in many ways. Additive manufacturing (AM) is a more recent example of a disruptive technology, which is likely to revolutionize the production sector and its supply chain.

AM-based production is different from the traditional, subtractive approaches where raw material is carved or cut followed by complementary steps such as forging, grinding, drilling, and assembly to finalize a product (Ying et al., 2022). AM consists of a layer-by-layer addition of compound material for producing the physical counterpart of a digital product. In addition to its implications for product design, performance, and technical features, AM has a disruptive impact on the supply chain processes, stopping them from continuing with the routines that are designed for accommodating traditional production methods. Different logistical supports may be required for operating with AM-based production.

AM requires further development from the supply chain and operations management viewpoints to facilitate a wider industrial reach. Recent studies developed conceptual frameworks or discussed the implications of AM adoption on supply chain and logistics using literature reviews and interviews (Rogers et al., 2016; Braziotis et al., 2019; Da Silva et al., 2020; Sonar et al., 2022). The relationship between various aspects of supply chain changes has not been investigated; such investigation helps understand the underpinning of AM adoption, which determines its suitability in various sectors and supply chains. This chapter uses a systematic approach to explore the mutual influence between major change factors. The chapter introduces a supply chain change matrix for suggesting the best course of managerial actions and facilitating well-informed AM adoption decisions. Outstanding research is summarized to suggest potential directions for future developments in the field.

The supply chain operations reference (SCOR; Supply Chain Council 2010) is used as a framework for discussing the related activities considering the logistical elements of supply chains – facility, transportation, inventory, as well as sourcing (Chopra & Meindl, 2015). The chapter also considers effective time horizons and the level of managerial influence at strategic, tactical, and operational levels (Gunasekaran et al., 2004). The plan, source, make-assemble, and deliver-return processes and their relationships to AM are separately discussed in the initial sections. Supply chain factors that are impacted the most by the disruptive nature of AM are identified in these introductory sections. The chapter is continued with a systematic analysis of the interrelationships between the identified factors and presents the supply chain change matrix. Finally, outstanding research and future directions are provided to contribute to this emerging supply chain topic.

## 2 Plan

The first step of the supply chain process deals with demand and supply planning as well as balancing resources to match market requirements. Outcomes of this stage regulate business rules to improve supply chain performance while making sure that the external regulatory and internal financial plans are fulfilled.

The major planning decisions pertinent to the ***facility*** element of supply chain management include: (1) how many supply chain echelons are required from the acquisition of raw material until delivering the product to the final consumer – network configuration; (2) where to locate facilities and allocation of market and supply points to each facility; (3) how much capacity should be made available in each plant and how flexible each facility should be; and (4) how to organize the departments inside each facility and across the supply chain network. These decisions are rather strategic with a medium- to long-term planning and decision time.

In an AM-enabled supply chain, the parts-products can be often produced in-house or outsourced to a single third-party service bureau – supply tiers will be shorter. Fewer machines are usually involved in the production of parts-products using AM; there is relatively less need for assembly with less space required. Companies will be able to make production capacity more distributed. With an increase in the availability of 3D printers due to technological development and reduced cost, the facilities can be located closer to the point of consumption. This situation will result in inbound logistics of raw materials that can benefit from economies of scale due to the limited variety of raw materials. Outbound logistics will offer a reduced response time to market demand at a reasonable cost.

Considering that AM machinery is generally more flexible than traditional manufacturing machinery, production plants can operate at a lower capacity given that fewer single-purpose machinery will be required. Departmental layouts within and across facilities will require more careful design operations in AM-based production when compared to traditional approaches. AM operations will require lessened material handling and less operator involvement. Alternatively, AM-based production tends to be cleaner than subtractive methods; this may help reduce the distance and barrier between production and other departments, which can improve information flow and multidisciplinary communications. Less required shop floor space and manpower, with streamlined supply processes, results in potential merger of production and distribution facilities in AM-based supply chains leading to reduced operational costs and time, with operational effectiveness improvements.

The second logistical element of supply chain management, ***inventory*** planning requires decisions at both strategic and tactical levels – which means short- to mid-term time horizon considerations. The most prominent inventory planning decisions include: (1) the type and amount of inventory to hold; (2) the location of inventory across the supply chain; (3) inventory replenishment processes; and (4) determining the state of the inventory items (i.e., quality) and dealing with excess inventory.

AM can radically change the nature of inventory planning in supply chains. *First*, the type of inventory will gradually alter in the production sector. Companies may not require part and component inventories, instead raw materials would be stored near 3D printing operations. The inventory portfolio will be less diverse and easier to manage in this situation. For example, quality control may be cheaper due to the limited variety of materials.

*Second*, time in the supply chain will decrease. A shortened value chain means time will become less critical for maintaining response levels. Assuming that replenishment will go as planned – that is, on-time delivery and no disruptions – the company can place new replenishment orders at shorter intervals. Inventory turnover and usage will improve. This result means the cash flow will also improve, and the company will be less impacted by the market turbulence. From a risk perspective, the stored inventory will generally be of less monetary value (little or no value added) and the costs of unforeseen events will be less.

This shift in inventory means it can be kept closer to the point of sale or consumption time. Given that the transformation of material to final products can be postponed and the same material can be used for a wider range of products, the chances of having excess inventory will decrease. The supply chain will be less burdened by inventory depth and width. The supply chain can operate more efficiently. Operational wastes and non-value-adding activities can be minimized.

*Third*, from the planning perspective, the possible changes in inventory of AM-based supply chains reduce the need for accurate forecasts. It will also be less likely to face stockout situations due to the use of standard or common raw materials and the possibility of fulfilling new orders in shorter times.

The third logistical element, ***transportation*** is responsible for moving raw materials, support tools, parts and components, and final products between facilities in a manufacturing supply chain. Planning of the transportation activities consists of determining the following major tactical and operational decisions: (1) What mode (s) of transportation to employ? (2) How much capacity to use and how to allocate the available capacity (load planning)? And (3) how to plan the operations (routing and scheduling)?

The selection of transportation mode is mostly impacted by the volume and weight of the shipping material, their monetary value, logistical requirements, the distance between the origin and destination, and geographical characteristics. Postponing final production closer to the point of consumption means the transportation volume per unit of product is smaller in an AM-based supply chain. This characteristic is particularly important because of having raw material as the dominant material flow and less packaging is required compared to traditional systems where the parts and components must be shipped with additional care.

Overall, fewer shipments between facilities may be required in an AM-based supply chain and the inbound logistics to the production facilities will be long haul and mostly for transporting raw material. Fewer material movements occur inside a production facility because of the streamlined value chain and by the fact that items can be produced in fewer steps. Given that the raw and unprocessed material has a lower monetary value per unit of weight, the need for long-haul transportation justifies the use of cheaper modes of transportation, such as maritime and railway shipping. In this setting, the use of third-party logistics service providers may become more prevalent. Considering that the frequency of shipment to each production facility can be reduced with full-truckload transportation of 3D printing material, the routing decisions become less relevant for inbound logistics. The reduced variety of shipping items in inbound logistics reduces the complexity of capacity allocation decisions and demand divisibility.

In general, AM can reduce supply chain *planning* complexities. Streamlined supply stages can address some bullwhip effect concerns. Lessened material diversity and greater supply pooling have implications for supply planning and demand forecasting in make-to-stock systems. AM can also facilitate a shift to make-to-order agendas in certain industries. The product and supply chain impacts of AM together alter the pricing element of supply chain management, especially for mass customization. In addition to improving the company's profitability, a customer that can benefit from highly customized products is more likely to tolerate revenue management practices, like different delivery time fares and pricing concerning service levels.

## 3 Source

The *sourcing* step of supply chain management consists of managing *infrastructure*, equipment, and *tools*, procuring *raw materials*, and *managing suppliers*.

AM-based production facilities in a supply chain can be equipped with a relatively smaller variety of machinery when compared to traditional manufacturing. This is because 3D printers are highly flexible and can produce a wider variety of parts or products with minimum setups compared to multipurpose subtractive machines. There is relatively less need for assembly operations, which reduces the need for extra operational space. Less need for tooling operations has also become possible with the recent development of hybrid AM technologies that complete the post-processing tasks on the same machinery.

A company that upgrades its current facilities with advanced 3D printers may save room for increasing the production capacity, repurposing freed space, or downsizing production sites. When designing new supply chain networks and facilities, the need for smaller production spaces enables organizations to invest in constructing a more distributed manufacturing network to better benefit from the supply chain impact of AM.

AM-based operations are generally more sustainable than traditional manufacturing due to significantly less production waste and externalities. In the context of infrastructure management, generating less noise and pollutants enables the decision-makers to locate the AM machines in the same facility as the engineering design and administrative offices. These aspects together make it easier to manage infrastructure in an AM-enabled supply chain.

One of the main advantages of AM over traditional manufacturing is the ease of using composite materials, which helps improve product characteristics and performance. Although the use of composite materials may extend the supply chains vertically, it simplifies the procurement procedure for the original equipment manufacturers, allowing them to contract out the responsibility of dealing with low-tier suppliers to the main supplier.

AM machines can produce complex geometries in a single production run with less need for keeping work-in-progress components and purchased subcomponent inventories. Inbound inventory to the AM-based production facilities is limited to a handful of materials. The variety of feedstock materials in the market used to be a major barrier to the wide adoption of AM technology, but the range of materials is extending quickly.

Currently, different types of metals, graphite, carbon fiber, and plastics can be selected as feedstock for AM machines. The production of modular products is another relevant advantage of AM that reduces the sourcing complexities in the supply chain of certain industries, like consumer electronics and mobile phones. Finally, the growing market of digital material on the open-access and paid platforms are expected to have a sharp impact on the sourcing element of the supply chain; the final product manufacturer may choose to purchase the digital product and produce the required components in-house. This situation reduces the product cost and sourcing complexities in the manufacturing supply chains and alters the demand chain, particularly in the downstream supply chain.

Overall, the sourcing process in supply chain management comprises answering the following tactical and operational questions: (1) What technology is suitable for producing the parts/products? (2) Can the parts be produced in-house, or the AM-based production procedure should be outsourced? And (3) how to select the best third-party printing service provider?

AM technology selection decisions should be made considering design requirements and desired printing material. This decision, in turn, impacts infrastructure requirements, operational costs such as energy consumption costs, and investment costs. Generally, 3D printing technologies can be categorized considering the production process – additive, solidifying, or lamination – and the base in which the items are produced such as liquid, solid, or powder. Vat photopolymerization uses light-activated polymerization in the production process, which requires a low energy level, placing this technology at the bottom of the energy list of the major AM processes; it is followed by material jetting, binder jetting, material extrusion, sheet lamination, and powder bed fusion. The AM processes based on directed energy deposition require thermal energy for melting the feed, which makes it the most energy-intensive AM technology (ISO/ASTM 52900, 2021).

The compartment size of the AM machines has been reduced significantly over years and the overall size of the machinery is mainly determined by the build size on which the products are processed. The learning curve for AM machines may vary, therefore it is important to ensure that the purchased machinery follows certain standards, both in software and hardware. Extrusion-based AM machines are comparatively cheaper than the other alternatives and various plastics can be used as feedstock (filament) for extrusion-based AM machines. Desktop 3D printers are widely used for private and home purposes while industrial extrusion-based machines are recently been employed for mass production of parts and final products.

Powder bed fusion–based AM is on the other edge of the AM technologies concerning the cost of machinery and equipment. Considering that metals can be used as feedstock for powder bed fusion–based AM machinery, this AM technology is currently the main technology used at the 3D printing service bureaus and is expected to dominate the application areas that require material removal.

Production complexity, the required endurance, quality (i.e., surface roughness and dimensional accuracy), and the size of the part/product are fundamental considerations in determining whether to use AM-based production methods. These factors may also vary from one 3D printing service provider to another due to the use of different brands and types of AM machinery. Overall, the selection of the 3D printing service provider requires the following considerations: the unit production cost, cost of raw material, service time, the range of material/color/size and AM technology choices, production capacity, and post-processing services.

The location of the AM service provider is important to take full advantage of the supply chain impact – that is, considering the ease of logistics of the final product. Finally, AM may have implications for supplier development; AM platforms facilitate the direct involvement of the supplier in the design and generation of the digital models and make it also easier to monitor and improve the supplier's performance. Besides, a smaller supply base forms strategic partnerships where the company can invest more in supplier development programs.

## 4 Make or Assemble

The *make* element of supply chain management is responsible for transforming raw materials and parts from the *source* activities into complete products for *distribution* to the final consumers. It consists of product development and launch, managing the production process, and activities like assembling, testing, and packaging. The major impacts of AM on the *make* activities include: (1) the supply chain's pull/push strategy and the respective decoupling point; (2) the scope and nature of the operations; and (3) quality management.

In an ideal operational situation, the products are made in direct response to customer demand with no inventories being kept along the supply chain (make-to-order). In most cases, companies are unlikely to be able to efficiently fulfill orders on time by applying a supply-chain-wide make-to-order policy. Manufacturing supply chains hold inventories to cope with demand fluctuations and benefit from the cost advantages of scale economies, the so-called make-to-stock approach, and push strategy. The decoupling point determines the boundary between “pull” and “push” operations in a supply chain.

In an AM-based supply chain, the possibility of having a highly distributed manufacturing network – closer proximity of the production facilities to the final customer – together with a streamlined value chain reduces the response time. This situation enables the companies to pursue just-in-time production and move the decoupling point closer to the ideal make-to-order approach. Additionally, a flat cost curve in AM makes the economy of scale in production less important when compared to traditional manufacturing. The mentioned advantages of AM may shift the supply chain of certain products away from make-to-stock. AM facilitates responsiveness and differentiation strategic agendas but may not result in cost-effectiveness in its current state of development.

From a product development and launch perspective, AM can facilitate a shorter time-to-market. This is mostly due to AM prototyping capabilities, the fact that the design procedure becomes faster and cheaper, and the improved connection between the design and production stages. With AM streamlining the supply chain process, the emphasis on soft operations and services, like design and marketing, will become more prevalent. In this situation, the make-to-order concept can be enhanced to engineer-to-order; that is, the design and engineering of the product will constitute a more significant proportion of the value chain in industries with a high degree of customization.

With a shift in supply chain capabilities, the operational scope can also be extended beyond the point of consumption; that is, integrating demand chain management into the supply chain. Big data analysis is currently employed for informing marketing activities, but little has been done to enhance the product design capabilities supported by big data analysis of unstructured data sources like social media. This will be particularly helpful for improving the design activities.

Disruptive new technologies – like blockchain and virtual reality – can be employed as enablers for a paradigm shift in supply chains. In these cases, products and services can be extended and may require business model adjustment. Many businesses may have to shift to providing digital products and services in addition to or instead of physical products. In this situation, the “make” process of the supply chain may experience a significant change. For example, if a product can be made using desktop 3D printers at home, the consumers may opt to purchase the digital document instead of the physical final product. Alternatively, they may prefer to take the digital document to a local 3D printing service bureau to have the final product in a shorter time and at a cheaper price. Either way, virtual reality can assist in facilitating the design process and improve the designer-customer interactions. As another example, the copyright and intellectual property-related issues of digital products can be addressed using blockchain technology.

The AM production process is different from traditional manufacturing approaches where the raw material is carved or removed, and additional steps like forging, grinding, drilling, and assembly must follow to prepare the final product. In contrast, AM constitutes a single production run with few post-processing requirements. The material cost, process type, and the extent of post-processing requirements determine the production costs.

Overall, the unit production cost with AM is cheaper than traditional approaches for low- to mid-volume production considering the flat cost curve. For high-volume production, however, the unit production cost is higher than traditional approaches in the current state of developments in AM. Despite the high investment cost and the unit cost for high-volume production, high flexibility in producing complex geometries, high surface roughness, and feature resolution with a fine level of detail make the AM a better alternative for producing certain products.

Technological development, demand growth, and a competitive market with more producers are expected to help lower the prices of AM machinery and feeding materials in the coming years. Besides, improved know-how of the operations management aspects will reduce the operational costs and facilitate the industrial reach of the 3D printing machines.

Testing the quality of raw material, work in progress, and the final product constitute another major aspect of the “make” activities in a supply chain. The streamlined value chain in AM-based supply chains reduces the testing and packaging needs. Although a highly distributed production network in AM-based supply chains may not benefit from economies of scale in quality control and delicate testing approaches, higher precision and flexibility of AM machinery compared to the traditional manufacturing approaches improves product quality.

AM can be used as an enabler for improving production performance – for example, by making tools, jigs, fixtures, or casts to be employed in certain operations. Similarly, a timely supply of parts or components for the repair and maintenance activities helps shorten the possible downtime and reduce the chance of machine breakdowns.

AM mock-ups and other assistance tools can come in handy for improving operator performance, when required, in the training programs. These support capabilities, in turn, improve the supply chain performance, for example, by avoiding delays caused by tooling shortages and decreasing reliance on tooling suppliers and maintenance service providers. Finally, and from a value chain perspective, using AM for the in-house production of parts and components enables the company to have better control over the quality variables and continuous improvement initiatives.

## 5 Deliver and Return

The *deliver* activities in a supply chain include order management and the routine warehousing and distribution operations for fulfilling the orders. *Return* activities consist of handling the returned items, like containers, packages, defective items, and end-of-life products.

AM adoption can radically change make-to-order and engineer-to-order supply chains. Receiving orders, making decisions on acceptance, rejection or backlog, and signaling the production department to initiate the “make” activities will all be impacted. Depending on the type of the product, the customer may customize the purchase at a retail store or a local service provider (e.g., footwear), or use the online platforms for selecting the design and configuration of the product (e.g., consumer electronics).

Metaverse – virtual reality – platforms can reduce shop visits for product customization with the help of interactive tools and new technologies, like virtual reality and holograms. While rejecting an order in traditional supply chains is often caused by raw material or production resource shortages, design and compatibility aspects may be the new considerations for order management decisions in mass customization businesses. Although the adoption of AM-based production may not significantly impact order management for make-to-stock production, the increased flexibility in both production volume and variety can facilitate order fulfillment in uncertain times. This flexibility potentially reduces the time between receiving an order, starting the production procedure, and delivering the final product.

Finally, using AM as a backup production capacity along with the subtractive machines, or vice versa, can help the traditional supply chains deal with demand fluctuations more effectively. This situation has implications for order management in both make-to-order and make-to-stock supply chains.

From the transportation management perspective, the frequency and type of last-mile services impact order fulfillment operations. The question is: Should the final products be sent directly from the production plant or the central warehouse for door-to-door service, or should customers pick up the item either from designated locations (like convenience stores) or the retail stores that may be comparatively further away? Either way, organizations should determine how much inventory of raw material and finished goods should be made available in each warehouse and retail facility to avoid lost sales and backlogs while keeping the overheads at an acceptable norm.

How these decisions are impacted by a shift to AM-based production is mostly about the differences AM makes in operational responsiveness or cost-effectiveness. Considering the distributed nature of AM and the proximity of production facilities to the final consumers, distribution operations are mostly business-to-consumer (B2C). B2C requires vehicle routing decisions to plan and optimize doorstep deliveries. The other significant supply chain impact of AM is the supply of products to remote areas and places with harsh climate conditions. The possibility of producing the items in remote places instead of having them regularly supplied from globally scattered suppliers helps the development of such areas, which is in line with sustainable development goals. This situation also reduces operational costs, distribution-related externalities, and supply chain resilience.

In addition to the cost of capital for holding inventories, warehousing costs are associated with the storage and management overheads as well as running expenses; this cost category is regarded as one of the main sources of supply chain expenses. In an AM-enabled supply chain, the cost of capital for inventories is relatively low because inventories are most often unprocessed with little value added. Additionally, the running costs are lower than a traditional supply chain considering that the depth and width of inventories are comparatively limited. These inventories often occupy less space, and the final products are lightweight when required. For the same reasons, consolidation of raw materials can lower the inbound transportation costs.

AM-based production is more distributed likely making last-mile delivery cheaper. In addition to the financial aspects, the market coverage and the control of the company over the logistics operations impact warehousing decisions. Overall, a cost-effective supply chain can benefit from AM adoption by lowering operational costs while responsive supply chains may use the saved overheads for improving service levels or extending the service range.

Product conformity and quality are expected to improve in AM-based supply chains. With fewer returned and defective items, the operational burden over the logistics capacities can be alleviated. Using less packaging along the supply chain will reduce the problem of dealing with the packaging material. End-of-life products and recycling operations means the processes of dismantling, separating, and recovery of components can be significantly changed by AM. The type and uniformity of raw material used in AM production and the fact that fewer joints and connections are used for attaching parts are some of the major factors impacting recycling operations. The product impacts of AM and the flexibility it provides may facilitate the design for disassembly, recovery, and reuse and improve the closed-loop operations. In this situation, the supply of the feedstocks may be facilitated through the "return" of used and end-of-life products in AM-based supply chains.

As a relatively new design concept with implications for logistics, it is expected that the do-it-yourself model will be advanced to a new level by AM. This change will occur in industries where the distribution of physical products can be replaced by the sale of digital products, which can be produced at consumer location.

As an alternative solution, new businesses, like local 3D printing service bureaus and hubs, should be established to provide production and design services that reduce the distribution expense and time and improves customer customization experience. AM can support disaster response and emergency use cases, where regular supply chains are impacted or cannot promptly supply the basic needs and medical requirements. Production of necessities, like ventilator and oxygen valves, face shields, swabs, and 3D printed lung models in the early phases of the COVID pandemic (Arora et al., 2020), and customized implants for surgery in emergency rooms are prime examples of the medical applications of AM.

## 6 Supply Chain Change Matrix

A systematic approach called the decision-making trial and evaluation laboratory (DEMATEL; Fontela & Gabus, 1976) can be used for developing the supply chain change matrix. DEMATEL explores the decisive factors in a system to help understand its underpinnings (Falatoonitoosi et al., 2013). It is worthwhile noting that DEMATEL does not determine the importance of the factors; instead, it analyzes the interrelationships between them to find the most influential factors and the cause-effect relations. In this definition, a factor may be considered the least important factor in terms of importance weight (which is determined using multicriteria decision-making methods like AHP, ANP, etc.), but shows the highest influence on the rest of the factors.

Expert opinion is the basis for analyzing the interrelationships between the supply chain change factors. This kind of analysis is particularly important when a new phenomenon, i.e., a disruptive technology, is being studied and there is not enough evidence to generate meaningful information. In a nutshell, the analysis defines the prominence and role of different supply chain changes caused by the adoption of AM-based production. A brief explanation of the computational steps is provided below, followed by a detailed analysis of the results, and summarizing some previously determined results in this chapter.

**Step 1:** Data collection. The supply chain change factors developed by experts are listed in Table 1. Expert opinion was gathered using the question: "When assessing the disruptive impact of additive manufacturing on the supply chain, to what extent does the factor in the row influence the factor in the column?" The answers are selected from "No influence," "Low influence," "Moderate influence," "High influence,, and "Very high influence," and are entered into every cell of the relationship matrix. The resulting matrix is called the direct-relation matrix. Simple averaging is used for aggregating opinions.

**Step 2:** The supply chain change matrix preparation. The computations begin with normalizing the direct-relation matrix. Every element of the direct-relation matrix is divided by the greatest summed value among all rows and columns. The resulting normalized matrix is then multiplied by the reverse of its difference from the identity matrix. The resulting matrix represents a convergence of the cell values after infinite rounds of multiplications.

**Step 3:** Prominence and net-causation analysis. The change factors should be categorized into the cause or effect classes to analyze the supply chain change matrix. The summation of matrix rows shows the total influence of a factor on the rest of the factors. The summation of the column values of the matrix shows the total influence received by each factor. On this basis, the prominence value refers to the total influence dispatched and received by a factor; greater prominence values show that the factor contributes greatly to the supply chain changes in the AM adoption process. The net causation determines the difference between the dispatched and received values. Change factors with a positive net-causation value are the major influencers and those with a negative value are significantly influenced by the rest of the change factors. It is apparent that the influencers should be given higher attention to ensure better outcomes in the supply chain transition process.

Expert opinion inputs are presented in Tables 2 and 3. The computational procedure explained above is applied for the analysis of the results.

Table 4 presents the supply chain change matrix resulting from the DEMATEL analysis; darker cells highlight higher total relationship values. On this basis, "supply chain strategy" has the greatest influence with its interrelationship with "outsourcing and service provider selection" being the most significant in the matrix followed by that on the "scope of operations." The supply chains that emphasize different strategies may take advantage of the AM adoption in different ways. For example, it might be more effective to implement a partial adoption of AM in a certain stage of the supply chain and a certain industry. Moreover, the company

**Table 1** Supply chain change factors

| Dimension | Symbol | Factor | Explanations |
|---|---|---|---|
| Strategic | $\mathbf{F_1}$ | Network configuration and facility location | How many supply chain echelons are required from the acquisition of raw material until delivering the final product to the ultimate consumer? Where to locate the production facilities and how to allocate market and supply points? |
| | $\mathbf{F_2}$ | Outsourcing and service provider selection | Can the parts be produced in-house, or the production procedure should be outsourced; if so, what criteria to consider for selecting the best third-party 3D printing service provider? |
| | $\mathbf{F_3}$ | Supply chain strategy | Where to place the decoupling point considering the push-pull view of the supply chain. What is the targeted competitive advantage: cost-effectiveness, responsiveness, and/or differentiation? |
| | $\mathbf{F_4}$ | Scope of operations | Modifying the scope of the supply chain activities (or the business model) when required. Adding new services and products, using new technologies for extending the customer experience, or revising outsourcing decisions |
| | $\mathbf{F_5}$ | Closing the supply chain loop | How the AM adoption benefits the five Rs (i.e., reduce, reuse, repair, rot, and recycle) for reducing waste and managing the take-back initiatives? |
| Tactical and operational | $\mathbf{F_6}$ | Production capacity | How much 3D printing capacity should be made available at each plant? How flexible each facility should be? Is there a need for keeping some subtractive production capacity? |
| | $\mathbf{F_7}$ | Production technology and material selection | What materials are required in the production of parts/products? What technology is suitable for producing them? What are the post-processing requirements? |
| | $\mathbf{F_8}$ | Operation schedules | When to produce the product and how to schedule the deliveries? How to coordinate the parties involved in the value chain? |
| | $\mathbf{F_9}$ | Inventory level, replenishment, and location | What type and amount of inventory to hold and where to keep these inventories across the supply chain? When to initiate the inventory replenishment procedure considering the lead time and availability of the supply sources? |
| | $\mathbf{F_{10}}$ | Quality control | How to check the state of the inventory items, including raw materials, the quality of services, and/or products. How to implement the process control measures? |
| | $\mathbf{F_{11}}$ | Transportation mode and capacity | What mode(s) of transportation to employ considering the type and size of the final products? How to allocate the available logistical resources? |

**Table 2** Input from one expert

| | $F_1$ | $F_2$ | $F_3$ | $F_4$ | $F_5$ | $F_6$ | $F_7$ | $F_8$ | $F_9$ | $F_{10}$ | $F_{11}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **$F_1$** | – | H | H | L | L | VL | VL | H | L | H | H |
| **$F_2$** | VL | – | VL | H | L | VH | VH | L | L | VH | L |
| **$F_3$** | VH | H | – | H | L | H | H | H | H | VH | H |
| **$F_4$** | L | VH | L | – | H | VH | L | H | L | L | H |
| **$F_5$** | L | H | H | VH | – | L | H | VL | L | L | H |
| **$F_6$** | L | H | L | VH | H | – | H | H | H | L | VL |
| **$F_7$** | L | VH | VL | H | L | H | – | H | H | L | L |
| **$F_8$** | N | L | L | H | H | H | L | – | H | L | L |
| **$F_9$** | VL | VL | VL | L | L | H | H | H | – | L | H |
| **$F_{10}$** | L | H | H | L | VL | VL | H | H | L | – | VL |
| **$F_{11}$** | L | H | VL | L | L | L | VL | H | H | L | – |

**Table 3** Input from another expert

| | $F_1$ | $F_2$ | $F_3$ | $F_4$ | $F_5$ | $F_6$ | $F_7$ | $F_8$ | $F_9$ | $F_{10}$ | $F_{11}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **$F_1$** | N | H | VH | H | H | H | L | L | H | H | H |
| **$F_2$** | H | N | H | H | H | H | H | L | H | L | L |
| **$F_3$** | VH | VH | N | VH | H | H | VH | H | H | L | H |
| **$F_4$** | H | H | H | N | L | L | L | L | L | L | H |
| **$F_5$** | H | H | VH | H | N | H | H | L | H | H | H |
| **$F_6$** | H | H | L | H | L | N | L | L | H | L | H |
| **$F_7$** | H | H | H | H | H | L | N | L | L | H | L |
| **$F_8$** | L | L | L | L | L | H | L | N | H | L | H |
| **$F_9$** | H | H | L | H | L | L | L | L | N | L | H |
| **$F_{10}$** | H | L | L | L | H | L | H | H | H | N | L |
| **$F_{11}$** | H | L | L | H | L | L | L | H | H | L | N |

strategy determines whether the product impact of the AM is required the most or the company should focus on the supply chain impact of the AM adoption. The supply chain phases that experience the heaviest load or the bottleneck may require a boost through the AM adoption.

Considering that tactical and operational factors received the greatest average influence in the change matrix, one can suggest that a great deal of change in supply chain activities from tactical and operational levels is mostly triggered by the changes the AM adoption imposes through the strategic elements.

A partial supply chain transition to AM may not require structural changes in the strategic elements of the supply chains, therefore a hybrid of subtractive and additive methods may be the best solution for many sectors. Overall, the extent and pace of adoption vary across industries. It is worthwhile noting that the greatest self-influence in the factor "outsourcing and service provider selection" suggests that any changes in this factor may result in sequential changes in the outsourcing activities due to identifying new operational needs and market opportunities.

**Table 4** The supply chain change matrix

| | $F_1$ | $F_2$ | $F_3$ | $F_4$ | $F_5$ | $F_6$ | $F_7$ | $F_8$ | $F_9$ | $F_{10}$ | $F_{11}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $F_1$ | 0,2698 | 0,4022 | 0,3578 | 0,3888 | 0,3374 | 0,3467 | 0,3271 | 0,3532 | 0,3682 | 0,3562 | 0,3667 |
| $F_2$ | 0,3263 | 0,3159 | 0,3154 | 0,4011 | 0,3363 | 0,3852 | 0,3790 | 0,3374 | 0,3657 | 0,3535 | 0,3365 |
| $F_3$ | 0,4363 | 0,4814 | 0,3118 | 0,4804 | 0,3926 | 0,4328 | 0,4367 | 0,4238 | 0,4417 | 0,4115 | 0,4240 |
| $F_4$ | 0,3356 | 0,4096 | 0,3252 | 0,3109 | 0,3326 | 0,3687 | 0,3342 | 0,3466 | 0,3489 | 0,3234 | 0,3605 |
| $F_5$ | 0,3592 | 0,4228 | 0,3727 | 0,4349 | 0,2808 | 0,3773 | 0,3836 | 0,3424 | 0,3846 | 0,3584 | 0,3831 |
| $F_6$ | 0,3340 | 0,3953 | 0,3111 | 0,4085 | 0,3317 | 0,2820 | 0,3463 | 0,3452 | 0,3736 | 0,3219 | 0,3334 |
| $F_7$ | 0,3341 | 0,4087 | 0,3114 | 0,3952 | 0,3318 | 0,3544 | 0,2748 | 0,3454 | 0,3605 | 0,3361 | 0,3326 |
| $F_8$ | 0,2639 | 0,3326 | 0,2808 | 0,3471 | 0,3018 | 0,3354 | 0,3021 | 0,2423 | 0,3420 | 0,2908 | 0,3153 |
| $F_9$ | 0,2894 | 0,3315 | 0,2668 | 0,3449 | 0,2873 | 0,3201 | 0,3127 | 0,3141 | 0,2548 | 0,2902 | 0,3275 |
| $F_{10}$ | 0,3107 | 0,3539 | 0,3022 | 0,3402 | 0,2950 | 0,3018 | 0,3360 | 0,3350 | 0,3350 | 0,2403 | 0,2947 |
| $F_{11}$ | 0,3016 | 0,3435 | 0,2670 | 0,3440 | 0,2870 | 0,3069 | 0,2857 | 0,3269 | 0,3402 | 0,2903 | 0,2420 |

**Table 5** Prominence and cause-effect analysis

| Factors | Dispatched | Received | Prominence | Net |
|---|---|---|---|---|
| **$F_1$**: Network configuration and facility location | 3.8740 | 3.5609 | 7.4349 | **0.3132** |
| **$F_2$**: Outsourcing and service provider selection | 3.8525 | **4.1973** | **8.0498** | −0.3448 |
| **$F_3$**: Supply chain strategy | **4.6729** | 3.4222 | **8.0951** | **1.2507** |
| **$F_4$**: Scope of operations | 3.7962 | **4.1960** | 7.9922 | −0.3998 |
| **$F_5$**: Closing the supply chain loop | 4.0998 | 3.5142 | 7.6140 | **0.5856** |
| **$F_6$**: Production capacity | 3.7828 | 3.8114 | 7.5942 | −0.0286 |
| **$F_7$**: Production technology and material selection | 3.7852 | 3.7181 | 7.5032 | **0.0671** |
| **$F_8$**: Operation schedules | 3.3540 | 3.7126 | 7.0666 | −0.3586 |
| **$F_9$**: Inventory level, replenishment, and location | 3.3392 | 3.9152 | 7.2544 | −0.5761 |
| **$F_{10}$**: Quality control | 3.4448 | 3.5726 | 7.0174 | −0.1279 |
| **$F_{11}$**: Transportation mode and capacity | 3.3353 | 3.7162 | 7.0515 | −0.3810 |

The prominence and cause-effect analysis are provided in Table 5 to analyze the supply chain change matrix with an overall lens. “Supply chain strategy” is regarded as the change factor with the highest prominence; this supply chain factor is the one AM adoption is expected to interact the most. “Outsourcing and service provider selection” is regarded as the second most prominent change factor; contracting 3D printing service providers can be the best starting point of AM adoption for the sectors that require more significant investments and for SMEs. As supply chains transition to AM, new activities may be added to the operations by either bringing back the outsourced activities in upstream to the focal company or adding new services and features to the downstream supply chain. This is confirmed by the fact that F2 and F4 received the most influence in the change matrix. The extent of changes in these factors may result in business model changes.

The supply chain strategy, network configuration, and closed-loop factors are the change factors with meaningfully positive net causation, meaning that these factors are the major influencers in the change matrix. Expectedly, "supply chain strategy" has the greatest amount of influence while receiving marginal influence from other factors; this is because the company's strategy determines AM adoption it seeks. As a prime example, a cost-effective supply chain may target centralized AM to take advantage of economies of scale to bring down costs while a responsive supply chain requires a highly distributed production network of 3D printers. The extent of decentralization is also expected to be industry specific and influenced by the market size. "Inventory level, replenishment, and location" are associated with the greatest negative causation value, which suggests that a change in this operational factor after the AM adoption is highly dependent on the changes in other factors.

## 7 Outstanding Research and Future Directions

AM is in the early stages of development; a reduction in AM machinery price, a higher level of autonomy, and shorter production times as a result of technological advances will facilitate AM adoption and its industrial reach (Khajavi et al., 2014). The supply chain know-how of AM is also quite important; the possible impacts of such a transition should be examined from different supply chain operational, tactical, and strategic perspectives. This section reviews outstanding AM-based supply chain management research based on which directions for future research are suggested.

**AM adoption decisions.** Despite the advantages of AM over traditional manufacturing approaches, AM adoption is not a one-size-fits-all solution. Many considerations should be examined when evaluating its suitability for a certain industry situation and use case. For example, demand size and feedstock material cost are recognized as influential factors (Scott & Harrison, 2015). From an operational perspective, the limited variety of materials and lack of expertise are some of the major factors that should also be considered (Choudhary et al., 2021). Legal aspects of AM adoption, like supply chain information integration, intellectual property, and counterfeiting issues (Chan et al., 2018), are other considerations which may require the adoption of cyber-physical systems (Gupta et al., 2020) and smart contracts of blockchain. AM enables a customer-centric supply chain based on value co-creation sources (Martinelli & Christopher, 2019); hedonic motivation and DIY mentality are key factors for AM acceptance (Halassi et al., 2019), which may or may not be in favor of its adoption for certain customer groups. Multicriteria decision-making and analysis models as well as expert systems are required to assist the multifaceted AM adoption decisions.

Application areas, like apparel, automotive, spare parts, plastic reforming, medical, and insole manufacturing industries, as well as humanitarian logistics, have been projected as the best venues for AM adoption. With a deeper analysis of the product and supply chain impacts of AM and the help of complementary technologies, this list can be extended. A comprehensive study on major product categories and the possibility of matching the groups with the existing use cases of AM will help the rapid adoption of AM. Finally, comparative studies on AM adoption in various industries and situations are another missing item in the academic literature that can be considered as a future research direction.

**AM adoption requirements and transition path.** AM adoption is more complex than deploying 3D printers in a production facility; or converting CNC machine using the available technologies and equipment; a supply-chain-wide transition is necessary to enable the shift. A change in this scale requires well-informed planning to ensure a smooth shift to AM-based production. Case studies in different sectors are needed to shed light on the prerequisites of AM adoption. Besides, AM implementation requires broad involvement from different supply chain partners (Luomaranta & Martinsuo, 2019), proactive top management, effective strategy for collaboration and innovation, skilled workforce for technology adoption, and resource allocation for digitalization (Priyadarshini et al., 2022). The planning aspects during and after the transition should consider these and additional considerations, a promising direction that requires investigations in the academic literature.

The present chapter identified the most influential supply chain elements and those that will be impacted the most because of AM adoption. This impact may also vary on different supply chain players. Manufacturers with diverse bills-of-material and direct digital manufacturing techniques are expected to be the change hot spots in a transition to AM (Sasson & Johnson, 2016); supply chain resilience should be studied considering the change hot spots during and after the transition. The need for local production of essential goods using AM machinery demands the availability of feedstock material and improvement in local design services (Corsini et al., 2022); these are the other related topics to investigate from a supply chain resilience perspective.

**AM adoption settings.** The optimum AM adoption setting varies for different situations. For example, in sectors with rather high customization, the retailer's profit will be maximized if the manufacturer leads the customization process (Sun et al., 2022). The degree of postponement, manufacturing technology, and production quantity are other case-specific variables (Ramón-Lumbierres et al., 2021). The same applies for supply chain network configuration. The best configuration for an AM-based supply chain may be the one that simultaneously benefits from centralized production and the flexibility of local manufacturing (Khajavi et al., 2018). Centralized supply chain networks may be desirable when the demand rate is high (Li et al., 2019). In other cases, a decentralized AM-based supply chain offers more flexibility and better service levels when the distances between supply chain entities are long and the average demand is high (Rinaldi et al., 2022).

Another topic to investigate is the extent of AM adoption in a supply chain. Partial adoption of AM, for example, as a supplementary production capacity, improves supply chain lead time and total cost (Chiu & Lin, 2016). AM machines can be purchased by any of the supply chain partners, but advantages may be significant when the manufacturer adopts AM technology (Arbabian, 2022). Supply chains' main hub can be equipped with AM and redundant production capacity can be considered in other facilities using traditional manufacturing means (Strong et al., 2018). It is also found that including an AM hub in the supply chains improves closed-loop operations concerning economic sustainability (Son et al., 2021). Direct recycling by shooting material from end-of-life is an interesting way of facilitating closed-loop operations.

System dynamics, game theory, simulation, and optimization models have been developed to study the configuration aspects of AM-based supply chains; most of these studies are generic and have not been tested in real situations and using real-world data, which should be the focus of future research.

**Supply chain mapping and cost analysis.** The next direction includes case studies in different sectors and regions for AM-based supply chain cost analysis, risk analysis, and mapping. In general, AM adoption brings about performance improvement at both firm and supply chain levels (Delic et al., 2019). AM adoption improves supply chain flexibility, which, in turn, reduces operational costs (Delic & Eyers, 2020). AM also decreases raw materials inventory considerably (Kunovjanek & Reiner, 2020). A significant cost reduction has been reported for small-scale supply chains of highly customized products, like the insole manufacturing industry (Cui et al., 2021). Such case-specific evidence is required in other industry situations to facilitate the shift to AM-based production. Besides, AM adoption for certain product characteristics may benefit the most from certain operational viewpoints; for example, in-site production of large and very large steel products is particularly attractive from a transportation perspective; this needs to be investigated through supply chain mapping and cost analysis.

**Sustainable supply chain and AM.** One effective way to promote the adoption of new technologies is to explore their implications for pursuing sustainable development goals. This is especially true when achieving certain targets is hard or infeasible with traditional technologies and methods. Sustainable supply chains and AM require more investigations to unfold the hidden opportunities of the new production technology. AM adoption increases production speed, competition over fashion cycles, and product price; these bring about positive social sustainability impacts (Hohn & Durach, 2021). There also is a positive interaction between AM machinery availability and consumer attitudes to social sustainability (Beltagui et al., 2020). It is a good practice to include environmental considerations in all steps of the possible AM-based supply chain transition. AM-based businesses can be more profitable when emission efficiency and waste minimization technologies are adopted (Thomas & Mishra, 2022). As another example, recovering 3D printing wastes has shown to be beneficial (Santander et al., 2020); such circular ways of supply chain operations require development in the academic literature.

Finally, the *human* aspect of AM-based production operations received recent attention; AM should be investigated from Industry 5.0 perspective, for example, by testing creative workspaces and learning platforms with the use of extended reality.

## 8 Concluding Remarks

Compared with the traditional manufacturing approaches, which use material removal and/or injection molding, AM can more effectively produce items with complex designs and compound materials. In addition to the product-related impacts, it is believed that both full and partial AM adoption decreases supply chain cost, improves quality, speed, and flexibility, and facilitates innovative business ideas. These benefits have made AM a new technology with disruptive impacts on the supply chain. This chapter explored the change factors considering the supply chain transition toward AM-based production.

The AM adoption disrupts, among other things, the way the supply chain elements interact. The influential interrelationships between the pairs of supply chain change factors under AM are, therefore, expected to be different than under traditional manufacturing. The DEMATEL method is used as a systematic evaluation tool to analyze the extent of mutual influence among the supply chain change factors. On this basis, the prominent factor was identified and the type and extent of factors' role in the AM adoption process were quantified. Supply chain strategy appeared to be the most decisive change factor given its influence on the transition of the tactical and operational elements. The outsourcing of the production activities to 3D printing service providers showed to be another major change factor involved in the AM adoption.

The chapter continued by providing future research directions. We found that conceptual modeling and analysis were the most frequent approaches for exploring AM adoption, particularly in studying supply chain strategy–related topics. The network configuration and facility location aspect of the supply chain has also been well supplied in the AM literature. Besides, there are several quantitative analyses of the inventory- and operations scheduling–related problems. The rest of the aspects explored in this chapter received limited attention in the academic literature and require multidisciplinary investigations to improve the know-how of the logistical support within and after the AM adoption.

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# Radio Frequency Identification (RFID) and Supply Chain Management

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## Contents



**Abstract**

Supply chain management environments have always been information-intense for collecting and processing data to determine its capabilities, productivities, delivery performance, and overall competitiveness. This chapter is targeted to the academic and business community and aims to inform and enlighten managers about the use of RFID in the supply chain. The work presented in this chapter is a collection of the past two decades that was sparked by the "*big bang*" of RFID. The recent RFID research overlaps with the Industry 4.0 technologies in the

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supply chain. We are at the gates of another technological explosion that will revolutionize the way we manage supply chains. RFID and the convergence of those Industry 4.0 technologies will soon change the landscape of supply chain management. Early RFID Academic interest in RFID generated a fast-growing body of literature. General research topics include RFID technology and applications, benefits, and business value. General research also suggests managerial guidelines and examines implementation challenges. Academic studies of RFID systems are dominated by case studies of big retailers and the path RFID-tagged products follow from distribution center to store shelf. The cases discussed grocery industry use, retail supply chains, and retailer RFID benefits and challenges. Other RFID applications for improving efficiency and effectiveness focused on retail product misplacement, shrinkage control, pull-based replenishment, vendor-managed inventory, and mapping supply networks. The chapter concludes with current concerns regarding RFID in the supply chain, research needs, and a look ahead to where RFID in the supply chain appears to be heading.

**Keywords**

Radio frequency identification · Supply chain management · Automatic identification data capture · Efficiency · Effectiveness · Real options

## 1 Introduction

Supply chain management environments have always been information-intense for collecting and processing data to determine its capabilities, productivities, delivery performance, and overall competitiveness. For more than a century, business information technologies have revolutionized the way firms design (and often redesign) their supply chains and management control systems. Historical examples include the telegraph used for railroad transportation scheduling, the telephone (and facsimile) for faster business communication, bar codes for automatic data acquisition, and electronic data interchange (EDI) for more efficient and paperless business transactions (Reyes & Jaska, 2006). While these technologies enhanced the business practices of those eras, the actual benefits were limited to the specific supply chain process. The Internet and the explosion of computer science of the 1990s helped to address those limitations and the trade-offs between cost, rich content of data, real-time information sharing, and the upstream and downstream integration between the business partners.

In recent years, much attention has been on automatic identification data capture (AIDC) technologies, which has been used in a variety of industries including manufacturing, transportation, distribution, retail, health care, and many other sectors. The most well-known and widely dispersed AIDC technology is the bar code (that dates back to the 1970s), which at that time was driven by the need for accurate and timely data that was gathered from the manufacturing, inspection, transportation, and inventory cycles within a business operation (Mara, 1987). Over time, the bar-code expanded to the logistics and retail sectors, where it gained exposure to the general public. However, the AIDC technology radio frequency identification (RFID) dates back to the 1940s and over time it was used as a propriety system for asset tracking in the 1970s, and then in the early 1990s, RFID applications began to extend to open systems for supply chain management processes (Reyes, 2011).

Since then, RFID has quickly caught on as an intriguing supply chain technology with flexibility for numerous applications. However, during the early 2000s with a limited and fragmented understanding of what RFID could do (or not do), the strong interest in RFID technology increased as a viable solution for improving supply chain operations.

Before 2000, most of the commercial RFID implementations were associated with animal tracking and access control (particularly transportation and retail theft prevention). Among the earliest uses of RFID was tracking livestock movement, mainly for inventory management. This was followed by RFID access control.

In its simplest form, RFID access control involves allowing certain people access to an area or resource while barring others from a similar level of access. The systems used to restrict entry can prevent individuals from looking at sensitive data, taking advantage of various resources, gaining access into areas for which they lack authorization, and even leaving such areas. The two primary applications of RFID access control began with transportation and retail theft prevention. In transportation access control, vehicles gained access to highways or bridges via toll tag. Retail theft prevention, used mainly for high-priced retail items, caused an alarm to sound if an item left the store without having the RFID tag removed by the cashier.

RFID applications moved to more diverse applications, ranging from the cashless payment at gasoline stations to the monitoring of paroled criminals. Additional early adoption examples of RFID applications include Hewlett-Packard placing RFID tags on its printer boxes and more recently Delta Air Lines implementing the use of RFID tags for tracking luggage. RFID tags on books are being used in many university library systems (including the University of Michigan and the University of Texas at Arlington) to facilitate students checking books in or out. JPMorgan Chase, a large US financial services company, had started using RFID chips embedded in its credit cards (nicknamed “blink”), which allowed the consumer to hold the card close to a reader (an RFID application called near field) instead of swiping the card through a reader and risking the magnetic strip being damaged.

One factor that has further facilitated RFID supply chain applications was the adoption of a global standard for data formats in tags. This Electronic Product Code (EPC) standard was developed by the Auto-ID Center, a consortium founded in 1999 by five leading research universities, anchored by the Massachusetts Institute of Technology and nearly 100 leading retailers, consumer products manufacturers, and software companies. In the mid-2000s the world’s largest retailer, Walmart, created a surge in RFID implementations by mandating that its largest 300 suppliers start using RFID tags on cases shipped to Walmart warehouses. Walmart’s desired outcome with RFID is to improve its overall supply chain operations by increasing inventory visibility, reducing theft, and reducing the overall cost of logistical operations while keeping track of inventory movements. Over the long term, some believe that companies will have little choice but to adopt RFID to remain competitive.

The structure of EPC tags was first developed at the Auto-ID Center at the Massachusetts Institute of Technology as “the internet of things” (IoT) and is now managed by a not-for-profit joint venture between EAN International and the Uniform Code Council known as EPCglobal (see https://www.gs1.org/epcglobal). This body manages the UPC (Universal Product Code) information found in bar codes and also sets the standards for how basic product information is encoded in RFID chips as well as how information is passed from RFID readers to various applications, including application to application.

## 1.1 Motivation and Organization of This Chapter

This chapter is targeted to the academic and business community and aims to inform and enlighten managers about the use of RFID in the supply chain. As the author of this chapter, the work presented in this chapter is a collection of two decades of my research in RFID in the supply chain. And includes the recent RFID research that overlaps with the Industry 4.0 technologies in the supply chain. We are at the gates of another technological explosion that will revolutionize the way we manage supply chains. RFID and the convergence of those Industry 4.0 technologies will soon change the landscape of supply chain management. This chapter provides a narrative of how it started, a historical view of where we have been, where are now, and what I believe is a look ahead. This chapter is divided into six sections and is outlined as follows.

The background section provides a short historical view of the RFID technology, the “*big band*” of RFID, and the early RFID history. The advantages of RFID technology are presented.

Research on RFID in the supply chain focuses on inventory management applications. The two primary research areas that persist are real-time inventory control and partner-to-partner visibility. The section concludes the with benefits, challenges, and limitations of RFID.

RFID in the supply chain is an ongoing interest. The current concerns section describes RFID simulation modeling as a topic that is important to practitioners and researchers. Item-level RFID tracking remains a current concern that requires investigation as we move toward an RFID-IoT supply chain.

In the emergent concerns, outstanding research, and future directions section, we offer direction for discussion and development of related topics for future RFID in the supply chain research from the Industry 4.0 lens. In particular, research investigation of RFID-based technology converging with other technologies like Internet of Things, blockchain, smart cities, and AI/machine learning.

In the managerial implications section, we describe how RFID fits with the organization’s strategy. Then we describe an approach for the management of uncertainty in RFID the technology investment and real options value to understand

and manage the risks with the RFID investment. Then we conclude with a practical approach toward an eight-step guideline for RFID implementation.

We then conclude with a summary, conclusion, and a look ahead.

## 2 Background

RFID is an auto data capture technology that uses radio frequencies to identify, track, and trace an object or product. As with many modern technologies, the RFID technology has its origin in military applications during World War II, when British planes were equipped with radio-frequency transmitters to identify them as friendly aircraft to British forces on the ground. RFID commercial applications began during the early 1980s. Then the "*big bang*" of RFID gained the attention of practitioners and academic research around January 2005 (Visich et al., 2009) primarily focusing on the consumer packaged goods and grocery supply chains. Today, these applications span several industries, such as aerospace, apparel, retail/consumer packaged goods, food/agriculture, logistics/transportation, manufacturing, smart cities, and many more. Hence, the maturity of RFID technology in the supply chain is no longer in question.

While there are both pro and con arguments, RFID in the supply chain has the potential to offer considerable benefits. A variety of applications already exist for RFID in the supply chain with countless reported cases in the fields of security, process control, hospital, consumer package goods, retailing, document management, perishable logistics, warehousing, distribution, and construction sites. As more companies consider the potential applications of RFID, a good understanding is needed of what RFID is (or is not), the current and future states of RFID technology, and the current and future applications of RFID, as well as the technology's advantages and limitations.

### 2.1 Why All the Hype?

RFID in the supply chain has, for the most part, been flying below the business innovation and best practice radar. Most of the propaganda and press that was given to RFID began with the mandates announced by the US Department of Defense (DoD) in 2003 and Walmart in 2004 for its suppliers' to use of RFID, which launched the "*big bang*" for RFID. At that time, RFID represented a new direction in supply chain management theory and practice. Equally important, it was not certain that all firms will adopt RFID because many managers are in a dilemma as to whether RFID was right for their organization or application. In some ways, RFID was like many other past technological implementations, but in some ways, it is not. The actual benefits and risks of RFID coupled with managers' evolving perceptions about these benefits and risks decided the speed at which RFID moved from the introduction and developmental stage to the maturity stage. Many RFID white papers published during the early 2000s described RFID and its advantages, primarily to aid managers in their effort to determine whether RFID was appropriate for their particular needs and give them some guidelines for implementing an RFID solution. Although RFID had been around for many decades, it took those mandates by the DoD and Walmart to spark massive interest in its potential for improving supply chain performance. Also contributing to this interest was the rapid acceleration and availability of computer science and Internet technologies that had been evolving and reshaping supply chain management processes and practice. As part of the considerations for RFID implementation, managers needed to filter out the hype and understand what the technology can do – and equally important, what it could not do.

## 2.2 Early RFID History

We cannot say that RFID is a new technology, although it took a few decades to leave the realm of scientific research and become practical for business applications. It is difficult to trace its true history because most research was done behind closed doors for military purposes. However, RFID uses electromagnetic energy, and its roots can be traced to research on the use of radar. One of the first major papers on RFID was by Harry Stockman: “Communication by means of reflected power,” published in October 1948, which described the technology as imperfect and said that much research and development would be needed before RFID technology could be put into practical use in various fields.

Since then, the number of research studies and the number of patents filed have continued to increase. By 2000, over 350 patents related to RFID and its use had been filed. Commercial applications began to flourish in the past few decades. Early companies such as Checkpoint, Sensormatic, and Togo developed electronic article surveillance (EAS) systems to prevent retail store theft, primarily for higher-priced items. This commercial use of RFID was quite effective in preventing theft. Major events in RFID commercial development can be traced to the 1975 declassification of research by Los Alamos Scientific Labs (LASL) with the published paper “Short-range radio-telemetry for electronic identification using modulated backscatter” (authored by A. R. Koelle et al.).

By the 1980s, interest in RFID began to grow rapidly. The initial development efforts in the United States focused primarily on transportation applications and personnel access. In Europe, the efforts were focused on short-range systems for animals followed by industrial and business applications. Although testing of RFID for collecting tolls had been conducted for many years in the United States, the first commercial toll application began in Europe in 1987, which was soon followed in the United States. During the 1990s, RFID technology continued to be implemented around the world. The first open-highway electronic tolling system, where vehicles could pass toll collection points at highway speeds, was instituted in Oklahoma in 1991. Then followed the first combined toll collection and traffic management system, installed in Houston, Texas, in 1992. Other RFID toll-tag developments such as multiple uses of the same tag for different purposes followed. For example, one tag could be used for both toll collection and access control (parking lot, gated community, etc.).

The twenty-first century has seen an explosion in the use of RFID technology for supply chain management applications. Many companies are now using RFID tags to track individual inventory items, cases, pallets, or equipment. RFID tags are being used within manufacturing plants, warehouses, and retail facilities. Some companies are also tagging individual parts that go into the finished product.

## 2.3 Advantages of RFID Technology

Until recently, bar codes were the most prevalent technology for object or product identification. Bar codes and RFID each have their own unique physical properties that make them easy or difficult to read under certain environmental conditions. Bar codes require an uninterrupted line of sight to be visible to a bar code reader, while RFID tags can be packaged either inside or outside an object and still be read. Bar code reading is impaired by dirt, moisture, abrasion, and packaging contour, while RFID is not as susceptible to those conditions. However, RFID tags can be affected by the metal and liquid properties of a product to which they are affixed. RFID tags may have read/write capability, whereas bar codes do not have such capabilities; therefore, more data can be stored on an RFID tag than on a bar code.

RFID provides a means to automatically identify and track items using tags that provide information in real-time about their identity, location, activity, or history, which is then processed and utilized by application software. RFID systems for the supply chain emphasize tagging of pallets, cases, and (in certain situations) individual items. In contrast to bar codes, which are used by more than a million firms in over 140 countries and 23 industries, RFID employs radio frequencies to transmit data to readers within a certain distance. RFID also offers several key technological advantages over bar codes, which are summarized in Table 1.

**Table 1** Key technological advantages of RFID over bar codes

| Bar codes | RFID tags |
|---|---|
| Bar codes require line of sight to be read | RFID tags can be read or updated without a line of sight |
| Bar codes can only be read individually | Multiple RFID tags can be read simultaneously and with greater speed and efficiency |
| Bar codes must be visible to be logged | RFID tags can be read even when concealed within an item |
| Bar codes cannot be read if they become dirty or damaged | RFID tags can cope with harsh and dirty environments |
| Bar codes are fixed at the time of printing | Rewritable RFID tags can be reused for multiple applications, lowering the cost of ownership |
| Bar codes must be manually tracked for item identification, making human error an issue | RFID tags allow complete automated data handling for paper reduction and greater overall efficiency, and automatic tracking, eliminating human error |

A key benefit of RFID over bar codes is made possible by the richness and timely availability of information about the location and status of goods worldwide to manufacturers, distributors, and retailers is what motivated retailers, such as Walmart, and the US Department of Defense to mandate the use of RFID by top suppliers. By comparison, other benefits include:

- *Absence of line of sight:* A line of sight is not required for an RFID reader to read an RFID tag. This is perhaps the most compelling advantage of RFID. An RFID reader can read a tag through obstructing material that is RF-lucent for the frequency used.
- *Contactless:* An RFID tag can be read without any physical contact between the tag and the reader. Among the advantages is the absence of wear and tear on the tags for reading and writing, as well as the readers. The biggest advantage is that operations are not slowed down for the reader to physically contact the tag.
- *Support for multiple tag reads:* Support for multiple tag reads is another important advantage of RFID. By using what is called an anticollision algorithm, it is possible to use an RFID reader to automatically read several RFID tags in its read zone within a short period. Depending on the RFID tag and business application, this advantage allows a reader to uniquely identify from a few up to many tags per second. Hence, the data collected from the tagged objects – whether moving or stationary – is a technological advantage compared to having to read one tag at a time.
- *Rugged:* Passive RFID tags can sustain rough operational environment conditions, such as heat, humidity, cold, corrosive chemicals, and mechanical vibrations to a fair extent. Some passive tags can survive temperatures ranging from −40 °C to 200 °C (−40 °F to 400 °F). In general, these tags are made to handle a specific application and operating environment.
- *Writeable data:* The data of a read/write (RW) RFID tag can be rewritten up to 100,000 (or more) times. However, the more common tag currently used is a write once, read many (WORM) tags.
- *Variety of reading ranges:* An RFID tag can have a read range from a few inches to more than 100 feet, depending on the frequency of the tag. A low-frequency (LF) passive tag has a read distance of just a few inches, while a high-frequency (HF) passive tag has a read distance of 3 feet. An ultra-high frequency (UHF) passive tag can have a read distance of 300 feet, and an active tag in the gigahertz range can have a read distance greater than 100 feet.
- *Wide data capacity range:* A passive RFID tag can store from a few bytes of data to hundreds of bytes. Active RFID tags can store virtually any amount of data and are not limited in their capacity range because the physical dimensions and capabilities of active tags are not limited.
- *Smart tasks:* In addition to being a carrier and transmitter of data, an RFID tag can be designed to perform other duties, such as measuring temperature.

Bar code technology’s applicability for real-time control is largely limited by the fact that items require a line of sight and must be individually scanned up close. With

RFID technology, multiple items can be scanned simultaneously without a line of sight and at relatively great distances – making frequent and accurate information regarding updates of inventory records more feasible. These are consistently up-to-date and accurate information regarding not only how many items are in the supply chain but also where those items are located (Srivastava, 2004). This becomes vital as the firms' supply chain strategies emphasize more customized outputs (Kärkkäinen & Holmström, 2002).

## 3 Research on RFID in Supply Chain

Early RFID Academic interest in RFID generated a fast-growing body of literature. General research topics include RFID technology and applications (Reyes & Frazier, 2007), benefits (Kärkkäinen & Holmström, 2002), and business value (Riemenschneider et al., 2007). General research also suggests managerial guidelines (Angeles, 2005; Reyes & Jaska, 2007) and examines implementation challenges (Li & Visich, 2006; Cannon et al., 2008). Academic studies of RFID service delivery systems are dominated by case studies of big retailers or distributors such as Sainsbury's (Kärkkäinen, 2003), Wal-Mart (Hardgrave, et al., 2008a, b), Metro Group (Loebbecke, 2007), and GENCO (Chow et al., 2006; Langer et al., 2007). Delen et al. (2007) describe the path RFID-tagged products follow from distribution center to store shelf. Cases discuss grocery industry use (Småros & Holmsröm, 2000; Prater et al., 2005; Gessner et al., 2007), retail supply chains (Gaukler et al., 2007), and retailer RFID challenges (Jones et al., 2004). Others examine RFID applications for retail product misplacement (Rekik et al., 2008), shrinkage control (de Kok et al., 2008), pull-based replenishment (Wang et al., 2008), vendor managed inventory (Szmerekovsky & Zhang, 2008), and mapping supply networks (Bi & Lin, 2009).

It has been widely agreed that much of the supply chain inefficiency can be attributed to supply and demand uncertainties. This is not necessarily the result of customer or producer attributes, but rather the lack of shared information across the supply chain partners. Although RFID cannot be expected to overcome ingrained patterns of information hoarding, the use of the RFID technology can provide a powerful weapon when supply chain partners do attempt to work collaboratively (Kärkkäinen & Holmström, 2002). The early research by Småros and Holmsröm (2000) and Småros et al. (2000) looked at RFID as an emerging and prominent enabler of vendor-managed inventory efforts specific in the e-grocery sector that could provide visibility to both e-grocers and suppliers and contributing to significant improvements in customer service and efficiency. The work was later expanded to a study demonstrating an extensive track record of profiting from the sharing of demand and supply information between Walmart and Procter and Gamble that involved using RFID to supplement their collaborative efforts (Angeles, 2005).

Compliance mandates by the US Department of Defense and Walmart requiring suppliers to use Electronic Product Code (EPC) RFID tagging on pallets and cases provided a strong push to mainstream the adoption of RFID in the supply chain, especially by manufacturers and distributors. That sparked an interest that led to other RFID initiatives and research. Other key players driving the growth and adoption include Tesco, Metro Group, Albertson's, and Target (Reyes et al., 2007). Table 2 summarizes some of the key mandated initiatives during the early 2000s. Tesco, a supermarket chain in the United Kingdom, has introduced RFID at the case level for tracking shipments between its 2000 distribution centers and retail stores. The Metro Group has focused on the store of the future, while Albertson's (the second-largest supermarket chain in the United States) also has RFID pilot studies in the Dallas, Texas, area.

In addition to the retail industry, Boeing and Airbus are two of many other companies that have implemented RFID to track inventories (including work in progress). Michelin has tested RFID transponders embedded into tires, where the primary purpose is to make tracking tires easier to comply with the US Transportation, Recall, Enhancement, Accountability, and Documentation Act (TREAD Act).

The early scholars investigated the issues and problems related to RFID technology and applications, such as how to redesign inventory management processes to exploit RFID, how to best ensure consumer privacy with RF tags and how to arrange RFID readers in a facility, and where to place tags on an item all require a fundamental understanding of RFID technology and its various potential applications. The scholars also explored the benefits and challenges of RFID in supply chain adoption. The following highlights the research trend.

Five specific publications found in the literature have provided extensive literature reviews on RFID in the supply chain. These five extensive literature reviews have been heavily cited in recent years. Table 3 provides a summary of extensive literature reviews.

**Table 2** Early RFID initiatives

| Company | Objective | Target implementation date |
|---|---|---|
| Michelin North America Inc. | Implanted RFID tags on selected tries to keep track of their performance and tread wear over a period of time | January 2003 |
| Metro Group (Europe) | Pilot testing RFID in the supply chain and warehouse of the Extra Future Store in Germany | April 2003 |
| Tesco Corp. (UK) | RFID tags are placed on cases of non-food items at the retailer's distribution centers and are tracked into stores | April 2004 |
| | An unspecified number of suppliers are required to tag cases delivered to some Tesco distribution centers | September 2004 |
| Target | An unspecified number of top suppliers are required to apply tags to pallets and cases to selected regional distribution centers | Late Spring 2005 |
| Boeing Co. | Suppliers are asked to place RFID tags on parts so they can be traced through their life cycle for manufacturing and maintenance | 2006 |

Source: Reyes and Frazier (2007)

**Table 3** Summary of extensive literature reviews

| Authors | RFID in the Literature |
|---|---|
| Li and Visich (2006) | Challenges and opportunities of RFID implementation in supply chain management<br>Impacts of RFID on each supply chain partner<br>Impact of RFID on the supply chain as a whole |
| Chao et al. (2007) | Technology innovation of RFID<br>Organization adoption of RFID<br>Organizational diffusion<br>Supply chain management<br>Health<br>Privacy and others |
| Ngai et al. (2008) | Technological issues<br>Application areas<br>Policy and security issues<br>Other |
| Visich et al. (2009) | RFID overview literature<br>RFID empirical studies<br>RFID analytical studies<br>Dimensions of RFID operational business value<br>Dimensions of RFID managerial business value |
| Reyes et al. (2016) | Constructs for RFID implementation<br>Implementation drivers<br>Management leadership<br>Barriers<br>RFID adoption stage<br>Benefits |

Li and Visich (2006) were perhaps the first to introduce a comprehensive literature review to demonstrate the challenges and opportunities of RFID implementation in supply chain management. They examined two dimensions: the impacts of RFID on each supply chain partner and the impact of RFID in the supply chain. By looking beyond, the application of one company, RFID provides a continuous flow of information throughout the entire supply chain. This then provides an increased synchronization of information flow and therefore enables better supply chain coordination, collaboration planning, forecasting, and replenishment decisions.

Using a bibliometric technique and a historical review method, Chao et al. (2007) analyzed RFID innovation, adoption by organizations, and market diffusion found in Science Citation Index journals from 1991 to 2005. Their analysis found supply chain management, the health industry, and privacy issues as the major trends in RFID, and concluded that RFID contributions will be more ubiquitously diffused and assimilated into our daily lives in the near future.

With the RFID academic research explosion, Ngai et al. (2008) pointed to several journals producing special issues on RFID. As a result, they organized a review of 85 academic journals published between 1995 and 2005. The framework for their reviews included a “content-oriented classification” of the RFID literature for the scope of their investigation. The papers were classified into four main categories: technological issues, application areas, policy and security issues, and other issues.

The technological issues focused on the RFID system itself, such as tags, readers, and communication infrastructure. The application areas consisted of applications beyond supply chain management, manufacturing, and logistics, including library services, animal detection, and museums. Policy and security issues related to the studies involved existing human rights policies, constitutional protections, and data protection laws. And other issues covered general overviews or usages of RFID.

Visich et al. (2009) provide an extensive literature review by classifying the existing empirical evidence of RFID on supply chain performance. They used the process-oriented framework proposed by Mooney et al. (1996) to classify the evidence by operational or managerial process and then for each process by effect: automational, informational, and transformational. The empirical evidence from this study showed that the major effects of the implementation of RFID are automational effects on operational processes followed by informational effects on managerial processes. They noted that RFID implementation has not reached the transformational level on either operational or managerial processes. RFID has an automational effect on operational processes through inventory control and efficiency improvements. An informational effect on managerial processes is observed for improved decision quality, production control, and the effectiveness of retail sales and promotions coordination. They concluded their study by proposing a three-stage model to explain the effects of RFID on the supply chain.

Reyes et al. (2016) is one of the more recent studies about RFID implementation in the supply chain. They provide an extensive review of the determinants for RFID implementation in the supply chain leading to a comprehensive adoption and implementation framework. The framework for RFID implementation in the supply chain is based on five constructs: (1) internal and external drivers, (2) dimensions of management leadership, (3) barriers, (4) level of RFID adoption, and (5) benefits. Their results offer new insights into RFID adoption factors and a broader understanding of RFID technology in the supply chain.

Other studies that continued the RFID in the supply chain interest explored the future impacts of RFID on e-supply chains in grocery retailing were investigated by Prater et al. (2005), building a business case (Riemenschneider et al., 2007), multiple perspectives on RFID benefits and risk (Cannon et al., 2008), and assessment of the antecedents and outcomes of RFID implementation in health care (Reyes et al., 2012).

In a multiple-phase survey among members of the Institute of Supply Management, Reyes and Frazier (2007) investigated the RFID adoption interest, perceived benefits, and challenges during the spring of 2005. At that time 76.9% of the respondents had not heard of RFID nor had plans to implement RFID within the next 2 years. They cited “not applicable,” “initial costs are too high,” and “expected benefits are not enough” – this explains the challenges that firms faced at the start of the RFID hype. Among the respondents at different phased of the RFID adoption, “accuracy and availability of information” was the most realized improvement – an example of what RFID was supposed to do.

As the RFID in the supply chain interest matured, two studies focused on the RFID impacts on supply chain performance.

Visich et al. (2009) provided empirical evidence of RFID impacts on supply chain performance. The research reviewed and classified the existing RFID research of the early 2000s by operational or managerial processes and its effect on the supply chain performance. The study showed that the major effect of the RFID implementation was automational effects on operational processes followed by informational effects on managerial processes. At that time, RFID implementation had not reached the transformational level in either operational or managerial processes. The study identified implementation areas in which supply chain professionals could implement RFID and have the greatest impact on performance.

Zelbest et al. (2012) studied the impacts on manufacturing effectiveness and efficiency. Using systems theory as a basis, an RFID utilization and outcome (s) performance model was developed. The findings indicate that utilization of RFID leads to improved manufacturing efficiency and manufacturing effectiveness. Efficiency improvements lead directly to improved organizational performance, and improvements in effectiveness lead directly to improved supply chain performance. The implementation of RFID technology can result in improved manufacturing efficiency and effectiveness. For the supply chain professionals, adoption of the technology should fully account for this potential efficiency and effectiveness-related benefits when determining the justification for the adoption of this technology.

These benefits and challenges have been discussed in detail since the *big bang* of RFID and are summarized in the following subsections.

## 3.1 Benefits

Tajima (2007) summarized the literature to provide insights into the strategic value of RFID. The benefits can be categorized into two group types. The first type of benefit is those that can be realized throughout the supply chain. The second type of benefit is those that can be realized by specific major supply chain participants.

### Benefits That Can Be Realized Throughout the Supply Chain

- *Reduction of shrinkage:* shrinkage occurs in various ways throughout the supply chain, from misplacement, spoilage, shoplifting, and organized retail crimes. RFID can reduce the occurrence of shrinkage (Prater et al., 2005). The estimated shrinkage cost in the United States is $30 billion per year and with RFID, it is believed be able to be reduced by a minimum of two-thirds (Twist, 2005). RFID has also been discussed as a solution to counterfeiting in the pharma supply chain and black market sales.
- *Reduction in material handling:* many benefits of RFID relate to the reduction of material handling cost and inspection time. In a study by Quirk and Borrello (2005), a 40% decrease in inventory counting time was demonstrated. Other studies discussed the reduction of other logistic processes, like receiving time, loading/unloading, and waiting time before unloading (Radko & Schumacher, 2004; Rutner et al., 2004). Moreover, RFID should also reduce the prone human

errors from labor-intensive operations like inventory counting, manual data entry, and put-away. As such, a reduction in material handling leads to lower labor costs and increased productivity.

- *Increased data accuracy:* in the retail industry, inaccuracy of inventory data is a major problem. For example, Raman et al. (2001) reported that 65% of the inventory records from 37 retail-chain stores contained some errors. As an auto-data capture technology, RFID could improve inventory records by reducing the human errors in material handling described. As such, RFID could then increase the accuracy of shipment data. An important feature of information accuracy is the potential for improving the quality and effectiveness of managerial decisions.
- *Faster exception management:* responding to unplanned events before they escalate into major problems is perhaps the most important benefit throughout the supply chain. RFID could support a faster exception and effective management decision making by providing more timely data acquisition to further better synchronization of material flow and information flow that could lead directly to improved supply chain performance (Zelbest et al., 2012; Reyes & Frazier, 2007; Kärkkäinen & Holmström, 2002).
- *Improves information sharing:* as long as the supply chain trading firms are willing to collaborate, RFID would increase the sharing of product demand and supplier capability data among the trading firms. Data sharing could then be readily automated with the use of RFID (Rutner et al., 2004), and the automation would consequently reduce the need for manual tracking of paper trails. Moreover, access to detailed supply chain data would enable RFID to offer flexible information sharing by customizing the level of aggregated or disaggregated supply chain data.

## Benefits Specific to Manufacturers and Suppliers

- *Production tracking:* RFID could be used to track raw materials, work-in-process inventory, and finished goods, and provide the status of the assembly during production. Kärkkäinen and Holmström (2002) provide an example of Ford's wireless Kanban system based on RFID improved the tracking of parts through the assembly process. Harley-Davidson used RFID for easier product customization by linking a motorcycle's serial number into the individualization of assembly instruction (Bear, Stearns Co. Inc., 2003).
- *Quality control:* RFID could be used to monitor and track quality control in the production process. Examples reported by Bear, Stearns Co. Inc. (2003) include Malden Mills tracking imperfections in Polartec fleece fabric using RFID and Nestle monitoring and tracking product trays to prevent poor product quality by certifying regular cleaning.
- *Supply and production continuity:* RFID could ensure continuity in the production process and ensure continuous supply availability by improving material tracking through the manufacturing process. For example, Toyota reduced the costly production disruptions by automating the receipt of inventory using RFID (Kärkkäinen & Holmström, 2002). With the use of sensor technology, this could be extended to provide regular equipment monitoring to reduce downtime and

maintenance costs in manufacturing tooling. Early pilot studies included real-time air-pressure tire monitoring in forward freight trucks for improving gas mileage efficiency.

## Benefits Specific to Distributors and Logistics Providers

- *Material handling:* in distribution and warehouse management, a reduction in materials handling is significant. According to Twist (2005), labor costs in warehouse operations account for 50–80% due to material handling. Hence, the reduction in material handling as previously stated is significant. Additional benefits for warehouse operations may include automated routing for cross-docking, fewer shipping delays, and a reduction in lead times for processing outbound logistics. A potential benefit would be a quicker customs clearance for border crossings.
- *Space utilization:* RFID could improve the efficiency and flexibility of space utilization. RFID could provide flexible space allocation by reducing product incompatibility problems, such as placement of hazardous products, and eliminating space requirements for bar code scanning (Rutner et al., 2004).
- *Asset management:* RFID could efficiently and effectively manage, track and trace, and provide visibility to a variety of assets. Better tracking of asset utilization consequently leads to better asset utilization, better shipment consolidation, reduction in fuel expenditure for transportation, improved reverse logistics, and lower capital costs (Visich et al., 2009). For example, a casino tracked 80,000 uniforms through the laundry process and TrenStar tracked 3 million beer kegs using RFID (Bear, Stearns Co. Inc., 2003).

## Benefits Specific to Retailers

- *Reduced stockouts:* RFID could help reduce stockouts and consequently reduces potential lost sales by increasing the accuracy in finished goods inventories. In the United States, poor product availability costs the retail industry approximately $30 billion annually (Teresko, 2003). Hence, reducing stockouts would allow retailers to then focus on strategic inventory management planning, like promotion tracking and execution, category management, shelf planogram layout, new product introductions, and even market price differentiation.
- *Customer service:* RFID can be used to improve the customer service experience. For example, at The Gap, the use of RFID freed staff from counting inventory and dealing with stockouts – resulting in increased staff availability for customer assistance (Roberti, 2003). Exxon Mobil also introduced an RFID-based automated payment system (tab-and-go) to reduce customer waiting time at the checkout (Bear, Stearns Co. Inc., 2003).
- *After the sale service:* RFID could efficiently respond to recalls by isolating bad batches of goods. It could further improve warranty processing and returns by efficiently retrieving information, like warranty details, service history, and authentication (Kärkkäinen & Holmström, 2002).
- *Lower inventory:* by improving inventory data records and reducing stockouts, then RFID could then reduce the need for safety stock. RFID could then further reduce

inventory by facilitating vendor-managed inventories, just-in-time deliveries, and more importantly, lead to smart automatic replenishment (Prater et al., 2005).

## 3.2 Challenges

Perhaps the leading challenge to designing an RFID application is achieving seamless integration and building consensus about the RFID strategy across the supply chain. First, it is difficult to design the application within a single firm (regardless of size) and then to extend it across a supply chain network of linked firms. Success has often been associated with the stronger channel leaders who are close to the ultimate customer and who have the buying power to influence the pace and direction of technology investment upstream in the supply chain.

Since the early mandates, issues that have surfaced, and continue to resurface, regarding RFID include security and privacy – especially today with the cybersecurity issues. Again, these issues are certainly not new to decisions on adopting business technology and should be at the forefront of any RFID considerations. While the public perception of security and privacy has some weight in the decision, it is mostly the organization's data security policies that must be examined to ensure customer data is not compromised. Privacy advocates are more concerned about customers being tracked and their buying behavior monitored. Several solutions have been proposed to eliminate the tracking of tags after products are sold.

A primary barrier to RFID adoption that is at the forefront of managerial concern is the difficulty of quantifying the cost-benefit ROI (return on investment) for acquiring this technology. While cost-benefit analysis is an ongoing business decision tool, many factors contributing to decisions on RFID adoption are like those involved in deciding whether to adopt the recent Internet-based e-commerce technologies. This adoption issue (which I call "show me the money") continues to be an ongoing discussion as the technology expands beyond the initial interest around inventory management. Other factors to consider are described later in the managerial implications section.

Like other technologies, RFID has its limitations. Some of the advantages have limitations.

- Performance: An RFID reader could partially or completely fail to read the tag data because of RF-opaque material, RF-absorbent material, or frequency interference.
- Environmental factors: Depending on the frequency, the read accuracy of the tags could be affected if the operations environment has large amounts of metals and liquids.
- Actual tag reads: Because the reader must use an anti-collision algorithm, the number of actual tags that a reader can uniquely identify (per unit of time) is limited.
- Hardware interference: If the RFID readers are improperly installed, then the readers can show evidence of reader collision.

- Penetrating power of the RF energy: The penetrating power of the RF energy is dependent on the reader's transmitting power and its duty cycle. For example, if cases on a pallet are stacked too deep, then a reader may fail to read some of the cases.
- Immature technology: While RFID technology has been around for many decades, the sparked interest has also sparked interest in types of applications. While it can be argued that RFID is a mature technology, an RFID solution may not be readily available, and thus vendors need to develop the products. The issue of maturity will continue.

## 4 Current Concerns

Technological advances continue to change the landscape in supply chain management practices (Gale et al., 2010). Several approaches to unlocking the value of RFID have been considered and are still important to practitioners and researchers for investigation. In particular, RFID is an automatic identification data capture (AIDC) technology and how can this technology be used as a tool for data analysis. While the value of information for inventory replenishment and supply chain visibility is a top priority for the supply chain profession, there remain gaps in the research for RFID toward a smart replenishment system and smart cities approach at item-level tagging in the retail supply chains.

Lee and Özer (2007), in a special issue on RFID in the journal of *Production and Operations Management*, highlighted several approaches to "unlocking the value of RFID" and labeled RFID not only as a disruptive technology but also as new information capturing technology for the supply chain management. They began with the current views on the RFID value (labor cost savings, inventory reduction, and reduction in shrinkage and out-of-stock inventory), and then extended the value of RFID to (1) visibility within a company, (2) visibility across companies with downstream information shared upstream, and (3) visibility across companies with upstream information shared downstream. As a result, many quantitative research papers on the application of RFID and "unlocking the value" have been published. In this section, we highlight five RFID simulation modeling studies that are important as we continue to unlock the potential values of RFID in the supply chain (Table 4).

Gaukler et al. (2007) developed an analytical model to explore the benefits of item-level RFID to manufacturers and retailers within a retail supply chain setting. The goal was to compare the expected profits under item-level RFID with the achievable expected profits without RFID. The model scenarios consisted of a centralized system (the base model) compared to a decentralized wholesale price contract. Both were examined with and without item-level RFID tagging. Additionally, two sub-cases were explored within the decentralized systems: either the manufacturer or the retailer as the Stackelberg leader with the major market power for the allocation of the item-level RFID tag cost between manufacturers and retailers for maximizing supply chain profits.

With the introduction of advanced information systems, such as RFID, Reyik and Sahin (2012) examined the economic impact of inventory record inaccuracies. The

**Table 4** RFID simulation modeling

| Authors | Assumptions and scenarios |
|---|---|
| Gaukler et al. (2007) | One manufacturer and one retailer<br>A single product supply chain<br>Backroom stocking decisions are made within a one-period vendor framework based on demand distribution knowledge<br>Focus on product availability on the retail shelf<br>Compares expected profits under item-level RFID with expected profits without RFID<br>Base model is a centralized system compared to a decentralized system; both comparing with and without item-level RFID<br>There is no cooperative between manufacturer and retailer in the decentralized model scenarios |
| Reyik and Sahin (2012) | Inventory management controlled by an infinite horizon, single-stage, single-product periodic-review policy<br>Focus on the behavior of a store inventory system exposed to inventory record inaccuracy<br>Shrinkage errors caused by a difference between the physical and information system inventory level<br>Two situations are compared: impact of shrinkage errors and the value of considering the inventory inaccuracy issues when optimizing the inventory and inspection policy<br>RFID as a visibility provider<br>RFID as an anti-shrinkage tool |
| Gu (2016) | Distributor and retailers use a periodic review base-stock policy<br>ASI sharing enables the focus retailer to predict the occurrences of a disturbance (e.g., a possible stock out at the distributor at a future time)<br>Single-product supply chain<br>Three lead-time distribution patterns and three distributor's expected service level<br>Explore how much ASI sharing can bring the benefits to retailer |
| Gu et al. (2017) | Three-echelon supply chain: manufacturer, distributor, retailer<br>The non-RFID base model has a vendor managed inventory agreement between the distributor and the retailer<br>The RFID-enabled model allows information sharing along the supply chain<br>Demand follows a normal distribution with 3 different standard deviations<br>The number of production lots during each distributor ordering cycle is tested at four levels<br>The production cycle time is varied across eight levels and though back-ordering is allowed there are no partial shipments |
| Reyes et al. (2021) | RFID is an automatic identification data capture (AIDC) technology and a tool for data analysis.<br>The simulation provides an example of how RFID, for collecting timely and relevant data, could be applied to supply chain analytics.<br>A simulation study of a two-echelon system of a retail store and a DC to model an inventory replenishment method that examines the value of using RFID for decision making. |

inventory management system is controlled by an infinite horizon, single-stage, single-product periodic review policy that is subject to shrinkage errors. These shrinkage errors are caused by the difference between the actual physical and information system inventory levels. They model two scenarios for comparison. The first scenario is the current practice where RFID technology is not used to track shrinkage and the inventory is therefore controlled by estimating the expected shrinkage rate. The second scenario then permits management of the joint ordering and inspection policy based on the information obtained on shrinkage errors when using the RFID technology. By comparison, the study shows how RFID deployment produces two benefits: total visibility of the shrinkage rate and the elimination of the shrinkage errors.

Gu (2016) presents a new concept and definition of advanced supply information (ASI). The value of advanced supply information in which retailers use upstream information about supplier's current availability and remaining lead time of orders to make inventory decisions is studied. In contrast to using demand information for the replenishment decision (which has been extensively studied in previous research), the ASI refers to the information on future supply in terms of quantity and timing. Two simulation models were developed to identify the value of ASI under various conditions. With RFID, the sharing of ASI efficiently and effectively between supplier and buyer is possible. Gu's model integrates the real-time ASI facilitated by the RFID system into the retailer's inventory replenishment decision-making process.

Gu et al. (2017) modeled a three-echelon supply chain of a retailer, distributor, and a manufacturer. In the non-RFID base model, the distributor and the retailer have a vendor-managed inventory agreement and replenishment quantities are based on an economic order quantity. In the RFID-enabled model, information is shared along the supply chain and the manufacturer has access to real-time demand information at the retailer to better plan production lot sizes. Their results showed the financial benefits of lot-splitting by the manufacturer as well as the mitigation of the bullwhip effect along the supply chain.

Reyes et al. (2021) examined the use of RFID as an automatic identification data capture (AIDC) technology and as a tool for data analysis. The primary purpose of this paper is to provide an example of how RFID, for collecting timely and relevant data, could be applied to supply chain analytics. We use a simulation study of a two-echelon system of a retail store and a DC to model an inventory replenishment method that examines the value of using RFID for decision making. They report on five of seven collected performance measures for each of the simulated scenarios. One important finding of this research is that with the improved inventory record accuracy that RFID technologies provide, grocery stores can take advantage of more efficient reordering policies. The research concludes with a look at RFID's implication for facilitating an inventory replenishment system generated by the DC instead of the retail stores.

These five RFID simulation modeling studies are highlighted as potential starting points we continue to unlock the potential values of RFID in the supply chain. Practitioners and researchers have long known that item-level tracking of products with RFID has an exceptionally high potential for the omnichannel fulfillment industry. Omnichannel fulfillment allows customers to move freely between channels of distribution, such as online, mobile, and physical retail channels.

Stockouts and overstock situations are common in traditional fashion retailing (Ovezmyradov & Kurata, 2022). Shrinkage and misplacement are other known issues. Omnichannel fulfillment combined with item-level RFID provides new opportunities for retailers and customers. Item-level RFID tracking can reduce shrinkage and improve inventory visibility with less labor. Additionally, RFID is the most common component of the Internet of Things, which can become increasingly important to the supply chain management and decision-making supported by Big Data Analytics.

## 5 Emergent Concerns, Outstanding Research, and Future Directions

This section offers direction for discussion and development of related topics for future RFID in the supply chain research from the Industry 4.0 era lens. In particular, outstanding research and future direction should consider scientific, theoretical, and research investigation of RFID-based technology converging with other Industry 4.0 technologies of Internet of Things, blockchain, smart cities, and AI/machine learning. Future studies could be explored with case studies and simulation.

RFID applications have targeted supply chain management and logistic processes. Casella et al. (2022) provide insights from a review of RFID technology in the logistics field and report that “tracking” and “monitoring” at a macro-level are the most popular and general applications in logistics. An RFID-based tracking and tracing system offers the needed visibility of items in the supply chain. The monitoring application is used with the inventory management system with the capability to monitor inventory levels, movement, and storage without human intervention. The future challenge and perhaps the best potential direction of research is the “localization” at a micro-level for both tracking and monitoring applications. This topic could then be investigated from an automated RFID-based replenishment system that combines the IoT and blockchain perspectives.

Much has been studied from a linear economic model, but very little has been from a circular supply chain. Emerging research in RFID technology driven by blockchain technology can help manage the complexities of circular supply chain management by establishing transparency and traceability across several industries. Paul et al. (2022) identified and categorized eight applications of blockchain-driven circular supply chain management: (1) suppliers’ choice and production, (2) control of materials in logistics, (3) deployment of information management resources, (4) supply chain management, (5) operations and production, (6) procurement, (7) reverse logistics, and (8) waste reuse through various circular supply chains. Adding RFID for product identification and tracking enables intelligence to the blockchain. The information from each RFID tag can be stored in a blockchain to trace the position of each item during its life cycle. Hence, an RFID-enabled blockchain can be used to provide a frontier for improving security and accuracy in the supply chain (Lacka et al., 2020). The added benefits could be a reduction in inventory loss, increasing the quality and speed of processing, and improving information accuracy.

The lean production system was introduced by Toyota in the 1960s and is well known as the Toyota production system or just-in-time manufacturing and has been applied to global supply chains. While the application of lean production and RFID technology has been explored for improving logistics operational efficiency, little has been studied on managerial decision-making effectiveness. The benefit and costs of using RFID in the supply chain have been extensively analyzed and promoted for increasing supply chain efficiency and decreasing labor costs. With a lean supply chain RFID-based system, potential benefits would include the replacement of labor through automation, cycle time reduction, and loss prevention. Bottani and Rizzi (2008) indicated that reengineering models for distribution centers and retailers could provide increased benefits gained through RFID for all processes applicable to fast-moving consumer goods. Chen et al. (2013) simulated receiving and shipping processes in central distribution centers and local distribution centers using RFID and focused on lean, RFID, and cross-docking. The preliminary experiments showed that the total operation time can be saved by 81% with the integration of RFID and lean. The saving in total operation time can be enhanced to 89% with cross-docking. The utilization of RFID technology can have significant labor cost savings while maintaining service capacity. This simulation study can be extended to further RFID-based applications in supply chain and logistics. For example, RFID coupled with AI/machine learning can automate the inbound logistics of receiving and storage. Based on an integrated smart cities system, the RFID tags can be read at inbound locations and the smart cities can effectively assign a storage slot within the distribution center based on anticipated outbound demand that would generate high-velocity throughput inventories for the picking and shipping processes – and thus potentially further reducing the total operation time. Continuous improvement and utilizing both the information flow and material flow in an RFID-based lean system in the Industry 4.0 era could be extended to a smart cities approach in supply chain management to increase the effectiveness and efficiency.

While RFID can be seen as a prerequisite to IoT platforms, by comparing RFID technology with Wireless Sensor Network (WSN) with different attributes, understanding the different protocols, and the working principle of RFID, there is great potential for the integration of the two toward a machine learning application. Due to the cost limitations still found in chipped RFID tags, a “chipless” RFID tag is an emerging solution that should be explored. Suresh and Chakaravarthi (2022) suggest the identification of sensing applications in agricultural, aviation, structural health monitoring, and food/chemical industries. Deployment of passive RFID tags at different places of the farm has already been in execution and added to the precision of agriculture farming, where the yields have been increased by continuous evaluation of soil moisture and temperature. In the aviation industry, RFID tags are already being used for effective baggage identification and tracking, with plans to expand to machine learning of the aircraft monitoring system collecting data obtained by strain, vibration, temperature, and humidity sensors of cabin environment transmitted to a central data repository. The health monitoring of the aircraft landing gear would be of interest as well. However, the aerospace industry is different from other industries due to the issues like extreme environmental conditions that add uncertainty, higher costs of the components, and compliance with regulations, standards, certification, and documentation. Finally, in the post-COVID pandemic, attention toward people's health and dietary habits has been given priority attention. To ensure food quality and safety, it is mandatory to monitor the packaged food products throughout the entire supply chain up to the end-user.

RFID-IoT offers a new operating solution in the supply chain. The evolution of RFID-IoT will bring a significant impact focusing on manufacturing, retailing, inventory management, transportation, assembly, asset tracking, location, and environmental detection (Tan & Sidhu, 2022). Arguably, the basic idea of RFID-IoT is not new (Ashton, 2009), but the convergence of these technologies has matured as a dynamic global network where each physical and virtual asset is individually identified with a unique ID. What makes this novel is that the interaction and communication among the objects and machines can lead to autonomously responses. In the supply chain, the RFID-IoT can then identify the status of an object, inventory stock level, equipment, machine, and even workers capturing real-time data for improving effectiveness in the decision-making process through the internet. The advantages of RFID-IoT are associated with product and resource management, operational management, and information management. However, from a technological perspective, the adoption of RFID-IoT is still challenging and should be explored.

## 6 Managerial Implications

While finding the ROI for the RFID in the supply chain implementation is a managerial concern, in this section, we focus on the management and practical issues. First, we describe how RFID fits with the organization's strategy. Then we describe an approach for the management of uncertainty in RFID and the technology investment and real options value to understand and manage the risks with the RFID investment. Then we conclude with a practical approach toward an eight-step guideline for RFID implementation.

### 6.1 How Does RFID Fit with the Organization's Strategy?

Conceptually, unlocking the business value of RFID in the supply chain begins with understanding what RFID can do and cannot do for the organization. Beyond the technology implementation, understanding the data captured with RFID, the managerial question is how does RFID with the organization's strategy? Based on the process-focused nature of RFID in the supply chain use, the business process-oriented framework proposed by Mooney et al. (1996) is an appropriate approach for unlocking the business value of RFID in the supply chain and fitting with the organization's strategy.

The business process-oriented framework was originally developed to facilitate the assessment of the business value of information technology and is appropriate to the RFID technology adoption. The typology of the process-oriented framework consists of two clearly divisible processes: operational processes and management processes. Operational processes are those activities that are required to complete the work of the organization that makes up the organization's value chain. The operational processes are affected by the RFID technology that can be used to improve the efficiency of value creation. Management processes are those activities associated with administrative, allocation, monitoring, and control that effectively and efficiently use the organization's resources. The management processes are facilitated through improved availability and communication of information. The use of RFID can improve efficiency and provide higher levels of available information for identifying, processing, and tracking goods as they move through the supply chain. Since RFID is an information and communication technology, the business process-oriented framework is therefore used to assist in the RFID technology adoption.

There are three stages that impact the operational and management processes for value creation through the RFID technology: operational, informational, and transformational. These are summarized in Table 5. In the first stage, automational, effects relate to the value derived from making the process more efficient. For operational processes, the metrics include labor cost reductions, improved reliability and efficiency, and reduced throughput and inventory costs. Management process metrics include a reduction in administrative expenses, better control of processes, easier reporting, and automation of routine activities. In the second stage, informational, effects are related to the ability of the technology to collect, store, process, and distribute the data and information. Improved utilization, quality of information and responsiveness, reduction of waste, and greater flexibility are proposed metrics for operational processes. Management process metrics include improved effectiveness, decision-making quality, resource usage, and higher levels of creativity. Finally, in

**Table 5** Business value metrics

| | Automational | Informational | Transformational |
|---|---|---|---|
| Operational<br>(Focus on efficiency) | Labor cost<br>Reliability<br>Efficiency<br>Inventory costs<br>Throughput | Utilization<br>Quality<br>Responsiveness<br>Waste<br>Operational flexibility | Product and service innovation<br>Cycle times<br>Customer relationships |
| Management<br>(Focus on effective decision making) | Administrative expense<br>Control<br>Reporting<br>Routinization | Effectiveness<br>Decision quality<br>Resource usage<br>Empowerment<br>Creativity | Competitive flexibility<br>Competitive capability<br>Organizational form |

Source: Mooney et al. (1996)

the third stage, transformational, effects refer to the ability of the RFID technology to create process innovation and transformation. Reengineered operational process metrics may then include product and service innovation and enhancements, reduction in cycle times in the organization's value chain, and higher levels of supplier relationships and customer relationships. Management process metrics may include improved competitive flexibility and capability, and perhaps a redesign of the organization.

Unlocking the business value of RFID in the supply chain is a three-stage process. The first stage primarily focuses on automation resulting in potential cost reductions of certain operational processes, such as labor costs and improved shipping and receiving efficiency, improved inventory control, reduced inventory costs, and improve a higher levels of throughput velocity. Following the automation, a major second stage for the informational effect is where RFID could trigger the automatic shelf replenishment which could then reduce potential stockouts. Finally, in the third stage, the transformational effects of RFID would be generated by redesigning or reengineering the operational process for improving resource flexibility and utilization.

## 6.2 RFID Technology Investments, Real Options Value, and Managing Risk

In general, technology investments pose opportunities and risks, leading to a positive or negative value for a firm and its customers (Devaraj & Kohli, 2002). Technology investments also provide opportunities to use managerial flexibilities available when adopting and using technology (Bowman & Moskowitz, 2001; Fichman et al., 2005). Real option evaluation methods can financially model and account for operational flexibility (Bengtsson, 2001; Bengtsson & Olhager, 2002; Fichman et al., 2005) and managerial decision-making flexibility (Shockley, 2007; Kodukula & Papudesu, 2006; Fichman et al., 2005). Following Kogut and Kulatilaka (2001, p. 745), we define a *real option* as an "investment in physical and human assets that provides the opportunity to respond to future contingent events." Real option decision characteristics include sequential investment opportunities over the present and future time periods, irreversibility of those investments, payback uncertainty, and the ability of managers to exercise discretion (Kogut & Kulatilaka, 2001; Adner & Levinthal, 2004b). Table 6 describes the characteristics. Uncertainty may result from various factors that occur over the technology investment life cycle, including flexibility enabled by technology, uncertain technology reliability, and future decision options made available.

Often, as time passes, managers learn more about the nature of a technology investment decision. This learning has value. In learning, a manager may better position the firm to benefit from making a technology investment. As such, many real-world options exist for a manager with respect to technology investments: delaying, investing more (or less) in a future period, terminating a project, portfolios of choices, and many combinations of options (Kodukula & Papudesu, 2006). Table 7 describes common real options.

**Table 6** Characteristics of real options investment decisions

| Real option characteristics | Description |
|---|---|
| Sequential investment | Project investment involves multiple stages over several time periods. First period investment sets the stage for subsequent follow-on project investment decisions |
| Irreversibility | Once spent, project costs cannot be fully recaptured |
| Uncertainty | Decision makers do not know with certainty what the benefits or payoff may be for a technology investment. Project investments also may entail risks. Technologies may evolve in unpredictable directions. Technology adoption may place unknown constraints on future investment decisions |
| Manager discretion | Managers can make intelligent decisions regarding how to structure a project, when to make future decisions, and how much to invest at a future time. Managers also can make decisions regarding qualities of investment outcomes |

Sources: Kogut and Kulatilaka (2001) and Adner and Levinthal (2004b)

Options thinking approaches provide managers with means to build real options into innovation plans, and to tactically extract real option value (Fichman et al., 2005). Formal real option analysis (ROA) applies financial option evaluation methods to estimate the value that options provide (Mun, 2006). ROA methods can provide decision makers with improved financial estimates and lead to increased managerial tendency to experiment and explore uncertain innovation opportunities (Bowman & Moskowitz, 2001; Fichman, 2004). As ROA often involves sophisticated numerical techniques (Kodukula & Papudesu, 2006), managers instead may rely upon qualitative insights and conceptual frameworks to inform them about investment scenario real options (Brealey et al., 2008), or use less formal tools such as decision tree models, scoring methods, or intuition (Fichman, 2004; McGrath & MacMillan, 2000).

Real options concepts relate to many strategic and technology management theories. Strategic capabilities chosen by managers can be thought of as irreversible investments in future opportunities, thus real options provide appropriate foundations to evaluate and value firm capabilities, exploration, and exploitation (Kogut & Kulatilaka, 2001). Organizational learning concepts also can be interpreted within a real options framework, including theories such as the Resource Based View and Knowledge Based View (Kogut & Kulatilaka, 2001). Since real options methods conceptualize the path-dependent nature of decisions, they resonate well with behavioral and evolutionary theories (Adner & Levinthal, 2004a).

Particularly relevant to RFID delivery systems, project managers can use real options to evaluate advanced technology innovation (Fichman, 2004), including RFID applications (Fichman et al., 2005). Yet to our knowledge, no study performs ROA analyses of RFID service delivery systems. Due to the complex uncertainty in IT projects, many executives rely on instinct rather than formal analyses of IT investments (Tallon et al., 2002). ROA provides a means to better account for uncertainty, but articles document the challenges of applying ROA to IT decisions

**Table 7** Common types of real options

| Real option name | Description |
|---|---|
| Growth option | A managerial option to create future growth. An initial investment creates an option to grow the project's (or company's) scope of activities if the immediate investment turns out to be a success. Growth options may relate to entering new markets, introducing new products, or adopting new technologies |
| Change scale option (Expansion option, Contraction option) | A managerial option to alter a project's capacity if the immediate investment turns out to be more (or less) successful than anticipated |
| Staged investment option (Sequential compound option, Compound option, Time-to-build option) | A managerial option to break the total investment up into a series of smaller incremental, conditional investments. This option creates a future option that depends upon the successful execution of a present option |
| Switch use option (Switching option) | A managerial option to vary the mix of inputs or production methods used, or to vary the mix of outputs produced |
| Learning option | A managerial option in which the project can resolve uncertainty through active learning |
| Deferment option | A managerial option to put off a decision until a later time period, by which time the manager has learned more about the decision scenario, or the environment has become more favorable for the project |
| Abandonment option | A managerial option to shut down or abandon a project, and sell off any related assets |
| Chooser option | A managerial option in which several possible strategies or tactics must be chosen between |
| Barrier option | A managerial option that depends upon whether a project has reached or exceeded some barrier event |
| Parallel compound option<br>Collections of interacting options | A project may be characterized by a collection of several options from the above types, with each of the options active simultaneously and potentially interacting |
| Rainbow option | An option whose payoff is determined by multiple sources of uncertainty |

Sources: Trigeorgis (1996), Brach (2003), Fichman (2004), Mun (2006), Kodukula and Papudesu (2006), Tiwana et al. (2007), Brealey et al. (2008)

(Tallon et al., 2002; Angelou & Economides, 2005). Conceptual literature describes the potential benefits of using ROA to analyze IT investments (Tallon et al., 2002; Fichman et al., 2005), and case studies of ROA use (Benaroch & Kauffman, 1999; Balasubramanian et al., 2000; Campbell, 2002). Empirical studies examine whether perceived real options drive IT project continuation, finding troubled projects are more likely to continue when managers perceived real options (Tiwana et al., 2006). Tiwana et al. (2007) observe managers may only recognize IT project real options when traditional NPV benefits are low. Opportunistic managers overlook real options until they provide project justification leverage. We instead contribute by exploring whether managers actively use real options embedded within RFID service delivery systems to induce learning and generate value.

## 6.3 An Eight-Step Guideline for RFID Implementation

In general, the purpose of this subsection is to help the supply chain professional with some guidelines for the RFID in the supply chain decision. The guidelines offer instructions to managers who are in a dilemma as to whether RFID is right for their organization or application. The following is an eight-step guideline for RFID implementation. Refer to Table 8 for a summary. These guidelines extend those found in Reyes and Jaska (2007).

### Step 1: Understand What RFID Can and Cannot Do

RFID is an exciting technology with great potential benefits for improving supply chain operations. However, before an organization can begin to implement RFID in

**Table 8** Guidelines for RFID implementation

| Step in implementation | Description | Personnel involved |
|---|---|---|
| Understanding what RFID can and cannot do | Getting past the myths | Key personnel that will use the RFID system and IT |
| Analysis of present system | Analyze the processes and outcomes of the present system | Key personnel using the present system, IT, and management |
| Build an ROI business case | Analysis of what potential benefits could be reached with RFID | Key personnel using the present system, IT, and senior management |
| Requirements analysis | Analyze the requirements and how RFID will be implemented | Key personnel using the present system and slated to use the new RFID system, IT, and management |
| Prototype testing | Test the proposed RFID system | Key personnel that will use the RFID system and IT |
| Implementation | Implement the RFID system | All personnel using the RFID system and IT |
| Monitoring | Monitor the RFID system to make sure it meets expectations | Key IT personnel and management |
| Continuous improvement | Look for improvements to processes and technology changes | Management, IT, and key personnel using the RFID system |

its supply chain, there must be a clear understanding of what RFID is (and is not) and where it would align with the organization's strategy and value chain.

**Step 2: Analysis of Present System**
As with any technology analysis, system requirements must be determined. This includes a thorough analysis of the system or process. The analysis requires a detailed process flow and interviews of key individuals who interact with the present system. The analysis of the present system provides a benchmark for identifying the starting point and what specific supply chain operation processes need improvement.

**Step 3: Building a Business Case**
Once an analysis of the present system has been conducted, an ROI business case is required. Specifically, what potential benefits could be reached with RFID.

**Step 4: Requirements Analysis**
Following the analysis of the present system, a new process model needs to be developed that would utilize RFID to its full potential. This includes an understanding of RFID capabilities and limitations. For example, improving customer service through more accurate and timely order delivery may require a complete redesign of the order delivery system.

**Step 5: Prototype Testing**
After the redesign or adjustment of the present system, RFID implementation will require extensive testing to ensure the new system will deliver the anticipated results. Adjustments to both processes and procedures will be necessary to help guarantee the success of the new RFID system.

**Step 6: Implementation**
Once the new system has been tested, then the implementation process can begin. This may require running both (old and new) systems in parallel to ensure accurate results.

**Step 7: Monitor**
Once implemented, the RFID system needs to be monitored and continuous improvement measures should be identified. This will ensure that the RFID system continues to meet expectations and advances as needed to meet the goals of the organization.

**Step 8: Continuous Improvement**
Continuous improvement is a necessary aspect of all supply chain activities. To reduce costs, maintain customer satisfaction, and stay competitive; continuous improvement is vital to success. It is in this stage that the option thinking approaches provide managers with the means to build real options into innovation plans and the third (transformational) stage of the business process-oriented framework.

## 7 Summary, Conclusion, and a Look Ahead

While RFID technology is certainly not new, the continuously increasing attractiveness of this technology is undeniable. RFID has been reshaping the supply chain management landscape. Since the *big bang* of RFID, the technology has been moving toward an RFID-integrated supply chain. It is unrealistic to believe that RFID will completely replace the bar code. However, RFID is a complementary technology for improving the end-to-end supply chain management network.

Understanding the benefits and the challenges is important for organizational performance. While a favorable ROI is desired, sometimes a direct financial measurement should not be the lone factor in determining the RFID adoption decision. Improving customer service also affects the bottom line and should be considered.

The primary challenges for designing RFID applications are operational, technical, and financial challenges. Security and privacy challenges continue to be a concern.

Supply chain professionals are constantly pressured to focus efforts and investments on reducing costs and improving customer service.

RFID provides persistent, real-time identification information with minimal human intervention. This allows for more frequent data collection and greater information capture. RFID further offers unprecedented levels of data reliability and intelligence that can be used to eliminate waste, align manufacturing with business priorities, maintain high levels of customer service, gain supply chain agility, and much more.

The RFID benefits and the associated costs with the price of readers and the potential impact on a firm's information technology (IT) infrastructure have been discussed. Although these are real costs that have affected the decision to deploy RFID systems, an important consideration is being overlooked and often neglected. For this technology to make a difference, the benefits should be realized systemwide closed-loop with trading partners and the value gained should transcend to the entire supply chain. Once a determination has been made regarding the usefulness of RFID in one firm, an analysis should then be extended across the supply chain to determine if performance holds for all supply chain members.

The benefits of RFID could be summarized into five broad areas:

- Automation: reducing manual processes through automated scanning and data entry reduces human error and improves productivity, thus allowing resources to be reallocated to higher-value activities.
- Integrity: improving the integrity of real-time supply chain information, with increased authentication and security and tracking capabilities, reduces errors, shrinkage, and counterfeiting while improving customer service and satisfaction.
- Velocity: minimizing the time spent finding and tracking needed assets increases product flow and handling speed.
- Insight: providing real-time information makes it possible for faster, better-informed decisions and the ability to be more responsive to the customer.

- Capability: providing quality enhancements, process improvements, and new applications helps to meet the demands of supply chain partners and enhance the customer experiences.

Ever since the Walmart and Department of Defense decisions to move RFID to the forefront as a strategy for improving supply chain operations, RFID technologies and applications have matured quickly. As a result, RFID applications have become more efficient and effective tools for improving supply chain operational efficiency and enhancing customer service.

Walmart's objective was to replace bar codes and scanners with RFID tags and readers to increase speed, efficiency, and security in the supply chain, and to reduce inventory levels, out-of-stock merchandise, and labor cost within the retail stores and warehouses. Other potential benefits in supply chain performance include (1) improved accuracy and security of information sharing across the supply chain; (2) reduced storage, handling, and distribution expenses; (3) increased sales through the reduction of out-of-stock merchandise; (4) improved cash flow through increased inventory turns and improved utilization of assets, and improved customer service and satisfaction; and (5) increased collaboration and planning across supply chain partners.

While inventory management is one use of RFID, other potential advantages are in homeland security, allowing agencies to screen people and materials as they pass through an airport, harbor, or any type of checkpoint. In health care, RFID can be applied in hospital settings to ensure that patients are not given new medication that interacts with other drugs already taken. The pharmaceutical industry can use RFID to resolve issues of counterfeiting and diversion of goods. RFID can be used to track assets from secure computers to priceless artwork. In courts of law, there are applications both to help manage the thousands of documents lawyers use to build a case and to protect the integrity of a chain of evidence for officers of the court. In libraries, RFID has reduced costs associated with lost inventory, as we would expect. Now a library can take a complete inventory of its holdings in a few days rather than months, and patrons can passively check books in and out by merely passing by a reader.

All supply chain managers should become familiar with RFID and its applications. As many companies implement RFID, a company that does not adopt then risks being at a competitive disadvantage. Customers may come to expect improved customer service from suppliers using RFID, through improved visibility and reduced stockouts. RFID also enables reduced inventory-related costs through improved processes, which take advantage of improved inventory visibility across the supply chain and trading partners.

Despite the challenges, more and more businesses are implementing RFID technology or at least exploring the potential. RFID capability will allow supply chain coordination to accomplish two major goals. First, it will allow for improved seamless inventory management among the supply chain trading partners with e-procurement and e-replenishment capabilities at the supplier-buyer interfaces (Reyes et al., 2021). Second, with improved inventory visibility, RFID will provide the potential for overall inventory reduction without hurting customer service levels. These benefits will be difficult for companies in competitive industries to pass up.

### 7.1 So What Is Next?

Not long after the *big bang* of RFID in the supply chain, the store of the future was romanticized as simply allowing customers to shop at the retail store and then walk out without human interaction at check-out. The item-level tagged items would be read at the exit and the transaction would automatically be registered and charged to the customer's credit card (a cashless payment method).

*The Jetsons* is an American animated sitcom that was produced by Hanna-Barbera Productions, and originally aired in prime time from September 23, 1962, to March 17, 1963. It was a comical version of a century in the future. In fact, it was viewed as the future of the Internet of Things and the utilization of robots and automation. In the animated sitcom, the future was idealized with multiple technologies that are now being considered in the industry 4.0 era: RFID-IoT, blockchain, smart cities, and blockchain.

*Player Piano* is the first novel by American writer Kurt Vonnegut Jr., published in 1952. The novel depicts a speculated community or society of an automated world that reduces the need for human intervention in the processes. Partly inspired by the author's time working at General Electric, the novel describes how the impact technology can have on the quality of life. The automation of industry and the effect that it has on society are the predominant themes. A player piano is a metaphor for a modified piano that "plays itself," where the piano keys move according to a pattern of holes punched in an unwinding scroll that has been replaced by machines instead of people. The story takes place in a near-future society that is almost totally mechanized, eliminating the need for human laborers. The widespread mechanization creates conflict between the engineers and managers, who keep society running, and the lower class, whose skills and purpose in society have been replaced by machines. While this seems to be a utopia of the near future, these ideas began with the beginning of the third industrial revolution during the early 1950s (known as the era of automation).

These three examples of predicting the future have some merit. However, the future is now. Motivated by the Industry 4.0 era (known as the era of smart factories), an important future RFID role is to enable global supply chain management environments that will have a greater need for information-intense data collecting and processing. These include the IoT, Industry 4.0, Artificial Intelligence and Machine Learning, and Blockchain (Reyes et al., 2021). In 1999 Kevin Ashton introduced the term *Internet of Things* to describe the idea of RFID connectivity with the internet for the purpose of gathering and saving information without the need for human interaction. By using RFID and sensors attached to objects, these devices can communicate and interact with other such connected objects over the internet. The idea of smart factories and smart facilities can be integrated with IoT, Blockchain, and RFID to reduce waste and improve the supply chain environment. From a managerial perspective, managing the dynamics of technologies for supply chain management, we are victims or beneficiaries of these converging technologies (Reyes et al., 2020). In the end, organizations should consider if the RFID technology can truly meet their strategic goals.

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# Servitization, Modularity, and Innovation in Supply Chain Management

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## Contents



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**Abstract**

Servitization is a value proposition that integrates service with product offerings, from which manufacturers are able to create solutions that add value and nurture long-lasting ties with customers. Services becoming a central part of many manufacturing company offerings have made servitization a business model innovation. Servitization can be quite complex in terms of configuring products with a wide range of services. The question for many manufacturers is how to manage the complexity and balance between innovation and standardization. In this chapter, modularization is introduced as an approach for managing the complexity embedded in servitization, with particular focus on product platform strategies, decomposition, product architecture, service modularity, components, and interfaces. The benefits and challenges posed by servitization and why modularity can be applied to ease the complexity of integrating product and services into new offerings pose many concerns. Concerns include developing product and service platforms, configuration of business models for digital servitization, and supply chain management for servitization. The emerging cross-disciplinary research on servitization, modularity, and innovation opens new research opportunities, such as in transitioning to the servitization supply chain, servitization strategies for sustainability in supply chains, and research methodologies in servitization. Implementation of digital servitization will lead the companies to restructure their supply networks to foster more integration and transparency in information sharing. Moving forward we identify eight opportunities to advance servitization knowledge.

**Keywords**

Servitization · Modularity · Innovation · Sustainability

## 1 Introduction

Many manufacturers are embarking on servitization as a strategy to compete through value propositions that integrate products with new development of services (Avlonitis et al., 2014). By creating integrated product-service offerings, manufacturers are able to create solutions that add value, nurture long-lasting ties with customers, and are difficult for competitors to replicate (Baines et al., 2009; Martinez et al., 2010). Servitization can generate higher profit margins and stable revenue streams (Wise & Baumgartner, 1999), differentiate a company from its competitors, increase product sales as well as create a loyal customer base (Vandermerwe & Rada, 1988; Baines et al., 2009).

Embarking on a servitization journey can be expensive, long, and risky for manufacturers (Neely, 2008; Gebauer et al., 2005). It often requires substantial investment in technology, company capability, network, and information technology (IT) systems (Ulaga & Reinartz, 2011). The process of servitization is also time consuming with delayed revenue streams, where profitability can take years to achieve (Gebauer et al., 2005; Neely, 2008).

The integration of products with services as a combined offering prompts manufacturers to revisit their business models. Depending on innovation level, servitization can be quite complex in terms of configuring products with a wide range of services. The question faced by many manufacturers is on how to manage such complexity and balance innovation with standardization.

In this chapter, modularization is defined as an approach for managing servitization complexity (Baldwin & Clark, 2000; Mikkola, 2006; Magnusson & Pasche, 2014; Hsuan et al., 2021). Modularizing a complex product, by dividing it into smaller pieces, makes the product easier to manage. The overall goal is to have a product in which the modules are fully decoupled from each other which makes it possible to make a change in one module without affecting other modules (Sanchez & Mahoney, 1996; Mikkola, 2003). The application of product and service modularity for managing the complexity embedded in digital servitization is elaborated in this chapter.

This chapter is organized as follows. The next section outlines the background on servitization. Section 3 outlines the literature foundation on servitization, modularity, and innovation. Section 4 discusses current concerns posed by servitization for many manufacturers, including developing product and service platforms, configuration of business model for digital servitization, and supply chain management for servitization. In Sect. 5, emergent concerns, outstanding research, and future directions are proposed with respect to transitioning in the servitization supply chain, servitization strategies for sustainability in supply chains, and research methodologies in servitization. Eight opportunities for advancement along these topics are proposed. Section 6 poses managerial implications of servitization. Section 7 is the summary and conclusion of the chapter.

## 2 Background

The term *servitization* was coined by Vandermerwe and Rada (1988), who observed that many companies, even industries, were shifting their core business and revenue generation by adding value to their core offerings through services to create competitive edge. They describe how traditionally product-focused companies develop new services for complementing their product offerings, and deliver additional functionality for the customers. The aim is to create and develop combination of product-service solutions that provide value to customers that exceed what products and services can do separately. That is, product-service solutions are used for describing offerings in which products and services are seamlessly integrated.

Wise and Baumgartner (1999) articulate why manufacturing companies, traditionally product focused, should aim for servitization. They explain that in the automotive industry, only 20% of the total potential revenue from the product's entire life cycle comes from its initial sale. By extending their business, and integrating more service in their offerings, automotive companies can capture more of these total revenues. Hence, there is a large potential for companies to increase both revenue and profit by having a servitization strategy.

The general view of service and what a service is has changed over time. In the *IHIP service school* (c.f. (Zeithaml et al., 1985)), to differentiate from goods, services are described as intangible (*I*), that is, services lack the tactile quality of goods; heterogeneous (*H*) where services cannot be easily standardized; inseparable (*I*) where services are simultaneously produced and consumed; and perishable (*P*) where services cannot be produced ahead of time and inventoried.

Around 2004 a new *service-dominant logic* started to develop. Considered a modern thinking in marketing, service-dominant logic argues that everything is a potential service, built on the following principles (Vargo & Lusch, 2004): service is the fundamental basis of exchange; the customer is always a cocreator of value; all economic and social actors are resource integrators; and value is always uniquely and phenomenologically determined by the beneficiary.

The implication following from a service-dominant logic is that a service focus is a means to create value, and especially for the customer. Hence, for companies moving toward servitization it is very important for them to focus on, and understand, the value creation dimension in their service development. One important, and fundamental, difference between a service and a physical product is that value is cocreated between supplier and customer during usage – a *value-in-use* (Vargo & Lusch, 2004).

*Value-in-use* means that that value of a service, compared to a product, is not determined when the service is sold or bought, but when it is used. For traditionally product-focused manufacturing companies, the development of integrated product-service solutions requires a deeper and extensive understanding of customer needs, requirements, and operations than what is needed when only developing products. For example, Raja et al. (2013) stress the importance of acquiring in-depth insight into customer processes. Both services (processes) and products can create value as they render a service. In product-service solutions, the goal is to integrate the products and the services in a way so they are adding a surplus value for the customer (Brax & Jonsson, 2009).

As services become a central part of many manufacturing company offerings, servitization becomes a business model innovation. For example, instead of only selling products, many companies are offering different types of leasing contracts, where customers pay for using the product, such as per month or per the number of hours the product is used. In the well-known Rolls-Royce concept of *power-by-the-hours* launched in 1962, customers were offered complete engine and replacement services on a fixed cost per hour flying basis.

The drivers for manufacturers to embark on the servitization journey include strategic, financial, and marketing (Baines et al., 2009). Strategic drivers focus on market differentiation with customization possibilities and developing services that are hard to imitate. Financial drivers aim at attaining stability of income over time, increased profit margins, becoming less sensitive to low-cost competition, creating greater distance from the price discussion, and being able to be less sensitive to economic cycles (with combined product-service offerings). For instance, during economic recessions, or the recent Covid-19 pandemic, companies that have suffered a loss of sales from new products, selling different types of services can be a way for the companies to survive. Marketing drivers are steered by demand for services requested by customers, selling more products through services, customer loyalty, and development of customer relationships.

Services differ on whether they aim to support the product or the customer (Mathieu, 2001). Services supporting the product can be, for example, basic installed-base services and maintenance services (Oliva & Kallenberg, 2003) or product life cycle services and asset efficiency services (Ulaga & Reinartz, 2011). In contrast, services supporting the customer focus on end user processes, such as through professional services and operative services (Oliva & Kallenberg, 2003) or advanced services focused on performance improvement (Baines & Lightfoot, 2013).

Although there are many benefits for a manufacturing company to have an increased focus on services, studies also show that servitization projects do not always become as successful as expected (Benedettini et al., 2015). It was found that only 21% of the companies were successful in implementing a servitization strategy – even with heavy investments, manufacturers that transitioned into services generated less profit (Neely, 2008), the so-called *service paradox* (Gebauer et al., 2005). This observation means that manufacturers have to consider ways to limit their costs for the development of new service offerings, such as through standardization – which provides positive economies of scale effects (Kowalkowski et al., 2015).

Servitization also entails significant organizational change (Baines & Lightfoot, 2013). Martinez et al. (2010) identify five categories of challenges that a company has to consider when moving toward becoming a product-service-oriented organization:

- Embedded product-service culture: Traditionally product-focused manufacturing companies often has an organizational culture that hinders the transition toward increased service focus. Therefore, the organization needs to foster a thinking of always to consider, and focus, on the end customer. It is about moving from transaction-based to relationship-based value creation.
- Delivery of integrated offering: Servitization and the development of integrated product-service solutions means that a broader range of personnel in the company are, and need to be, exposed to the customer than previously. There is also a risk that when the organization is under stress it tends to revert to a focus on product rather than the whole integrated product-service solution.
- Internal processes and capabilities: Companies need to adapt their internal processes. The existing product development process might not the suitable for

developing services. In addition, existing key performance indicators (KPIs) might not be suitable for the development of integrated product-service solutions and offerings.

- Strategic alignment: Some companies face a challenge in establishing an alignment of mindset and understanding toward service provision. It is important to have common mindset and language and to *think like a customer*.
- Supplier relationships: Moving toward offering integrated product-service solutions makes it necessary to get closer insight into the problems and opportunities of customers, which calls for a high degree of cooperation between the service provider and its supporting network. However, even if information sharing in the downstream supply chain (between the service provider and its customers) becomes increasingly intense, it is often much more limited in the upstream side (between the service provider and its suppliers).

We now focus a few topics related to servitization including digital servitization, modularity, and innovation, in particular, product platforms, modularization strategy, product architecture, interfaces, modularization function and measures, and service modularity.

# 3 Literature Foundation

## 3.1 Digital Servitization

Servitization is about competing through strategic value propositions that integrate service with product offerings (Avlonitis et al., 2014). Digital servitization (DS) integrates product, service, and software into the offerings. A barrier to achieving the desired integration is the lack of a business model and operations direction. Based on the development of innovative solutions and strategy, firms need to configure or reconfigure their business models to enable competitive operational excellence in delivering DS solutions. Whatever DS integration strategy a manufacturer plans on adopting, the decisions must be made and the subsequent implementation strategy established in the light of the company's capabilities and willingness to innovate its business model – in both the short and long term.

Manufacturers should be concerned with the following issues: (1) operationalization of their business model innovation in relation to integrated product, service, and software systems strategy; (2) the trajectories to take for implementing the desired strategy; (3) the management of complexity embedded in the business model for DS; (4) the processes for integrating product, service, and software systems into DS strategies; and (5) resources required to implement the business model. The integration of products services with software requires (re)-configuration of a manufacturer's business model to manage the complexity of DS. One approach to manage the complexity of servitization is through modularization strategies.

### 3.2 Modularity and Innovation

Many companies are increasing the extent of offerings with customized products, as a way to gain competitive advantage (Magnusson & Pasche, 2014). Greater customized product offerings result in more product variants to manage. Many companies have implemented product platform strategies to efficiently deal with this increasing product variety (Jha et al., 2014; Mikkola, 2006).

### 3.3 Product Platforms

Meyer and Lehnerd (1997, p. 7) define a platform as "a common structure from which a stream of derivate products can be efficiently developed and produced." The overall aim for a company to adopt and implement a product platform strategy is to increase the commonality among different products as well as between different product variants (Kim & Moon, 2017). The development of products based on platform strategies has been widely applied in the automotive industry. For example, Volkswagen's MQB platform allows the assembly of multiple car models in their factories.

By defining a standard base – platform – of subsystems, components, and interfaces a large number of derivate products can be efficiently developed (Meyer & Lehnerd, 1997). Components and subsystems in this platform can be reused in the development of new products and product variants (Halman et al., 2003). Hence, this platform-based system facilitated continuous product introductions and innovations.

A product platform can also be considered as a set of physical elements and components that are common across a variety of different products (Sköld & Karlsson, 2007). By sharing components between different product variants gives companies positive economy of scale and scope effects (Magnusson & Pasche, 2014; Sköld & Karlsson, 2007). Reusing components from previous products in new product development also enhances benefits such as reduced product development lead time and cost (Mikkola, 2006).

Commonality sharing and components reuse are common practices in the development of new products. As such, companies can gain from reduced development lead time and costs. The common components can potentially reduce the number of suppliers needed, hence decreasing the need for coordination with the suppliers during the development of new products. In turn, the reduction of the number of variants of different components eases the complexity of material handling.

### 3.4 Modularization Strategy

Closely related to platform strategy is the modularization, a strategy for managing complexity by decomposing complex products into smaller pieces, modules, each consisting of a number of components (Baldwin & Clark, 2000). A key aim in product modularization is to define standardized interfaces between the different modules (Mikkola, 2006).

A product module is characterized as a distinguishable and separable unit of a larger system, a unit whose behavior is largely independent of the others, a unit where interactions among components are stronger than the ones taking places among different subsystems, and a unit where actors are grouped together or located in the same place.

Modularization strategy makes it possible to mix and match different components – and variants of components – into highly customized products fulfilling customer-specific needs and requirements. It not only reduces product development costs and lead times, but also enables the configuration of flexible products that are easier to upgrade and repair.

It is rather common that companies combine the use product platforms and product modularization simultaneously even though the overall aim of these two strategies differ slightly. While platform strategy gives economies of scale and scope benefits, product modularity gives positive effects in terms of economies of substitution. Economies of substitution include the possibility to upgrade, or customize, products by only upgrading single modules or components, while the rest of the product is unchanged (Magnusson & Pasche, 2014).

## 3.5 Product Architecture

Closely related to product modularity is the product architecture. Product architecture is concerned with the mapping of components from functional elements to physical components (Ulrich, 1995). Four different types of product architectures exist and are characterized by how the mapping is done from functional elements to physical components, as shown in Fig. 1. The simplest form of product architecture is the modular design, in which one function is allocated to one single module. The most complex form is the integrated design, in which several functions are allocated to several different modules. Between these two “extremes” one can find two other types of product architectures, namely function sharing and function distribution.

Product architectures can vary from modular to integral (Mikkola, 2003). While modular architectures are concerned with standardization and economies of scale, integral product architectures focus on performance and craftsmanship. A modular architecture includes a one-to-one mapping from functional elements in the function structure to the physical components of the product, and specifies the decoupled interfaces between components.

A modular product architecture also makes it easier to respond to changing customer demands, and to develop customized products (Simpson, 2004). An integral architecture, on the other hand, includes a complex (not a one-to-one) mapping from functional elements to physical components or coupled interfaces between components (Ulrich, 1995). Hence, it is not possible to make changes in one component or module without incurring changes in other components or modules (Mikkola, 2003), however, making it possible to optimize product performance such

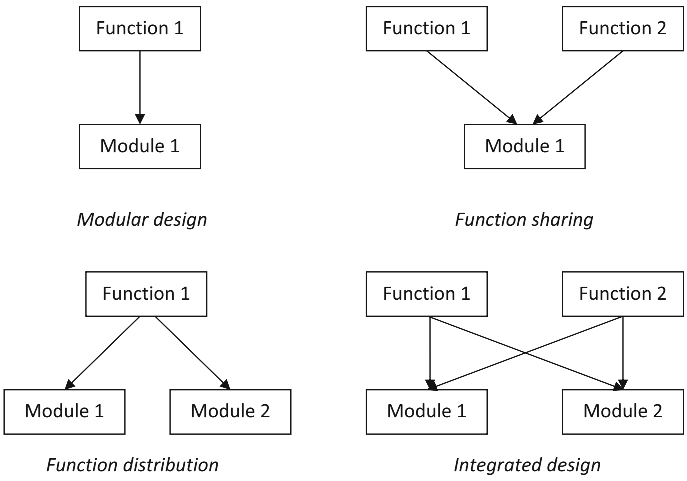


**Fig. 1** Different types of product architectures. (Erens & Verhulst, 1997)

**Table 1** Differences between modular and integral product architectures (Mikkola, 2006)

| | Modular product architecture | Integral product architecture |
|---|---|---|
| Design criteria | Commonality sharing | Maximum performance |
| Component boundaries | Easy identification | Difficult identification |
| Redesign to architecture | Without modification | With modification |
| Interfaces | Decoupled | Coupled |
| Outcome | Economies of scale | Craftsmanship |
| Product variants | High | Low |
| Nature of components | Standardized/Generic | Unique/Dedicated |
| Component outsourcing | Easy | Difficult |
| Learning | Localized/Dispersed | Interactive |
| Synergistic specificity | Low | High |
| Component substitutability | High | Low |
| Component recombinability | High | Low |
| Component separability | High | Low |
| Nature of innovation | Autonomous | Systemic |
| System design strategy | Decomposition | Integration |

as the product's size, shape, and weight (Muffatto & Roveda, 2002). Table 1 shows the differences between modular and integral product architectures.

There are positive and negative effects associated with modular and integral product architecture designs. A modular product architecture has the benefit that it can be used as a flexible platform for leveraging a large number of product variations enabling companies to gain cost savings through economies of scale from component commonality. It also makes it possible to introduce technologically improved products more rapidly. In addition, having a modular product architecture minimizes the physical changes required to achieve a functional change. In a modular product architecture, a change can be done in one component/module without leading to changes in other components/modules (Mikkola, 2003).

### 3.6 Interfaces

Interfaces are of great importance in product modularization. To define and standardize the interfaces for different variants of a module is what creates the flexibility to develop and offer customized products. Interface specification defines the protocol for primary interactions across component interfaces, and mating geometry in the cases where there are geometrical connections (Ulrich, 1995). However, there are also different types of interfaces between modules, not only the physical interfaces. Table 2 shows some examples of different types of interfaces.

For example, in some products two components can be placed in different parts of the product, although they are related to each other in the sense that they have to work together to fulfill a function. One example of such functional interface is the climate system in a car: There are components distributed in the instrument panel and in the engine compartment, yet they must work together to fulfill a certain function.

There can also be situation in which two components can be attached to each other without having any functional relation. A practical case of this situation is the engine compartment of a car in which there are various components that are attached to each other, but they actually do not need to be in order to fulfill functions. Since all of these components are competing for the same space in the engine compartment, they can be described to have a spatial interface toward each other. These components therefore have a spatial interdependence. This practically can mean that if one

**Table 2** Different types of module interfaces (Sanchez, 2000)

| Type of interface | Description |
|---|---|
| Attachment interfaces | Define how one component physically attaches to another |
| Spatial interfaces | Define the physical space (dimension and position) that a component occupies in relation to other components |
| Transfer interfaces | Define the way one component transfers electrical or mechanical power, fluid, a bi-stream, or other primary flow to another |
| Control and communication interfaces | Define the way one component informs another of its current status and the way that other components communicate a signal to change the original component's current state |
| Environmental interfaces | Define the effects, often unintentional, that the presence or functioning of one component can have on the functioning of another (e.g., heat, magnetic fields, corrosive vapors, radiation, etc.) |
| Ambient interfaces | Define the range of ambient use conditions (e.g., ambient temperature, humidity, elevation, etc.) in which a component is intended to perform |
| User interfaces | Define specific ways in which users will interact with a product |

of the components has to be made larger, the others probably have to be made smaller, otherwise not enough space exists.

### 3.7 Modularization Function and Measures

For more complex products it is very difficult to achieve a 100% fully modular product architecture due to the existence of many functional relations and interfaces (as described above) between different components event if they are not physically attached to each other. As such, the aim of adopting product modularity strategy is to develop a product architecture toward being more modular. There is a continuum between the modular and the integral product architecture, or a degree of modularity.

There is not an all-or-nothing perspective when discussing modularization; some degree of modularity can be found in any product and can be increased or decreased depending on many different factors. Most products or systems embody hybrid modular-integral architectures (Mikkola, 2006). In practice, two physical components connected by an interface are almost always coupled to some extent, and hence it is seldom that a change actually can be made in one component without requiring changes also in the other components.

Products have an architecture that is a mix of the *function sharing* and the *function distribution* (Erens & Verhulst, 1997). Mikkola (2006) classifies four types of components (standard, new-to-the-firm, customizable, and non-customizable) and introduces a *modularization function* to measure the degree of modularity embedded in product architectures imposed by respective components and interfaces. Chrysler Jeep's windshield wiper systems and Schindler elevators showcase the applicability for the function.

The product modularity – and product architecture logic – is extended to investigating organizations and processes. Defining an organization's product and process architectures is a critical step in clarifying the nature of the technological knowledge resources and organization has access to delineate the relationships between an organization's knowledge resources. Product modularity also facilitates the decoupling of tasks – that is, different product development tasks can be carried out in parallel, where the development teams can work autonomously without the need for intensive coordination during the product development project.

The fundamental modularization principles are applied to the design of product development organizations (Brusoni & Prencipe, 2001). Standardizing interfaces between different modules in the physical product makes it possible to decompose a large and complex product development project into a number of smaller and more manageable subtasks that then can be distributed and accomplished by a number of different individuals. The product development process, and the development project, can be efficiently coordinated if the development of all modules conforms to the standardized module interfaces. This is referred to as *embedded coordination* (Sanchez & Mahoney, 1996), meaning that the standardized module interfaces allow for coordination with minimal managerial effort, contributing to shorter product development lead time.

It is suggested that product modularization can improve companies' ability for innovation (e.g., Hsuan et al., 2021) because it is easier to develop and combine new product modules, thereby accelerating the introduction of new products. Alternatively, it is also argued that product modularity hinders developing innovative products when modules are reused, thereby leading to similar product designs. In any case, adopting product modularity can lead to organizational challenges, in the sense that different organizational functions might favor different ways of managing the product modularization and prioritization of modules and interface solutions (Persson & Åhlström, 2006). This can cause complex trade-offs which calls for the involvement of management to take decisions on what to prioritize (Persson & Åhlström, 2013).

## 3.8 Service Modularity

Recently the concept of product modularity has extended to investigate service systems in terms of service modularity and service architecture (Brax et al., 2017). As mentioned, service systems differ from product systems in many ways (Brax et al., 2017; de Blok et al., 2014). Services are activities that are essentially intangible and perishable, with production, delivery, and consumption of services taking place simultaneously. Service systems are designed to create consistent service offerings that achieve the strategic vision of the organization.

Roth and Menor (2003) mention three interrelated elements that a service system design should consider: (1) strategic service design choices; (2) service delivery system execution, renewal, and assessment; and (3) customer perceived value of the total service concept. A service module is defined as "a system of components that offers a well-defined functionality via a precisely described interface and with which a modular service is composed, tailored, customized, and personalized" (Tuunanen et al., 2012, p. 101).

Similar to product systems, service systems can be portrayed in a continuum of basic to advanced services (Hsuan et al., 2021). Basic service systems tend to have many standard elements (e.g., generic, mass services), high levels of replicability (i.e., easily copied), low levels of customization (i.e., customers cannot personally change the nature of the services offered), low consulting portions and specialization (i.e., low involvement of professional services), and low cost for customers (Brax et al., 2017).

Examples of basic service systems in the maritime industry include fleet management, simple repair and maintenance, call centers, and the availability of spare parts. Advanced service systems, in contrast, have few standard elements (e.g., service shops and professional services), low levels of replicability (i.e., imitation by competitors can be difficult), high levels of customization, consulting portions, and specialized elements (i.e., delivered services are per customer's needs), and can be expensive for customers. Examples of advanced service systems include piracy prevention training, financial services, smart services, R&D consulting, and dedicated software updates.

Voss and Hsuan (2009) provide a categorization of service architecture based on whether choice of service modules to be consumed at a point in time and whether the service modules are consumed consecutively. Furthermore, built on the *modularization function*, they provide a conceptualization of service architecture and develop the *service modularization function* to measure the degree of service modularity deriving from unique service and their replicability across family of services. Examples from cruise ships and banks illustrate the applicability of the model.

## 4 Current Concerns

The various benefits and challenges posed by servitization along with how platform and modularity can be applied to ease the complexity of integrating product and services into new offerings pose many concerns, including developing product and service platforms, configuration of business model for digital servitization, and supply chain management for servitization.

### 4.1 Developing Product and Service Platforms

There is a wide range of benefits for companies to gain from implementing a platform strategy in joint development of products and services (Jagstedt & Persson, 2019). The overall aim of adopting a platform strategy is to be able to develop customized products and services in an efficient way, to gain positive economies of scale and scope effects (Magnusson & Pasche, 2014).

Ongoing studies (Kreye et al., 2022) of several Nordic manufacturing companies facing servitization transformation shows that many companies are also adopting a platform strategy in their development of customized services. This adoption is occurring because it is too costly to develop fully unique services for every single customer. The use of a platform strategy for service development has generated benefits such as shorter development lead time, shorter delivery time, increased variety in service offerings, decreased development cost, and improved quality (Kreye et al., 2022). Some companies also find it easier to align service offerings across products and regions, and for the customer to grasp complex service offerings.

There are also challenges in developing service platforms; for example, conflicting requirements from different organizational functions affecting the platform design, thus difficulty having one common platform for all markets (Kreye et al., 2022). It is also a challenge to balance between a top-down and bottom-up approach in service platform development. When developing services, it is very important to do it in close cooperation with the customer to be able to identify how the services are intended to add value to the specific customer. However, to get positive economies of scale effects of the platform, there need to have both a top-down approach and central decision-making.

### 4.2 Configuration of Business Model for Digital Servitization

One current concern for manufacturers is not knowing how to manage the complexity of business model innovation when integrating product, service, and data or software systems. Hsuan et al. (2021) introduce modularity as a concept for managing the complexities embedded in business model innovations for digital servitization (Fig. 2).

The business model innovation (Level 1) is decomposed into four levels of granularity: servitization and digital servitization (Level 2), product, service, and software architectures (Level 3), and product, service and software modules (level 4).

Following a similar conceptualization logic of product architecture (modular and integral) and service architecture (basic and advanced), software architecture ranges between open and proprietary. The Digital Servitization Cube (Fig. 3) shows that there are eight distinct offerings configuration, DS1–DS8. DS1 is the most generic offering configuration (modular product, basic service, and open software) and DS6 is the most integrated offering configuration (integral product, advanced service, and proprietary software).

In their ongoing investigation of Danish manufacturers, Hsuan et al. (2021) show that there are endless trajectories a manufacturer can pursue, with the departure point starting at any of DS offering configurations. There is not one-size-fits-all strategy and there is no guarantee for success because balancing standardization and innovation is not trivial. The undertaken journeys of manufacturers showcase the trade-offs and risks considered (between standardization and innovation) in the configuration of required resources for business model innovation. They suggest that it is crucial for managers to have a good overview of product, service, and data/software competences of their organization and the resources required for the desired journey vis-à-vis the competitive landscape of its business.

### 4.3 Supply Chain Management for Servitization

As servitization extends a company’s core product to offer customer outcomes (Fischer et al., 2014), the company has to be even more aware of how to integrate customers into its processes, especially in service development. When developing new services, customers can be involved in strategic planning, idea generation, idea screening, business analysis, formation of cross-functional teams, service design and process system design, personnel training, service testing and pilot run, as well as test marketing and commercialization (Alam & Perry, 2002).

Digitalization accelerates the integration processes. As such, digital servitization opens a wide range of possibilities for manufacturers to innovate their business models, potentially creating new markets and fostering new partnerships. These possibilities require manufacturers to have a clearer view of their supply chain

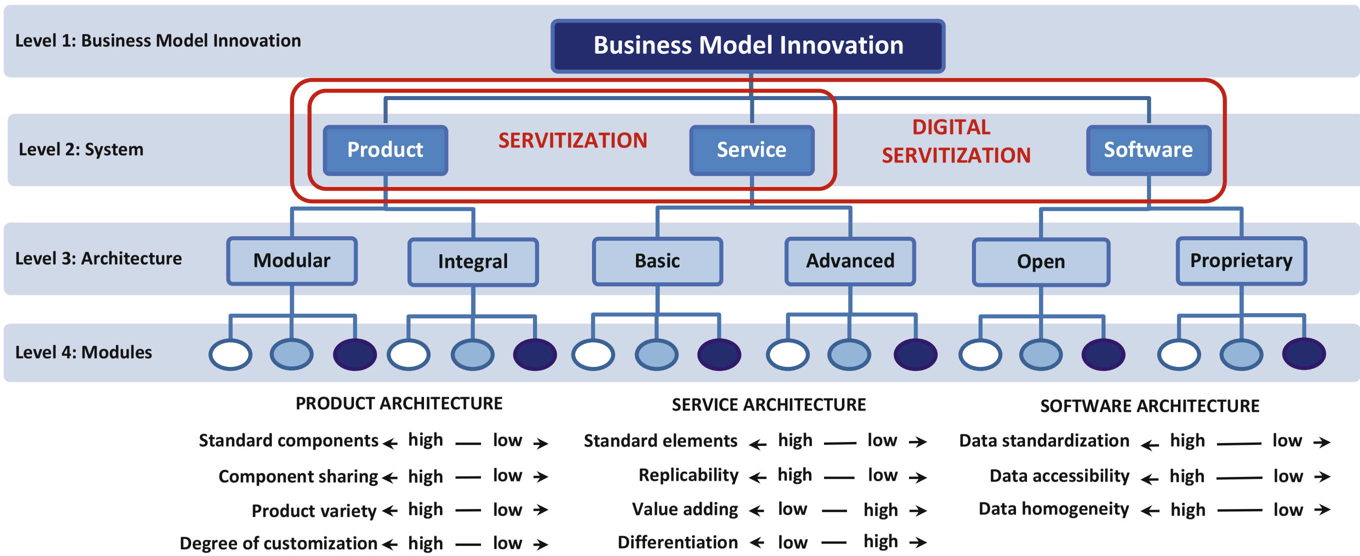


**Fig. 2** Decomposition of business model innovation for digital servitization

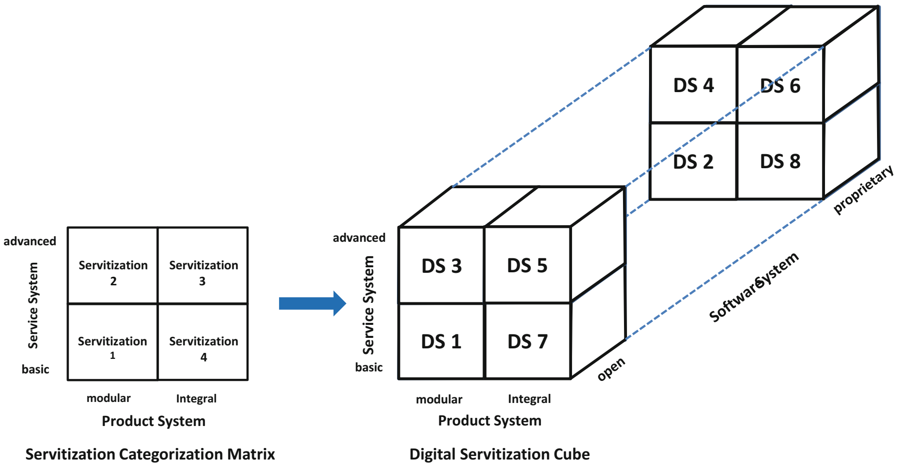


**Fig. 3** Digital Servitization Cube and DS strategies

networks and ways for identifying opportunities and challenges. This view might entail changes in structure and business processes of supply chain networks (Lambert & Enz, 2017).

Network structure considers collaboration and relationship with the partners, be arm's-length or strategic partnerships. Supply chain management considers the integration of the entire set of business processes – including order fulfillment, demand management, production planning, supply management, and product development – that provides products, services, and information that add value for customers. The literature suggests that the higher the level of integration with suppliers and customer, the greater are the benefits gained by all parties (Mikkola, 2003).

## 5 Emergent Concerns, Outstanding Research, and Future Directions

In their literature review on innovation within and across borders, Carrillo et al. (2015) identify servitization as one of the key topics for future research, particularly: (1) investigation of a manufacturer's ability to appropriate value from servitization; (2) operational implications of transitioning from products to services; (3) configuration of operations to deliver advanced services; (4) integration of product design and service design to address customer needs; and (5) in-depth empirical studies on the roles of interfaces in the context of service modularity and potential trade-offs between innovation on modules versus innovation on the system. The emerging cross-disciplinary studies on servitization, modularity, and innovation open new research opportunities.

## 5.1 Transitioning to the Servitization Supply Chain

As a firm embarks on servitization, it has to consider its transition process with respect to a wide range of issues including its servitization maturity level (Martinez et al., 2010), complexity of products and related systems (Raddats et al., 2016), service portfolio (Eggert et al., 2011), relationship with customers (Brax & Jonsson, 2009), contracts (Neely, 2008), production institutional structure (Araujo & Spring, 2006) vis-à-vis other manufacturers (Raddats & Burton, 2011), and organizational culture (Baines et al., 2009; Martinez et al., 2010).

Managing the service-driven transformation process requires a shift in management perspective (Barnett et al., 2013). It requires that the organization is willing to establish alignment between external environment, strategy, and organization of activities (Neu & Brown, 2005). Due to the multifaceted dimensions of servitization, very little is known about how companies manage long- and short-term change with respect to their activities and networks in their servitization journeys.

The transition process requires an interdisciplinary theory that integrates service management and human decision-making (Gebauer & Friedli, 2005). Furthermore, servitization strategies are context dependent, which means that decisions and activities have to be organized and coordinated, within and across organizational boundaries.

As servitization extends into the customer processes, firms have to find efficient ways of delivering the product-service offerings, from basic products to solutions or service-based offerings (Araujo & Spring, 2006). Fostering a service orientation mindset entails the development of innovative services that support the customer (Gremyr et al., 2010), which is coupled with the strength of relationships the organization has with its customers (Mathieu, 2001). For many firms, this relationship building entails the (re)configuration of resources and capabilities via their networks. Firms often rely on their network partners for complementary resources or obtain the sources of competitive advantage through supply chain management, which calls for a closer supplier-buyer-customer relationship (Hsuan et al., 2015; Halldorsson et al., 2007).

The gradual move toward additional customer value provokes the need for creating external alignment (Matthyssens & Vandenbempt, 2008) with stakeholders (e.g., match the needs and requirements of the purchasing group) and customers (e.g., match between buyer's requirements and vendor's offering strategies), crucial to achieve value and gaining mutual benefits (Wong et al., 2012; Gobbi & Hsuan, 2015). The literature on inter-firm alignment in the context of servitization is scarce.

There are many potential directions for future investigation and consideration. We provide a few here.

**Future opportunity 1:**
- Understanding interorganizational relationship management in servitization supply chain

The literature is rather rich on portraying the successful servitization transition of companies such as Atlas Copco (Kastalli & van Looy, 2013), Rolls-Royce, Xerox International, ABB, Nokia, and others (Baines et al., 2009). Such cases provide rich insights into the challenges when implementing servitization. However, there are limited insights into what a company commencing on the digital servitization journey should do to handle these challenges, as digital servitization requires radically different knowledge and competences (Tronvoll et al., 2020). As such, the literature is scarce on frameworks in integrating product-service-software dimensions to theorize the transitional trajectories (Kohtamäki et al., 2019).

**Future opportunity 2:**

- Developing change management tools and frameworks for managing digital servitization journeys

Implementation of servitization as a strategy requires that the manufacturer is willing to reconfigure, change, and to innovate its existing business model (e.g., Clemente et al., 2019). For example, the traditionally product-focused company might decide that it will no longer sell products and profit from selling spare parts later when the product needs to be overhauled and repaired. Instead, increasing number of manufacturers are offering the customers different types of leasing contracts, where the customer pays a certain amount of money per month, including "everything" like repair, insurance, etc. In this case, the manufacturing company changes and extends its scope in the product value chain.

In this new business model, the usual profit of selling spare parts instead becomes a cost that the traditionally product-focused company would like to minimize. Consider a manufacturer of trucks. In the traditional business model, the customer can purchase the truck directly from the manufacturer but get the services, such as overhaul and repair, from any third-party service company. This model can have detrimental impact for the manufacturer because it cannot control the quality of services rendered and parts used to replace the repaired component. It is not uncommon that a truck, or car, owner buys cheaper spare parts from another company than the one which was developed for, manufactured, and sold to the customer.

With servitization and business model innovation, the truck manufacturer would manage and control the whole overhaul and repair process through various mechanisms, such as leasing contract, to keep control of the product throughout its whole life cycle. This would provide opportunities for companies to carry out these activities in-house, hence obtaining the control of quality of these components and modules as well as to prevent piracy components from noncompliant suppliers.

Digital servitization poses additional challenges with the development of competences, requiring manufacturing companies to innovate business models that consider integration of functional silos (product, service, and software) as well as the configuration of resources within and across its firm boundaries (Hsuan et al., 2021). This opens doors on research opportunities, such as on mapping and measuring the degree of supply chain integration (or disintegration) for (digital) servitization strategies over time.

**Future opportunity 3:**
- Determining how business model innovation for servitization changes the boundaries of the firm
- Identifying servitization strategies that change the boundaries of the firms in the supply chain

## 5.2 Servitization Strategies for Sustainability in Supply Chains

The life cycle view, enabled by servitization as a business model innovation, of product and service management requires the manufacturer to consider how it can contribute to improved sustainability. There are additional opportunities for upgrading the product and remanufacturing to extend the total lifetime of the product. These activities can reduce the overall amount of waste and be socially responsible. This effort entails a holistic and interdisciplinary perspective to get a better understanding of the benefits and obstacles in managing the life cycle of integrated product and service offerings, from product and service development to product return, disassembly, and refurbishing.

**Future opportunity 4:**
- Understanding to what extent do servitization strategies contribute to addressing sustainability issues (such as waste) in the supply chain

Although research on product modularization has been extensive, not much focus has been on how product modularization is implemented as a strategy for improving both sustainability and profitability for traditionally product-focused companies moving toward a service-based business model. This shift could mean that instead of selling physical products, the manufacturing companies can offer customers different types of leasing contracts.

**Future opportunity 5:**
- Determining how modularity principles be extended to investigate servitization for sustainability and profitability in the context of servitization
- Understanding product modularization to help facilitate sustainability (less waste), for example, in terms of easier product disassembly, upgrading, and reuse
- Understanding what challenges companies face when adopting a product modularization strategy to achieve sustainability

Increased sustainability can be facilitated by a more modular product structure. Modularization means standardized interfaces and decoupled modules, which means that it is easier to replace or upgrade one module in the product without causing disruptions in the surrounding modules (Seliger & Zettl, 2008). Moreover, a module that has been replaced in the product can be repaired or remanufactured, and subsequently be used in another product – at the products end of life. This process reduces the total waste of spare parts. The total product lifetime is also extended, hence contributing to increased sustainability. In a business model with leasing contracts, for instance, instead of selling products, the usual profit of selling spare parts become a cost. Hence, the reuse of repaired modules should decrease the costs for the manufacturing company and increase its profitability.

**Future opportunity 6:**

- Developing product modularization to facilitate sustainability (less waste) in terms of easier product disassembly, upgrading, and reuse for servitization
- Designing product architectures for disassembly, upgrade, and reuse for servitization

Different organizational functions might favor different ways of managing product modularity. For example, functions may organize components into modules in different ways or choosing different module interfaces and product architectures (Persson & Åhlström, 2006). Sometimes this situation entails trade-offs that call for management involvement to make decisions on which solutions to prioritize. For instance, in order to benefit from product development and production functions, the company integrates these two functions together. However, in doing so it limits the accessibility of modules and components in the product that need to be overhauled and repaired. Hence, it might affect the service and after-sales (i.e., repair) functions negatively.

There are also other important aspects to take into consideration during the product development process, such as the need for a more extended life cycle view of the product and its use – which requires customer and supplier participation. As mentioned, when the usual profit of selling spare parts becomes a cost, decisions regarding materials and solidity have to be revisited in order to extend the total lifetime of the product. Another risk is that a modular product with standardized interfaces between the modules for different product variants might translate into a product with higher weight, compared to a nonmodular product, which would affect sustainability negatively.

**Future opportunity 7:**

- Overcoming challenges companies face when adopting a product modularization strategy to achieve sustainability

## 5.3 Research Methodologies in Servitization

Servitization opens up research and practical opportunities to explore insights from multidisciplinary domains and research communities, such as service science, industrial marketing management, and operations management. The majority of research on servitization is based on qualitative methods (such as exploratory and descriptive case studies) that are not theoretically driven but aimed at theory building (Rabetino et al., 2018). This presents limitless research opportunities for theoretical development and contribution with different methodologies and approaches.

**Future opportunity 8:**

- Advancement of servitization research through multiple research and investigatory methodologies

## 6 Managerial Implications

Many of the future opportunities we have introduced need to be addressed by research study, but they also represent possibilities for practical consideration. We identify practical managerial implications in this section.

Servitization poses challenges for firms to embrace new challenges related to services, be integrating simple services (e.g., helpdesk, repair, maintenance, etc.) to design of new service concepts (e.g., remote sensing monitoring, professional consulting, etc.). Despite the benefits for why firms can gain from pursuing the servitization strategy, the challenges can be taunting. These challenges include (Carrillo et al., 2015, p. 243): identification of customer needs for integrated product and services offerings (Raja et al., 2013), formulation of attractive value propositions, configuration of operational capabilities to create and capture value, and revision and innovation of business models.

Sustainability adds another layer of complexity for management as well as creating new markets and ecosystems. Servitization has the potential to generate higher profit margins and stable revenue stream. It also contributes to differentiation from competitors, increase product sales as well as create a loyal customer base (Rabetino et al., 2018). However, to be successful in servitization, the manufacturing and traditionally product-focused company needs to cocreate (between supplier and customer) its services since the service need to add value when it is actually used.

Being closer to the customer might cause the risk of ending up in very expensive unique solutions that are difficult to scale up in a cost-efficient way. Therefore, an important managerial implication is that companies could consider implementing a platform strategy in its development of customized services because platforms can offer a useful way to organize a large portfolio of service offerings for different customer segments. Global services companies can use platforms for structuring their global service business and offer customers a standardized interface for services in an efficient way. It is also important for companies to be aware of, and balance between, a top-down and bottom-up approach in this development of a service platform.

Servitization and business model innovation toward offering different types of leasing contracts instead of selling products will change the selling of spare parts – that is often a very profitable business for many manufacturing companies – from profit to cost centers. The managerial implication from this result is companies investing more time and cost in the design phase to improve the product quality, reducing the need for spare parts later.

The business model of offering leasing contracts can potentially provide the OEM increased control of its products and subsequent overhaul and repair. As such, it will be more difficult for competitors to offer cheaper counterfeit spare parts. This will also affect boundaries of the firm, offering leasing contracts including product overhaul and repair is a vertical integration since the OEM integrates activities in later stages of the product value chain, activities most often accomplished by external actors before the company started their servitization journey.

## 7 Summary and Conclusion

Many manufacturing companies are implementing servitization as a strategy to increase their competitiveness and to create long-term relationships with its customers. However, many companies are still struggling to get the potential benefits from servitization implementation. As the market demand for customized goods continues to increase, being able to offer customized products is a way for companies to improve its competitiveness.

Customization possibilities also add complexity to the operations since it leads to increased number of product variants. To address this complexity many manufacturing companies, for many years, have adopted product platform and product modularization strategies. Similarly, the solution to offer more customized services and integrated product-service solutions is also enabled through platforms and modularity strategies. Nevertheless, when adopting a modularization strategy, companies need to balance the conflicting requirements from different organizational functions as well as between top-down and bottom-up approaches in developing efficient platform for service offerings.

Servitization and business model innovation force companies to consider changes in their organizational boundaries. Companies might consider to bring back activities in-house that were previously accomplished by external actors, and by this improve both its profitability as well as increase the control of products throughout the whole product life cycle. This can be facilitated by product modularity since a modularized product consists of decoupled modules with well-defined interfaces in between. Thereby any single module can be repaired, upgraded, or replaced in a short time and without affecting the rest of the product. Implementation of digital servitization will lead the companies to restructure their supply networks to foster more integration and transparency in information sharing. Moving forward this chapter proposed eight future opportunities to advance research and practice on servitization.

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# Sustainability and the Digital Supply Chain

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## Contents



**Abstract**

In the digital age, with growing awareness of sustainable development particularly in supply chains, there is need to provide insight on how the application of emerging information technologies may aid in actualizing supply chain sustainability. In this chapter, we discuss the relations between sustainability and the

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digital supply chain. The digital supply chain has the potential to improve sustainable practices and achieve sustainability goals. Specifically, we utilize the lens of the triple-bottom-line (TBL) approach, to illustrate how digital technologies can aid in supply chain sustainability improvements spanning economic, environmental, and social dimensions. Furthermore, using technology-organization-environment (TOE) theory, we emphasize that sustainability in digitally enriched supply chains can be facilitated by factors that relate to technological, organizational, and environmental contexts. We evaluate relevant constructs and implications for managers and decision-makers to further explore digital supply chains for sustainability implementation and improvements.

**Keywords**

Sustainability · Digital supply chain · Triple-bottom-line approach · Technology-organization-environment (TOE) theory · Digital technologies

## 1 Introduction

Supply chains are the backbone of economies and society and largely interact with nature. These interactions are complex and include interrelations and feedbacks between supply chains, nature, and the economy (Ivanov, 2020). Supply chains are strategic for actualizing sustainability objectives and increasing overall organizational performance and competitiveness. With increasing concerns over climate change, firms are constantly being pressured by a range of different stakeholders to consider sustainable development goals in their decisions. In response, some leading companies like Hewlett-Packard, IBM, and Walmart have started to integrate sustainability into their business models (Jin et al., 2021). Even in the automotive sector, major OEMs such as Jaguar and Land Rover have placed sustainability at the core of their business and supply chin strategies with their REIMAGINE initiative (https://media.jaguarlandrover.com/news/2021/06/sustainability-drive-jaguar-land-rover-strategy-new-executive-appointment-and (Accessed: November 13, 2021)).

As early as 2005, the CEO of Walmart, Lee Scott, made a commitment to sustainable development in their global supply chains, thereby motivating more than 200 suppliers to reduce the negative environmental impacts of their products (Bui et al., 2021). Company resolve to be sustainable encourages their supply chains to act on health and environmental issues since no single company can solve such issues on their own. Addressing these issues requires systemic whole supply chain change (Liu et al., 2021). The quest for sustainability has started to change the competitive landscape forcing organizations and supply chains to rethink their processes, their technologies, their products, and their business models (Shoukohyar & Seddigh, 2020). This quest culminates in United Nations (UN) sustainability goals adopted by the UN in 2015 detailing the 2030 Agenda for Sustainable Development, a blueprint for global welfare for current and future generations (Tsani et al., 2020).

With this backdrop, a new direction has emerged for practitioners and researchers to examine if and how digitally enriched supply chains can be instrumental in assisting firms in rethinking their business processes, technologies, and organizational models for achieving sustainability goals. Here, we focus on the nexus between implementing digital technologies for digitizing supply chains and achieving the triple-bottom-line (TBL) (economic, environmental, and social) dimensions of sustainability.

Recently, there has been an unprecedented application of emerging information technologies such as artificial intelligence (AI), big data analytics, blockchain, and machine learning in various domains. This application has ushered in the digital era – a new industrial transformation – that has resulted in some potential benefits. For instance, within the manufacturing context, this new era of industrial revolution has triggered the development of smart factories, intelligent manufacturing system architectures, and intelligent manufacturing technology systems (Liu et al., 2020).

Various researchers have provided perspectives on the application of digital technologies for improving quality, efficiency, cost, customer service, and overall manufacturing competitiveness. Likewise, the digital transformation has been felt across supply chains as well as the handling of supply chain operations within firms and across firms – this influence is the key to undergoing a rapid revolution.

We define the digital supply chain as an intelligent, value-added, novel network that utilizes new approaches, specifically digital transformation with technologies to create competitive value and network effects (Nasiri et al., 2020). This situation is highly significant as market forecasts indicate that 76% of global population has access to Internet and about 50% is actively using social media features (Penthin & Dillman, 2015). For instance, social media features using pictures and videos have a significant effect on alerting the masses on malpractices and other sharp practices. In addition, 90% of Internet users are online buyers, and about 43% apply advanced big data technologies. Furthermore, the Internet of things (IoT) is being increasingly popular. Over 26 billion "things" under IoT are being predicted to become operational (Manavalan & Jayakrishna, 2019).

Conventional supply chains consist of physical facilities scattered geographically that assist in the movement of raw materials from the initial suppliers to the manufacturers and finished products from the manufacturers to the end users (Buyukozkan & Gocer, 2018). Since the primary goal of organizations is to maintain and strengthen their core competencies in a dynamic market environment, companies are required to maintain interactions with their dealers through digital supply chains for improved operational efficiency.

In digital supply chains, physical warehouses are represented by data centers; physical boxes are captured by bits, while physical trucks are represented with bandwidth. Core technologies that drive the digital supply chains include augmented reality, cloud computing, sensor technology, IoT, nanotechnology, self-driving vehicles, 3D printing, robotics, big data, and unmanned aerial vehicle (Wang & Sarkis, 2021). Insights can be provided on the benefits of digital supply chains via the application of these core technologies, which can be laden with complexities.

Currently, the literature on digital supply chains is in its nascent stage. Consequently, the impact of digital supply chains on sustainability performance and its potential gains remain under-explored in theory and practice (Beaulieu & Bentahar, 2021; Liu et al., 2020).

The application of the core technologies of digital supply chains may be regarded as "revolutionary" in business operations, but very little is known of how such might forge a pathway to sustainability advantage (Raut et al., 2021). Furthermore, it is still unknown about how digital technologies might aid in reducing negative environmental impacts like pollution. Also, insights are not available on the economic sustainability since implementing digital technologies for supply chain digitization can be capital-intensive (Khan et al., 2021). Hence, this chapter aims to review the following questions:

Can digitally enriched supply chains help organizations improve their sustainable practices to achieve sustainability goals? What are the sustainability implications for each of the digital technologies within supply chains from a TBL and *technology-organization-environment (TOE)* theory perspectives?

The remainder of this chapter is structured as follows: in Sect. 2, a literature review on digital supply chains, its importance, and enablers is presented. Literature on the TBL of sustainability, namely, economic, environmental, and social dimensions, is presented in Sect. 3. Concerns over long-term sustainability of digital supply chains, unsustainable patterns, and reasons for unsustainable patterns are presented in Sect. 4. The summary of the chapter with relevant recommendations and future directions is presented in Sect. 5.

## 2 Basic Concepts in Digital Supply Chains

In this section, we will present a brief discussion on digital supply chains and some key technologies that can be utilized during implementing digital supply chains for expected performance gains.

### 2.1 Defining Digital Supply Chains

The digital supply chain is an intelligent best-fit technological system that is based on the capability of massive data disposal and excellent cooperation and communication for digital hardware, software, and networks (Buyukozkan & Gocer, 2018). As such, digital supply chains exist to support and synchronize interactions within and between organizations by making services more valuable, accessible, and affordable with consistent, agile, and effective outcomes (Buyukozkan & Gocer, 2018; Manavalan & Jayakrishna, 2019; Nasiri et al., 2020). In fact, available published studies in the extant literature indicate that "digital supply chain" and "supply chain 4.0" are used interchangeably, often with similarities in theoretical underpinnings. As such, the concept of the digital supply chain is still developing.

Studies that analyze their nexus with performance benefits and especially with regard to sustainability benefits are scarce (Haddud & Khare, 2020; Queiroz et al., 2019). Some of the notable features of digital supply chains include speed, flexibility, global connectivity, real-time inventory, intelligent, transparency, visibility, scalability, innovative, proactive, and eco-friendly (Nasiri et al., 2020; Queiroz et al., 2019).

## 2.2 Core Digital Technologies

In the era of digitalization, digital technologies including the IoT cloud computing, blockchain, additive manufacturing (3D printing), and big data analytics are the most commonly cited in the extant literature (Li et al., 2020). Many of these digital technologies are being piloted, deployed, or implemented by companies in order to improve their data-processing capabilities and their supply chain management and control activities.

### IoT

As one of the emerging information technologies, IoT comprises the infrastructure that assists in establishing the interconnectivity of physical objects and also facilitates the collection and transfer of data sets between connected devices (Manavalan & Jayakrishna, 2019). The main aspects of IoT comprise (1) the sensing aspect that is responsible for incorporating radio frequency identification (RFID) tags, sensors, and actuators; (2) the service aspect which aids in incorporating services and applications through middleware technology; (3) the networking aspect for supporting the transfers of information through wireless sensor networks; and (4) the interface aspect for displaying information, identifying problems, and recommending solutions to the user (Li et al., 2020).

The network aspect is equipped with Internet-based technologies, which allows IoT devices to communicate with each other in close proximity (e.g., RFID, Bluetooth, ZigBee) but also to share data among networks for distributed data processing through wider area networks. Prior studies exist on the topic of IoT in supply chain management in extant literature.

### Cloud Computing

Cloud computing is defined as a bundle of resources that are virtualized and distributed, which can be utilized as a service through software, infrastructure, and platform. Cloud computing is used to actualize the aggregation, management, and optimal allocation and use of information and data in the form of remote service (Li et al., 2020). The deployment models as indicated by prior research studies include private clouds, community clouds, public clouds, and hybrid clouds. Prior studies exist on the topic of cloud computing in supply chain management (Ali et al., 2021; Novais et al., 2019).

### Additive Manufacturing

Additive manufacturing sometimes called 3D printing or rapid manufacturing refers to a set of process technologies that can directly produce parts through the incremental addition of material layers, using data from 3D computer models (Delic & Eyers, 2020). Additive manufacturing is a technology that has the potential benefit to actualize “frictionless” manufacturing without the use of product-specific jigs, fixtures, dies, or cutting tools (Hedenstierna et al., 2019). Although past published studies exist on additive manufacturing, yet its application in supply chain management is still a growing research stream (Afshari et al., 2020; Ghobadian et al., 2020; Yilmaz, 2020).

### Blockchain

Blockchain technology uses cryptography to guarantee that a distributed digital ledger recording transactions cannot be changed (i.e., it is immutable). With the addition of smart contracts composed of script code, further transactions and processes can be automatically executed (Lim et al., 2021). As such, it enables a distributed consensus mechanism that allows its participating entities to be informed of every event and transaction by creating an irrefutable record in the public ledger (Dutta et al., 2020). Blockchain technology is currently applied in the financial sector and other nonfinancial sectors like e-government, credit analysis, e-commerce, and supply chains.

In the trade industry, Maersk and IBM cooperate to use blockchain technology to solve problems in cross-border supply chains because it increases information transparency and realizes information sharing among trading partners (Lim et al., 2021; Saurabh & Dey, 2021). It generally runs on high part of the Internet protocols as another application layer and does not require a third party to initiate economic transactions between related parties (Sahebi et al., 2020). Although there are numerous potential benefits of blockchain technology, its applications in supply chains are still in a nascent stage (Lim et al., 2021). Nevertheless, many research scholars have studied the application of blockchain technology in supply chain management (Pournader et al., 2020).

### Big Data Analytics

As one of the emerging information technologies, big data analytics has the potential to revolutionize business transactions in many industries by enabling companies to plan and act ahead of market competitors and offers a competitive advantage to firms (Sundarakani et al., 2021). Big data includes heterogeneous formats, characterized by volume, variety, velocity, and veracity and developed by firms to transform accumulation of data into useful information that can improve decision-making and support improved supply chain performance (Benzidia et al., 2021). Currently, the implementation of big data analytics in supply chains is still in nascent stage in spite of the numerous potential benefits including contributing to sustainability improvements (Raut et al., 2021; Sundarakani et al., 2021).

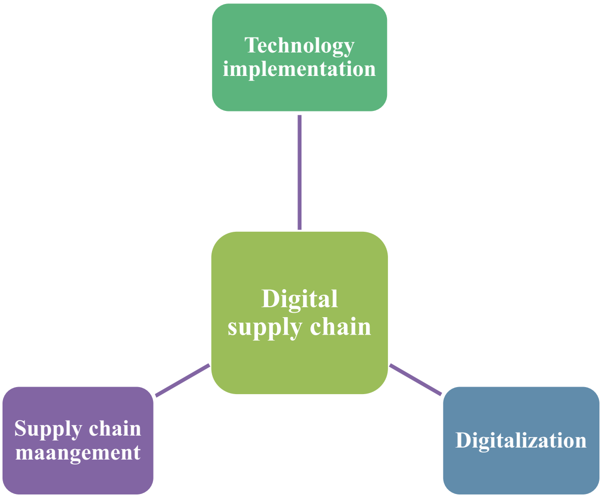


**Fig. 1** Digital supply chain framework

## 2.3 Framework for Developing Digital Supply Chains

The framework for implementation is based on the key desired digital evaluation objectives for supply chains, which is also essential in rethinking and redesigning entire supply chains by mapping the areas of digitalization, technology implementation, and supply chain management as illustrated in Fig. 1. Below, we discuss the areas in details.

### Digitalization

Digitalization is based on advancements in information and communication technologies which can considerably improve organizational operations and strengthen the linkages and agility of their supply chains. Digitalization is regarded as an emerging phenomenon with currently unclear definitions (Frederico et al., 2020; Orji et al., 2022b). Supply chain digitalization can include traditional technologies that have been established for decades such as electronic data interchange (EDI), electronic catalogs, and more recent sophisticated and far-reaching technologies like cloud computing, IoT, big data analytics, blockchain, and AI (Beaulieu & Bentahar, 2021; Orji et al., 2020). The application of such digital technical innovations can assist supply chains to improve on historical practices with benefits that include real-time synchronization and information flows, highly personalized production, and greater levels of flexibility and agility (Beaulieu & Bentahar, 2021).

However, emerging digital technologies may necessitate overhauling business models and the roles of supply chain partners. Digitalization requires supply chain stakeholders to develop sufficient technical expertise and hands-on experience (Seyedghorban et al., 2020; Zangiacomi et al., 2020). Digitalization needs to be aligned with organizational strategic plans rather than a hastened attempt to acquire emerging digital technologies (Hartley & Sawaya, 2019; Kittipanya-Ngam & Tan, 2020).

### Technology Implementation

Digitalization has allowed "smart" to become the epicenter of already ongoing technological developments, utilizing limited resources and leaving behind environmental footprints (Nizetic et al., 2020). The term digital technologies refers to a collection and paradigm of various intelligent and innovative technologies in the era of Industry 4.0., such as big data analytics, IoT, and cloud computing, which realize connectivity, communication, and automation (Li et al., 2020).

The deepening of technology implementation in supply chain systems has been disruptive to traditional operational methods in areas such as product development, production efficiency, and customer service. However, the acquisition of digital technologies may increase the dynamics of competition between firms in the business environments and even culminate to serious financial and environmental burdens on firms. In other words, digital technologies can be a harbinger of negative and unintended sustainability consequences. Yet, the nexus between these digital technologies and sustainability improvements is in nascent stage in available extant literature. Indeed, the impact of implementing digital technologies for improved sustainable performance can be well studied from a supply chain perspective (Li et al., 2020).

### Supply Chain Management

Globalization has increased the complexity of supply chains with greater interdependence and interconnections (Ivanov & Dolgui, 2020a; Pan et al., 2021). This calls for investments in information and communication technologies to facilitate, maintain, and enable the interdependence and interconnection. Information technologies can be utilized in supply chains to reduce information asymmetries and actualize effective supply chain management. Effective supply chain management relies heavily on the utilization of well-analyzed data. Data-driven decisions lead to better results in complex business environments. The introduction of information and communication technologies in supply chain management can significantly improve process-oriented performance, reduce energy consumption, and provide supply chains with a ubiquitous information infrastructure (Garrido-Hidalgo et al., 2019).

## 3 Sustainability Implications of Digital Supply Chains

Sustainability in digital supply chains can be referred to as management of materials, information, and capital flow, as well as collaboration and cooperation among the supply chain partners while implementing all sustainable developmental goals along the TBL of economic, social, and environmental dimensions (Bui et al., 2021).

## 3.1 Unsustainable Patterns

Unsustainable patterns in supply chains are hindrances to implementing sustainable initiatives. Marginal environmental practices, dangerous working conditions, and chronic overtime issues are some of the unsustainable patterns that are experienced in many developing countries. In their developed counterparts, observable unsustainable patterns may include lack of systematic accident reporting and a high concentration of harmful chemicals that are airborne (Villena & Gioai, 2020). Here, we outline the most common unsustainable patterns in supply chains to include lack of environmental management systems, chronic overtime issues, high rate of job turnover, high percentage of temporary workers, and lack of systematic accident reporting.

## 3.2 TBL Approach to Sustainability

The concept of TBL originally served as an accounting framework that included environmental and social dimensions within the conventional finance-centric business performance model (Goh et al., 2020; Smith et al., 2020). The TBL evaluates economic, environment, and social performance simultaneously (Budak, 2020).

### Economic Sustainability of Digital Technologies

Some of the notable measures of economic sustainability that can be implied from implementing digital technologies include cost minimization, flexibility, improved quality, and increased operational efficiency (Beaulieu & Bentahar, 2021; Goh et al., 2020; Smith et al., 2020). Below, we present the economic sustainability implications of the core digital technologies.

### IoT

The IoT perception capabilities build upon a variety of identification and tracking technologies that enable remote monitoring of physical objects without the need to be in "line of sight" (Koot et al., 2021). Consequently, through this basic concept of IoT, which entails sensing the physical world by interconnecting physical objects without the need to be in "line of sight," operational costs can be minimized for utmost economic sustainability improvements.

### Cloud Computing

Through implementing cloud computing, companies can make use of relevant and personalized information from the cloud service provider through the Internet without investment in complex and on-premises intermediaries. As such, cloud computing can aid supply chains to improve reduced investment costs and actualize improved economic sustainability performance (Ali et al., 2021).

### Additive Manufacturing

Additive manufacturing can enable firms to fulfill customer on demand eliminating expensive warehousing requirements resulting from uncertain customer demand. Thus, additive manufacturing can be highly significant for supply chains to achieve flexibility and overall improved economic sustainability.

### Blockchain

Blockchain technology may revitalize the supply chains by ensuring that information shared is authentic and traceable during transmission between supply chain partners and may facilitate transactional security in risky scenarios (Hald & Kinra, 2019; Tijan et al., 2019).

The adoption of blockchain technology is considered desirable due to its unique features such as real-time information, information sharing, cybersecurity, reliability, traceability, visibility, and transparency, and these features may also improve supply chain operational performance.

### Big Data Analytics

Overall business and financial performance can benefit from the application of big data analytics to organization supply chain management processes (Bag et al., 2020). The strategic improvements available through big data analytics such as forecasting and statistical and operational analysis via optimization techniques significantly contribute to enhancing operational efficiency (Bag et al., 2020).

## Environmental Sustainability of Digital Technologies

The notable measures of environmental sustainability that can be derived from the deployment of digital technologies include pollution control, green design, and resource optimization (Hald & Kinra, 2019; Kouhizadeh et al., 2021; Liu et al., 2020; Tijan et al., 2019). Moreover, some of the digital technologies like IoT, cloud computing, and blockchain are considered as multi-stakeholder technologies. In essence, these multi-stakeholder technologies have implications for integrating stakeholder input across the supply, and this has implications especially for environmental and social issues. Below, we present in details the environmental sustainability implications of digital technologies.

### IoT

The implementation of IoT can culminate in environmental sustainability improvements (Koot et al., 2021). IoT can enable reduced waste in circular supply chain management. Furthermore, IoT can be integrated with other digital technologies like blockchain to effectively track environmental conditions, which may be threatening to sustainability (Kouhizadeh et al., 2021; Manavalan & Jayakrishna, 2019).

### Cloud Computing

Cloud computing will assist in the future advancement of a firm's supply chain systems since it is characterized by resources that are massively scalable and virtualized, with reduced infrastructural support needs, rapid information deployment, and green potential of computing.

#### Additive Manufacturing

Additive manufacturing can assist firms to effectively manage the challenge of design changes deployment in the product life cycle (Ali et al., 2021). This may eliminate unnecessary inventory holding expenses, and firms can update product designs more easily without creating high levels of scrap or obsolete items. Hence, implementing additive manufacturing can enable environmental sustainability improvements in supply chains.

#### Blockchain

Blockchain technology is highly essential in revitalizing the supply chain through ensuring that information shared is authentic and traceable during transmitting between supply chain partners and transactional security in a risky scenario (Hald & Kinra, 2019; Tijan et al., 2019). Consequently, these features have notable impact on supply chain design and organizational and operational functions.

Furthermore, blockchain can enable supply chains to overcome challenges that relate to information silos, opacity of information, and product tracking difficulties (Jeong & Hong, 2019; Jia et al., 2020; Jiang & Ke, 2019; Zhang & Guin, 2020).

#### Big Data Analytics

Effective initiatives for actualizing resource management can be achieved through the use of big data analytics. Furthermore, big data analytics can enable green and circular economy practices implementation which can increase environmental performance and reduce relational and task conflicts among stakeholders, thereby resulting in overall sustainability improvements (Benzidia et al., 2021). Prior studies show that big data analytics can enable supply chains to reduce carbon emissions, improve supplier collaboration, and also increase competitive edge and productivity efficiency.

### Social Sustainability of Digital Technologies

Notable measures of social sustainability that can be derived from the use of digital technologies include visibility and information disclosure, worker health and safety, and rights of stakeholders (Afshari et al., 2020; Ghobadian et al., 2020; Orji et al., 2020; Raut et al., 2021). Below, we outline the social sustainability implications of digital technologies.

#### IoT

The adoption of IoT in supply chains can facilitate supply chain social sustainability. For instance, integrating IoT in supply chains can enable the collection of enormous data which can facilitate trust among supply chain partners for effective collaboration and integration (Joshi & Gupta, 2019). Such data may include observations of poor work conditions, sharing information across the supply chain related to available employment opportunities, community relationships that can be improved through gathering information on supply chain partner performance, etc.

#### Cloud Computing

The adoption of cloud computing is appealing. This is because it enables network access that is convenient and universal to a shared pool of computing resources which are configurable and can be provisioned to release swiftly with little effort from the management or interactions from the service provider. As such, there is minimized costs of investment and maintenance of information infrastructure, resulting in innovativeness and global competitiveness. Furthermore, cloud computing may also allow supply chain partners who are in developing countries or smaller and resource-constrained ones to get access to software they might not have had access to. Within this context, equity concerns are effectively addressed, and there can be a bridging of the digital divide (social concerns).

#### Additive Manufacturing

Since there is high need for multiple partners in the supply chains to collaborate frequently to a common end, additive manufacturing can be utilized to aid in the electronic sharing of files in the design stage coupled with the localized manufacturing of prototypes for each supply chain partner (Afshari et al., 2020). In such a situation, manufacturing firms can easily collaborate with new partners and facilitate integration and collaboration processes which might be impossible to achieve through conventional means (Ghobadian et al., 2020), for utmost supply chain social sustainability improvements. Additionally, the additive manufacturing can also assist suppliers and manufacturers whose transport infrastructure is poor so they can produce locally through utilizing basic raw materials which is also an equity issue.

#### Blockchain

The implementation of blockchain can contribute to improving supply chain social sustainability (Orji et al., 2020). In fact, blockchain can enable supply chains to develop visibility, demand, and optimization which can ensure that records are shared and secured simultaneously since only stakeholders are authorized within the network (Sundarakani et al., 2021). The adoption of blockchain technology is considered desirable due to its unique features such as real-time information, information sharing, cybersecurity, reliability, traceability, visibility, and transparency which can improve the scope of supply chain management and operational performance. Blockchain technology can contribute to supply chain social sustainability via reduction in unethical, corrupt, and counterfeit practices (Kouhizadeh et al., 2021).

#### Big Data Analytics

Big data analytics have the potential to improve supply chain social sustainability. For instance, big data analytics can assist firms to facilitate circular economy implementation which can reduce relational and task conflicts among stakeholders

(Benzidia et al., 2021). Additionally, big data analytics shows a positive effect on swift trust, flexibility, collaboration, and control which enables agility, coupled with operational flexibility and improved business and supply chain performance (Raut et al., 2021). Indeed, there are quite a number of social sustainability measures that can be analyzed and captured from thousands of suppliers and supply chain partners through implementing big data analytics. For instance, it is possible to identify various patterns and employ data analytics to predict and prescribe solutions to social concerns including issues related to corruption, slave labor and inequities, etc.

## 4 Concern over Long-Term Sustainability of Digital Supply Chains

Companies have become more interested in the long-term sustainability objectives but realize that attaining such heights can only be possible through effective collaboration with supply chain partners that share similar objectives. Managers are likely to be more interested in implementing digital supply chains when there is adequate understanding of the long-term sustainability benefits for their firms (Benzidia et al., 2021).

### 4.1 Minimizing the Symptoms of Non-sustainability

Certain symptoms characterize non-sustainability in supply chains. These include shortages of materials, delayed deliveries of goods, vulnerability of the supply chains, and absence of effective supplier collaboration and integration (Ivanov & Dolgui, 2020a, b; Majumdar et al., 2020). These symptoms have become more apparent in global health such as COVID-19 pandemic and other natural disasters, supplier risks, inefficient transportation facilities, materials traveling very substantial geographical distances, political instability, demand risks, and economic crisis (Ivanov & Dolgui, 2020a).

Additionally, prominent illicit trading, unethical production practices, and fragile supply chains have put industries under immense pressure from customers and governments to follow sustainable production practices. Consequently, companies are pressured to be transparent in their operations and also to facilitate visibility at both the strategic and operational levels. Many industries are subjected to strong criticism due to unfair labor practices and the use of toxic materials, largely because of opaque supply chains.

The current environment provides both opportunities and incentives to implement digital supply chain solutions to seek to surmount these challenges. The COVID-19 pandemic has caused unprecedented disruptions to business models and has highlighted the non-sustainability of many existing supply chains (Ivanov & Dolgui, 2020a, b; Majumdar et al., 2020). The International Labour Organization (ILO) estimated that the pandemic wiped out about 7.2% working hours of approximately 125 million full-time employees in the Asian continent (ILO, 2020). Thus, implementing digital supply chains can enable traceability of secured information sharing and facilitate product quality monitoring, operation control, real-time data acquisition, transparency, and visibility in the supply chain. Since trust is a prerequisite for supply chain partnerships. Digitalization in the supply chains facilitates and sustains collaboration when such partners are dispersed geographically around the globe and can foster trust. Implementing digital supply chains with blockchain and electronic data exchange facilitates collaboration through adequate information sharing to ensure and build trust.

Digital supply chains can help to remove doubts in third-party supply chain auditors' documentation and human code-of-conduct violations' reporting. Also, blockchains can be utilized in the logistics monitoring system for parcel tracking in a given supply chain which supports a shared and immutable ledger recording of all transactions. Blockchains remain a suitable means of creating chronological chain of records in order to facilitate material traceability since supply chains are faced with the challenge of ensuring raw material provenance and product authenticity. In addition, digital tools like social media and mobile phone cameras uploading to the cloud have aided in exposing poor practices particularly at the bottom of the pyramid. For instance, the child labor and some cases of slavery on cocoa farms in Western Africa were exposed through the use of digital tools (Ange & Ross, 2020).

## 4.2 Enablers of Long-Term Sustainability of Digital Supply Chains

We identified the enablers of sustainability in digital supply chains through an extensive search of journal contributions, abstracts, and keywords available in SCOPUS using keywords such "enablers," "digital supply chains," and "sustainability." The identified enablers of sustainability in digital supply chains were classified using technological, organizational, and environmental contexts/perspectives based on the TOE theory (Kouhizadeh et al., 2021; Orji et al., 2020).

### Technological Enablers

Technological enablers include availability and access to technological infrastructures, sufficient security and privacy, positive perception to digital technologies, quality data, and technology maturity (Afshari et al., 2020). In addition, emergent technologies from other Industry 4.0 technologies may also enable each other. For example, IoT and blockchain integrated together. Also, there is emergent technology such as quantum computing (Sarkis et al., 2021) that can act as enabler for implementing digital supply chains.

### Organizational Enablers

The organizational context encompasses the internal characteristics of firms that can facilitate effective implementation of digital technologies in the supply chains (Orji et al., 2020). The organizational enablers include sufficient budgetary allocations, top management support, effective organizational policies, high skilled employees, and organizational change culture (Orji et al., 2022a).

#### Environmental (Institutional) Enablers

This context concerns the external environment of the firm that can facilitate the implementation of digital supply chains for sustainability improvements. The environmental enablers include customer awareness of digital supply technologies, government regulatory framework, presence of reward and incentives, effective supply chain collaboration, and industry and stakeholder participation (Raut et al., 2021).

### 4.3 General Challenges to Implementing Digital Supply Chains

In a similar vein, we present a brief discussion of the challenges/barriers to implementing digital supply chains based on the TOE theoretical perspective.

#### Technological Barriers

In the context of digital supply chains, technological barriers comprise of barriers that stem from the limitations of the digital technologies that are utilized in digital supply chains. Such barriers create technical challenges that include scalability, usability, and interoperability (Kouhizadeh et al., 2021). For instance, digital technologies still suffer from latency and throughput issues. There is also another barrier that tends to border on disagreements among digital technology communities and actors that leads to “technology split” (Kouhizadeh et al., 2021). There is also barrier that pertains to accessibility concerns coupled with data immutability and digital technologies’ public perceptions.

#### Organizational Barriers

The organizational barriers to implementing digital supply chains include financial constraints due to the cost associated with additional investments that tends to increase with larger implementation. Other barriers include lack of commitment from top or middle management, lack of standardization, and lack of comprehensive understanding on the implementation of digital supply chains (Dutta et al., 2020; Nizetic et al., 2020).

#### Environmental (Institutional) Barriers

In the context of digital supply chain, these barriers can be classified into two, namely, supply chain and broader external barriers. Supply chain barriers include customer lack of awareness about digital supply chains, data confidentiality and privacy concerns in interorganizational systems, cultural and geographical differences between supply chain partners, and lack of information sharing policies (Kouhizadeh et al., 2021). On the other hand, the broader external barriers include lack of governmental policies, market competition and uncertainty, and lack of external stakeholder involvement in implementing digital supply chains (Dutta et al., 2020; Nizetic et al., 2020).

## 5 Conclusion

In a digitally driven system, core digital technologies can assist firms to implement strategies that are data-driven for the effective data collection of material characteristics and operational parameters across the product life cycle. Consequently, these technologies can enable companies to improve the vertical and horizontal integration of supply chains and result in sustainability improvements (Tao et al., 2018). This is particularly interesting since rapid expansion of industrialization plays a significant role in boosting the economy, bringing benefits to the organizations and prosperity for society, which results in increased supply chain activities causing threats to socio-environmental sustainability (Shete et al., 2020). With the increased awareness of negative socio-environmental impacts of business activities, the implementation of sustainability initiatives has been undertaken in many supply chains (Chowdhury & Quaddus, 2021; Jianying et al., 2021; Jin et al., 2021).

Sustainability in digital supply chains helps to link development and environmental issues and drives political and economic change "glocally," and, as such, sustainable initiatives must concentrate on local social development and interconnected environmental issues as well as on global economic consequences (Tsai et al., 2021). Implementation of digital supply chains is being considered as viable initiatives to aid supply chain sustainability improvements. Currently, there is deficit of knowledge on how implementing digital supply chains may translate to improvements in the economic, environmental, and social aspects of supply chain sustainability. Hence, we have presented relevant insights on how digital supply chains might improve sustainability and explored the sustainability implications of implementing digital technologies in supply chains.

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# The Lithium-Ion Battery Supply Chain

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**Abstract**

With the spread of electric vehicles in recent years, the supply chain of Lithium-ion batteries (LIBs) has become a very important issue. The rapid rise in demand for electric vehicles also introduces some supply chain problems in LIBs. In this chapter, the current and future problems in LIB supply chain processes are addressed. It is seen that supply problems may arise with the increase in demand for materials such as cobalt and lithium, which are basically used in battery production. In this context, LIB recycling processes are very important. In addition, various studies on this topic focus on minimizing sustainability problems. It is important for future research to consider technological transformations from a cost and sustainability perspective. The holistic LIB supply chain processes need to carefully consider the dynamically changing electronic vehicle market, considering concerns such as collaborations, political influences, safety, and security.

**Keywords**

Lithium-ion battery · Circular supply chain · Sustainability

## 1 Introduction

As the global growth of electric vehicles (EVs) continues, the demand for lithium-ion batteries (LIBs) is increasing. In 2021, 9% of car sales was EVs, and the number increases up to 109% from 2020 (Canalys, 2022). After repeated cycles and with charge and discharge over the first five years of usage, LIBs in EVs are severely degraded and, in many cases, no longer match the performance standards for EV batteries. Increased LIB usage ultimately results in LIB material shortages and waste. This large quantity of end-of-life (EOL) batteries and resource limitations requires that recycling LIBs from EVs and other products is necessary. Creating a second life for LIBs will become an inevitable topic from an economic, environmental, and social perspective. By 2028, it is anticipated that the LIB market size would be $6.55 billion (Fortune Business Insights, 2022).

EOL LIBs, particularly those from EVs, have high usage values. Compared to manufacturing batteries from scratch, remanufacturing LIBs delivers cost reductions (Chen et al., 2022). EOL LIBs from EVs can also be used for energy storage and other purposes that have lower restrictions. From an environmental, social, and economic perspective, promoting the second life of EOL batteries and completing the supply chain are important. Throughout the whole supply chain, EOL LIB management can reduce resource consumption and waste emissions (Yıldızbaşı et al., 2021).

A more comprehensive circular supply chain can be closely tied to approaches for managing LIB resources and sustainability. Several obstacles occur, especially complex supply chains, for LIBs. Incorrect recycling activities, mechanical damage, improper storage, overheating, or deterioration in batteries can lead to fires, explosions, and other hazards, including the release of harmful gases, such as hydrogen fluoride (HF), which can cause serious injury and property damage (Sonoc et al., 2015). Therefore, it is imperative to understand the concerns about LIB supply chains. Organizing and studying the LIB issues in the supply chain will be helpful in greater understanding and management.

The remainder of this chapter is structured as follows: Sect. 2 describes the concepts of LIB supply chains and its obstacles. The main concerns of LIB supply chains are illustrated in Sect. 3. Section 4 provides managerial implications. Sections 5 and 6 include future research directions and conclusions, respectively.

## 2 The Lithium-Ion Battery Supply Chain

The supply chain of LIBs combines forward and backward activity streams to maximize economic and environmental benefits. At the core of the broader circular economy concept, the LIBs supply chain has received widespread recognition in academic study and practical implementations in various fields. It integrates forward (material suppliers, manufacturers, merchants, and users) and reverses logistics (collection, testing, sorting, disassembly, remanufacturing, reusing, and recycling) activities.

The main activities involved in the LIBs supply chain are shown in the Fig. 1. These activities include the production of LIB as well as the installation of such batteries in products, such as EVs. The mining and extractive processes are typically where the forward linear supply chain gets its start. The increasing number of EVs, and other products requiring LIBs, being manufactured places a significant emphasis on the processes involved in the LIB supply chain. The extraction of raw materials from land is the first step in the supply chain, which is followed by the processing of raw materials into chemically active substances (Sun et al., 2019). Raw materials from mines are transported to facilities that are responsible for the manufacturing of cells and their subsequent processing (Mayyas et al., 2021).

Cells are necessary for the manufacture of batteries. These cells are then shipped for assembly by different transportation modes or maintained in inventory. After cells are assembled, the produced batteries are installed in EVs – or other products such as phones, and appliances. EVs are available for purchase by the end user (Chung et al., 2015). The recycling of already used products can exist within the last stage of the supply chain at the end-of-life of products using LIBs. Reusing and recycling are both options for the components gained by disassembling previously used LIBs (Yıldızbaşı et al., 2021).

The closing-the-loop collection of activities at a product's end-of-life (EOL) is referred to as the reverse supply chain. The end-user often initiates the reverse supply chain for LIBs by gathering EOL LIBs or products containing batteries,

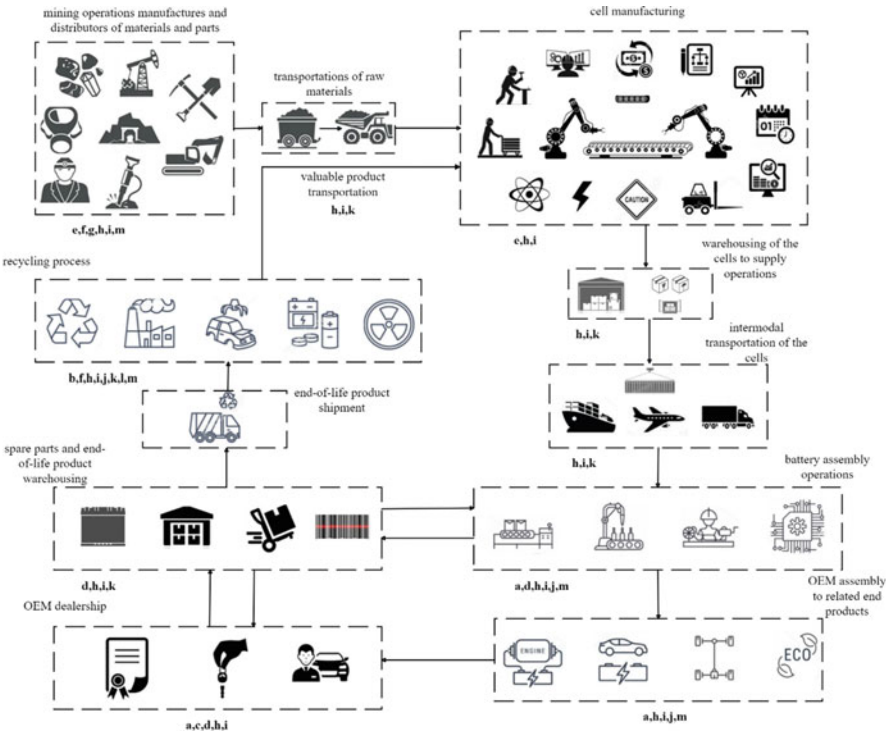


**Fig. 1** A Diagram of a Lithium-ion battery supply chain

disassembling them, and then managing the EOL products through various means, including the frequently mentioned options of reusing, remanufacturing, and recycling.

Many different operations are completed throughout the entire LIB closed-loop supply chain activities from raw material production to recycling of used products. Each one requires some form and usually differing managerial decisions and risks. It is important to manage different parameters effectively for efficient and effective cyclical supply chain management. For example, the geopolitical stability of the countries who supply LIB raw materials, which is the beginning of the supply chain, is important, because the unstable geopolitical situation may lead to the emergence of supply risks (LaRocca, 2020). Basic elements such as cobalt raw material are available in a few countries such as the Democratic Republic of Congo.

Cobalt and lithium, the two main components of LIBs, are scarce, and most EOL LIBs are improperly disposed of rather than collected, which pollutes water and soil. However, unstable political conditions and trade difficulties in these countries can cause fragility in the supply chain (Ruiz et al., 2018). In addition, the social conditions in the countries where raw materials are supplied cause serious concerns in terms of sustainability. Dust inhalation, food and water pollution, and exposure to high levels of radiation pose various risks to workers working in mining operations. Poor sanitation and inadequate security measures are often observed in the mining camps (Chen et al., 2022). In addition, harsh working conditions and widespread child labor are also reported in raw material source countries (Chu et al., 2022). Thus, economic and business concerns need to be balanced and consider various environmental and social concerns along the LIB supply chain.

In Fig. 1, the flows related to the supply chain processes of lithium-ion batteries are presented. These flows depict step-by-step processes from the extraction of ore at the source to the final product operations. Recycling processes within a circular framework are also considered within the same flow. The letters underneath each operation are associated with the headings in the next section. The current problems within each operation can be analyzed by relating them to the headings in the following section.

## 3 Concerns in the Lithium-Ion Battery Supply Chain

In this section, major issues in the LIB supply chain are identified by examining numerous critical concerns. In this context, businesses may want to both reduce costs and overcome problems that may arise in supply chain processes by establishing production. The LIB supply chain steps associated with the issues identified below are associated with the primary activities and relationships identified in Fig. 1.

### 3.1 Integration and Consolidation Across the Supply Chain

Original equipment manufacturers (OEMs) are vertically integrating upstream to ensure battery supplies and capitalize on the economics of centralized manufacturing. For example, businesses such as Tesla, an EV OEM, has taken on this supply chain strategy.

As production links closer to mining and extraction, there may be a rise in mining and processing supply chain consolidation. In these situations, it is expected that cooperation capabilities can increase, especially in battery production. This consolidation at the other end of the supply chain can take advantage of economies of scale; that is, significant opportunities can be obtained for EOL products allowing them to cost less.

Although these consolidating and vertically integrated strategic alliances are gaining in significance, it is still anticipated that the production of cathodes by cell manufacturers will remain a specialized work sector, with the necessity to spend enormous amounts of money on research and development (R&D) and generally growing pricing pressure. LIB cathode material producer market is destined to stabilize, as consolidation and integration becomes more prevalent (Bernhart, 2014).

### 3.2 Improved Recycling Capacity and Requirements

Given the past decade trends, it is anticipated that demand for batteries will exceed supply in the near future. Even if production capacity can be ramped up to meet demand, over the longer term, reserves of critical raw materials are likely to fall short of demand projections. This situation indicates the need for upscaling improved recycling technology and recycling operations. This expectation assumes that there are no major shifts in the composition or materials of batteries.

This expectation also demonstrates the need for adding LIBs into a recycling process to reduce the negative effects that the manufacturing of EVs has on the surrounding environment. In this context, recycling operations have an essential position in terms of both supplying the demand of customers for LIBs and decreasing the environmental impact of these batteries. It has been suggested that the utilization of manufactured LIBs be cascaded via an application hierarchy, from manufacturer to recycle, to optimize resource use and lifespan implications. The hierarchical process considered here consists of prevention, re-use, recycling, recovery, and disposal. This framework has been extended to encompass the realm of battery recycling technologies. For instance, “Prevention” entails the design of LIBs using non-critical materials (high economic significance but facing supply risks) and the pursuit of lighter electric vehicles with compact batteries. “Re-use” emphasizes the importance of utilizing electric vehicle batteries for a second life. “Recycling” involves the comprehensive process of extracting and recovering the maximum amount of materials from batteries while ensuring the preservation of their structural integrity and quality (e.g., preventing contamination). “Recovery” entails harnessing specific battery materials as a source of energy through techniques like pyrometallurgy. Lastly, “disposal” refers to the final stage where no value can be extracted, and the waste is directed toward landfill disposal. This optimization can contribute additional considerable value to LIBs supply chain from perspective of raw material consumption, hazard waste emission, and cost decreasing (Harper et al., 2019).

EOL batteries have been termed “waste.” Yet, waste can be a highly vital resource (Jha et al., 2013). Many countries do not have access to the components and minerals that are used in the production of car batteries and having access to these resources – waste or virgin material – is essential for maintaining a steady supply chain. EOL EVs will be a beneficial secondary resource for essential elements (Reinhardt et al., 2019). For example, rare earth metals existing in high-cobalt-content batteries need to be recycled to increase cobalt supply. If hundreds of thousands of EVs are manufactured each year, careful management of the resources used in the production of EV batteries will undoubtedly be necessary to maintain the long-term viability of the EV automotive industry of the future (Zhang et al., 2020).

Recent life-cycle studies have shown that the implementation of existing recycling techniques in the current production of EV LIBs may not, in all instances, result in reductions in greenhouse gas emissions in comparison to the original manufacture (Mauger & Julien, 2017). The current environmental and economic sustainability of recycling is reliant on the amount of cobalt included in recycled materials; thus, more effective processing methods are immediately required to enhance both aspects of this sustainability. However, as a result of economic and other factors, the quantity of cobalt contained in cathodes is decreasing, which means that recycling using the technologies that are now in use will become less profitable due to the decreased value of the materials that are recovered (Mauger & Julien, 2017).

There are now only small quantities of used batteries from EVs for recycling. There are concerns about the efficiencies (and inefficiencies) of scalability in connection with recycling processes as a result of the substantial growth in the needed amounts of these materials. Given the significant capital expenses associated with mineral processing techniques, it becomes vital to explore alternative avenues to attain larger number of recycling of LIBs. In addition, it is imperative to seek out innovative approaches for recycling other materials rather than only focus on economically viable element (Harper et al., 2019).

### 3.3 Economies of Scale Increase the Potential for Advancements in Battery Technology

Battery technology markets are expected to increase in the future as manufacturing of batteries reaches an economy of scale levels to reduce costs. Market improvement also means developments that can either migrate away from LIBs to ones that employ new, more available raw materials or that may extend the usable life of batteries, enhance the range and cell energy density, decrease charging time, and improve efficiency while lowering the quantity of essential raw materials needed per battery (Bauer et al., 2018).

Over the past few decades, LIB technology has seen considerable reductions in both their expenses and pricing. LIB technologies have also evolved to accommodate a wider variety of applications. These applications now include mobile electronics, power tools, EVs, and more recently, static stockpiling. Each of these applications supports a unique set of cell-level characteristics. Nevertheless, because of the growth of technologies for EVs and the growing demand in the market, there is a need for substantial new commercial breakthroughs and advancements in battery technology to help reduce costs and maintain availability in the supply chain (Zeng et al., 2019).

### 3.4 Requirement for Facilitating Services and Technology

As LIB adoption matures, new services will be needed, including battery care and servicing, software, and other technologies that manage and optimize battery functioning, performance, recycling, and more (Woody et al., 2020).

The increase in the number of EVs will bring along the need for service and will also reveal new problems. The proliferation of service providers and the positioning of these services is just one of these problems. Innovative approaches such as preventive and predictive maintenance for battery maintenance services will require improved efficiencies. In recent years, in anticipation of lengthening the life of LIBS, one of the most prominent study topics has been the concept of predictive maintenance (Chen et al., 2021). The installation and expansion of electric charging stations and their maintenance are also key issues that need to be considered across the supply chain (Narasipuram & Mopidevi, 2021; Ma, 2019; Akbari et al., 2018).

Environmental risks associated with LIBs and rechargeable batteries of the next generation have not received sufficient consideration. Recycling plays a significant part in the overall viability of future batteries and is influenced by the characteristics of the batteries themselves, such as the dangers they pose to the surrounding environment and the worth of their materials (Fan et al., 2020). As a result, the EOL recycling has to be included in the design of battery systems. The recycling processes of large-volume batteries that have reached the end of their useful life should be evaluated in depth from various technological perspectives and supported with them such as blockchain technology, and they need to consider economic feasibility, environmental impact, social sustainability, and safety (Júnior et al., 2022).

### 3.5 Geopolitical Risks

Some of the resources that are necessary for the manufacturing of batteries are only found in a few regions throughout the world. Some of these regions are prone to political instability, while others face conflicts with other countries on diplomatic fronts. For instance, Australia, Chile, and China control the majority of the world's lithium extraction industry. China also has a monopoly on the world's chemical processing and manufacturing industries (LaRocca, 2020).

In this situation, the emphasis on the supplier side implies that concerns about the accessibility of physical resources take precedence. Essential organizational components of demand and end-use players in the process of reorganizing supply chains tend to be disregarded. In this particular setting, there have been recent demands for a strategy that takes a "whole systems" perspective to comprehend the geopolitics of the transition of energy system infrastructure. Understanding how the geopolitical ramifications of transformation transcend further than the relatively limited problem of resource and commodity supply security (although this is an essential aspect) will be important. For example, it will also involve changes in the geopolitics of technology, production, and demand. All these considerations portend a whole systems approach. This perspective may be accomplished by looking at the energy revolution from the perspective of a complete system (Olivetti et al., 2017; Sun et al., 2019).

### 3.6 Environmental Risks

Even if automobiles do not produce any pollutants from their tailpipes, the production of batteries will have a huge effect on both the environment and society. The extraction of lithium consumes vast quantities of water, and some industrial techniques release a significant quantity of carbon dioxide. In addition, for many years, a number of mines have been plagued by serious human rights violations (Chu et al., 2022).

Sustainability challenges span the entire technology lifecycle and supply chain of energy storage systems, and especially LIBs. Therefore, raw material processing activities, battery production, battery logistics activities, EV use, and battery recycling processes each should be examined from a sustainability perspective.

LIB raw materials include lithium, cobalt, nickel, and manganese, where each of these resources is needed to provide electrochemical functionality. Cobalt may cause some of the most serious sustainability problems in the long run. The cobalt centralized supply chain process brings with it greater risks of interruptions and price increases. This situation also weakens competitive power considerably. Ensuring a long-term, stable supply of cobalt will require expanding the geographic diversity of the supply chain, as well as developing secondary resources through increased recycling (Yang et al., 2021).

To provide a green supply chain by reducing the dependence on single raw materials in the production of LIBs, alternative sources, new technological designs, and long-lasting batteries are needed. Although such investments are quite costly, they can provide very profitable returns on electricity consumption and recycling processes in the long run. Therefore, the main motivation should be to focus on sustainable options to preserve the material and energy value found in LIBs (Costa et al., 2021).

### 3.7 Social Risks

LIBs are widely acknowledged as a crucial component as portable technologies for storing energy. However, the existing production technology relies on a number of essential elements, including lithium, cobalt, nickel, manganese, and graphite, all of which are linked to a variety of social repercussions along their supply chains. Societal implications of LIBs have received relatively little attention – especially when compared to environmental, business, and supply chain risks.

One significant social issue linked to LIB production is the potential for human rights abuses in the mining of key minerals. For instance, the extraction of cobalt in certain regions has been associated with child labor and hazardous working conditions (Helbig et al., 2018). Similarly, the mining of lithium has raised concerns regarding water scarcity and displacement of indigenous communities (Olivetti et al., 2017). These issues necessitate a comprehensive examination of the LIB industry's social responsibilities.

Another crucial aspect is the safety of LIBs themselves. While LIBs offer efficient energy storage, their use and end-of-life management pose safety risks, including thermal runaway and the potential for fires or explosions (Feng et al., 2018). These safety concerns have been exemplified by incidents such as the Samsung Galaxy Note 7 battery explosions (Yun et al., 2018). It is essential to prioritize the development of safer battery technologies and robust safety measures to mitigate these risks.

To ensure responsible and sustainable development of the LIB industry, it is imperative to analyze and address these pressing social issues. This requires careful consideration of the societal implications and the implementation of ethical practices throughout the supply chain (Easley et al., 2022).

As the demand for lithium-ion batteries (LIBs) continues to soar in various sectors, including electric vehicles, renewable energy storage, and portable electronics, the need for social responsibility within the LIB industry becomes increasingly apparent. The production and supply chain of LIBs raise significant concerns regarding social impacts, including human rights violations, labor exploitation, and environmental degradation (Koese et al., 2023). Social responsibility in the LIB industry involves acknowledging and addressing these concerns to ensure that the entire lifecycle of LIBs aligns with ethical and sustainable practices. It encompasses responsible sourcing of raw materials, ensuring fair labor practices and worker welfare in battery manufacturing, implementing environmental stewardship measures, engaging with local communities, and promoting transparent and collaborative relationships with stakeholders. By prioritizing social responsibility, the LIB industry can mitigate the adverse effects associated with its operations, foster positive social change, and contribute to the development of a more sustainable and equitable future. As a result, an analysis of the LIB industry's most pressing concerns about social responsibility is needed and requires careful consideration (Thies et al., 2019; Yıldızbaşı et al., 2021).

## 3.8 Price Risks

The costs of battery raw materials have been very volatile, and they reached an all-time high in 2022 because to supply imbalances during the recovery from Covid-19. This was the year they broke the previous record. Increasing battery manufacturing to satisfy the growing demand would not come cheap, which is another point to consider. During the next 8 years, a required CAPEX of between 250 and 300 billion Euros is anticipated. Europe is generally going to account for around a third of that total (Bernhart, 2014).

## 3.9 Supply and Demand Risks

The demand for batteries is expected to continue growing, which will make it difficult to keep a steady supply of LIB materials. Nickel and cobalt will both have limited supply levels, but there is a very strong probability that there will be a significant shortage of lithium (Olivetti et al., 2017).

In addition to these shortages, lead times are an important factor to consider: When moving from the discovery phase to the construction of a full-scale mining operation for lithium, the process may take multiple years. It may take twice as long to process nickel. In this context, the ineffective use of raw material resources means that the demands of the growing battery technology cannot be met, given that the rapid increase in the number of EVs and the customer demand will likely cause serious supply problem.

The rarity of ores used in battery production shows that recycling processes are important to meet the demands. Therefore, the imbalance of supply and demand in the coming years can be seen as one of the biggest pressures on the growth of the EV market (Murdock et al., 2021).

### 3.10 Battery Regulation and Adoption

EV use has long been controversial due to a lack of regulation and a general global agreement. To identify risks, problems, and gaps in business models and regulations for the management of EOL EV batteries, future research in this field will need to include additional empirical investigations. In addition, the comparison of such models between emerging nations and industrialized ones will bring further insights that will be valuable.

There are three major battery markets, namely, the European Union, the USA, and China. However, the regulations in these markets are generally aimed at protecting human and environmental health. In addition, the regulatory policies of these three major markets differ due to their competitive advantage. Therefore, there is no regulatory business and other impact consensus. In this regard, there is a need for standardized regulations for LIBs, from production to end-customer and to cover recycling processes (Ruiz et al., 2018; Bielewski et al., 2021).

### 3.11 Collecting, Storing, and Transportation Batteries

Collection and transportation of used LIBs are important EOL LIB management concerns that need to be properly handled. Future study should be directed toward determining LIB collection and storage locations. Such management investigation should consider both the current and the planned infrastructure in addition to analyzing the local environmental, financial, and social effects. In addition, there is a need for more consideration of safety and regulatory concerns, as well as financial implications of battery warehousing (Ditch, 2018).

Many studies and practices ignore the processes involved in collecting and transporting LIBs. This is because most studies focus more on recycling and reuse processes. However, shipping costs account for a large proportion of LIB production. In this context, considering factors such as transportation mode, distance, fuel costs, and transportation network in the LIB supply chain allows more realistic cost calculations to be obtained (Yang et al., 2021).

### 3.12 Recycling Operations Based on Circular Economy

It is necessary for there to be rules in place that provide more comprehensive recycling and reuse capabilities for a *circular economy* of batteries to advance (Mossali et al., 2020). The policies should have as their primary goal a greater energy efficiency for the reclamation operations, as well as closed-loop recycling that makes use of bioreagents and is advantageous when hydrometallurgy is used.

Current recycling practices can produce a significant amount of greenhouse gas emissions (particularly when involving energy-intensive pyro processes), make use of synthetic chemicals that pose a potential threat to human health, and influence the quality of ecosystems (Velázquez-Martínez et al., 2019). A bio-hydrometallurgical recycling strategy, on the other hand, makes use of microorganisms and biotechnology to leach and recover target metals at a potentially cheaper cost and with less negative effects on the environment (compared to pyro- or conventional hydrometallurgy) (Pagliaro & Meneguzzo, 2019; Neumann et al., 2022). These new technologies need to be considered in circular economic and recycling practices, where the benefits of recycling are not outweighed by the environmental and social costs.

## 3.13 Safety Risks

Although there are many studies on LIB supply chain management in the literature, one of the main issues, safety, is overlooked. Safety concerns are anticipated to become more prevalent and have a severe impact on the economic, environmental, and social elements of the EOL management of LIBs (Chen et al., 2023). Since EOL management and circular economy practices are becoming increasingly important for sustainability research but are not well-studied from a safety standpoint, investigating safety issues within the LIBs supply chain can generally help safety research.

In the LIB supply chain ecosystem, safety issues can arise at multiple supply chain stages including transportation, shipping, storage, inventory, and operation. Safety concerns must be considered in the management processes of these activities. For example, in LIB transport and storage activities, factors such as temperature and humidity can cause chemical effects. Sealing and insulation problems at the storage stage are just a few of the main problems to be solved. In addition, the effect of the pressure factor in air transportation and measures against accidents that may occur in train and road transportation are some of the safety problems. Dismantling for recycling is a human-intensive process, and improper working conditions may cause some risks. In this context, security risks in the LIB supply chain are one of the main problems of recycling processes. Specific studies are needed in this direction (Abada et al., 2016). LIB fires and explosions in supply chains can result in injuries and economic losses.

LIB EOL practices can inform broader circular economy issues, where safety is rarely emphasized. The number of safety incidents related to LIBs is increasing and has resulted in injuries, environmental damage, and negative social impacts. Multiple safety issues can arise in every supply chain process. Further characterization and measurement of these safety issues are important to mitigate them.

In the LIB supply chain, collection marks of EOL LIBs are where the closed loop process or reverse logistics stages begin. To boost collection rates of critical resources in LIBs, many nations are creating restrictions on EOL LIB collection. Inadequate disposal methods like incineration and landfills can contaminate the soil, the air, and the groundwater, which increases the risk of fires and other safety-related events. As long as safety issues persist, demands on resources, the environment, and the economy will increase worries and necessitate managing the reverse supply chain.

Disassembly is another possible activity in EOL LIB management and typically includes disassembly, shredding, and separation after collection. Manual disassembly is the primary method of disassembly (Chitre et al., 2020). Due to the large number of personnel involved, irregular handling, lack of safety precautions, or irregular emergency response are potential safety hazards. During remanufacturing, some damaged cells can be replaced with new cells or qualified cells from other EOL LIB packs.

Recycled LIBs are typically employed for energy storage, such as in stationary applications that require lower current densities than those found in battery packs for EVs. The most popular circular economy practice for EOL LIBs is recycling (as has been emphasized from the previous risk discussion sections). Recycling is a supply chain practice. The two industrial recycling techniques now in use are pyrometallurgical and hydrometallurgical procedures. The use of chemicals in the LIB recycling process and the high-temperature environment increases the safety issues associated with recycling.

Lithium and other reactive materials found in LIBs can readily cause thermal runaway outside of the acceptable operating range. Adverse reactions can happen even under normal working settings because of high temperatures. EOL batteries are also to blame for waste disposal-related fire incidents, which endanger the entire waste management industry and their supply chains.

These safety-related issues are just part of the many existing and prospective safety concerns. The various safety difficulties in EOL management, where LIBs have multiple processing stages, go far beyond these instances. In-depth research and assessment of safety in the LIB EOL situation are required in light of these findings as well as any additional evidence that may emerge in the future (Chen et al., 2023).

## 4 Managerial Concerns and Implications Across the Lithium-Ion Battery Supply Chain

Concerns have been raised over whether the available lithium resources are sufficient to supply the growing LIB demand and the rise of LIB-powered EVs. As previously stated in this chapter, the major LIB supply chain activities include mining, transportation, inventory, sustainability, recycling, technology, and the geopolitical environment. It is clear that a future driven by LIBs will have to address the problem of limited resource availability and the variety of issues discussed in Sect. 3 of this chapter. Unequal distribution of lithium resources globally will mean likely severe shortages of lithium, which poses a significant threat to the availability of LIBs (Speirs et al., 2014).

There is little question that future demand for lithium will dramatically rise; hence, it is essential to adopt a preventative strategy to identify and solve some of the challenges that are now being faced by the supply chain. If this shortage forecast does not change, there is a concern about substituting material dependency in the transport industry for dependence on fossil fuel. If these shortage and resourcing issues are not addressed, there is a possibility that they may disrupt the supply chain in the future, which would influence the EV market's future (Martin et al., 2017). For the lithium-based EV industry to be sustainable, it is necessary to analyze and address the existing problems in depth.

LIB supply chain fragility is a current and pernicious problem. Geographical location, the geopolitical situation, competitive market, capacity, technology, and recycling, which are some of the important factors for the LIB supply chain, are areas organizations, managers, and theorists should investigate and improve (Olivetti et al., 2017).

The chapter supports the contention that current research and analysis need to carefully examine and design LIB supply chain processes resiliency. In particular, the uncertainty of raw material data and political uncertainties in geographical regions greatly increase LIB supply chain fragility. While resource uncertainty in LIB production is a major problem, supply uncertainty for LIBs is a serious issue. This uncertainty causes volatility and fluctuations in prices, further limiting effective planning and forecasting for future demand and revenue. Although short-term supply-demand balance uncertainties are replete, capacity problems also impact long-term strategic planning for supply chains and their network design, for example.

Collaborations within the LIB supply chain is another important and current concern. These collaborations should include country, organizational, and non-governmental organizations. They need to begin at the strategic level, because the basic raw materials in LIB production are usually concentrated in certain regions. Collaborations strengthen supply chain processes so that production can be adequate against sudden demand fluctuations.

Emerging technologies also offer significant opportunities for managing LIB supply chain processes. For example, blockchain technology can provide a more transparent information flow in terms of traceability and recycling of products (Júnior et al., 2022). Big data analytics are needed at the point of demand, supply, and pricing. Uncertainties in forecasting, preventive maintenance, and sustainability can be reduced by processing the available data with machine learning and AI algorithms (Hua, et al., 2020). Developing robotic technologies can reduce employee-intensive processes and minimize security risks (Sharma et al., 2019). As a result, governments and companies should play a supportive role in the integration of emerging new technologies for the proper management of LIB supply chain processes.

## 5 Future Research Directions and a Circular Economy Perspective

LIBs have seen widespread use as a source of electrical power for electric vehicles (EVs) as a result of its many advantageous characteristics, which include high energy storage efficiency, high dependability, and high durability. Increased manufacturing and use of LIBs on a broad scale will result in a scarcity of raw materials and an significant increase of expired cell. The disposition of LIBs that have been retired requires careful consideration because of the possible adverse effects on the economy, resources, and the environment. This chapter section identifies future issues facing the LIB supply chain based on these prognostications.

The absence of a suitable collecting method for wasted batteries, limited quantities, and uncertainty on the whole cost of LIB recycling are key obstacles facing future LIB recycling. Fewer end-of-life LIB batteries are recycled in comparison to the amount of lead acid and NiMH batteries that are currently recycled. This difference in recycling activity and quantity between traditional and LIB batteries is a consequence an absence of environmental legislation, poor support from manufacturers, and insufficient accessible information on the economics of LIB recycling (Mayyas et al., 2019). In this context, a waste management and circular economy perspective is a very important field of study for LIB supply chains – effectively seeking to eliminate resource constraints due to both environmental sustainability and demand increases.

LIB supply chain processes are in need of effective data tracking and digital security. Throughout the LIB product's lifecycle, data related creation, usage, remanufacturing, repurposing, and recycling should be integrated and exchanged along the supply chain and potentially to other stakeholders. For these emergent issues, concerns about data security and data privacy need to be taken into consideration. It is possible to make full use of innovative technologies such as big data, block chain, cloud-based, and cybersecurity technologies in order to guarantee the privacy and integrity of data. Future research and development need to consider new technologies, especially in LIB supply chain processes. This field of study will gain in importance in the future and is already showing signs of significant growth and importance.

With the proliferation of EVs, regulations are needed to guide OEMs and manufacturers. In order to increase the efficiency of all stakeholders in the LIB supply chain, improvements can be made at points such as process, structure, and configuration. Process definitions can be made from a circular economy perspective, such as certification, warranty, battery recycling and reuse, and remanufacturing. These regulatory policies can be similar to waste electrical and electronic (WEEE) regulations that exist internationally. Such regulatory policies will help to ensure support and development of CE practices and principles so that LIB supply chains can provide greater and more effective social benefits.

Privately, economic advantages are a primary motivating factor behind LIB logistics and supply chain activities. As a result, in order to remain competitive with newly made batteries, the cost of remanufactured and reused LIBs needs to improve. During the recycling process, it is necessary to use more efficient operational methods, affordable materials, decreased amounts of energy, and practices that are environmentally friendly. In addition, in the not-too-distant future, supply chains that are to the mutual advantage of all players should be formed. These activities and directions are not trivial. Progress in these areas requires a transdisciplinary multi-stakeholder research, development, and implementation program. Multiple disciplines from scientific, social science, economic, and business communities – to name some – need to work with practitioners ranging from communities to other industries to maintain a holistic social systems transition.

Although reuse and recycling processes are taken into account in the current situation, many waste batteries still emerge and many technical, economic, technological, environmental, and commercial steps need to be taken in this critical issue. In terms of these five features, it is important to present practical solutions by considering the LIB supply chain in future studies.

## 6 Conclusion

Electric vehicle growth and various other electronics product increases are expected to put greater demands on lithium-ion batteries (LIBs). The LIB supply chain will need to undergo significant change if battery manufacturers are going to be successful in meeting the tremendous increases in these product demands. Technologies currently employed stretch back over many two decades, to a period once batteries were far smaller and focused on more for individual devices than for huge battery technology.

Batteries may now be made that are far more powerful and can last much longer. For these and other reasons, understanding and advances in LIB supply chains are more important than ever. LIB growth and usage means reducing carbon rates and protecting limited resources. In this chapter, the focus is on the main problems in the LIB supply chain processes. By evaluating each problem specifically, a roadmap of concerns for both administrative and future studies is set.

Lack of resources, geopolitical risks, sustainability, technological implementation, regulations, and commercialization are some of the main issues in LIB supply chain processes. In order to overcome these problems, specific studies are needed on economic, technological, environmental, social, and political grounds. This chapter brings to the forefront the core LIB supply chain concerns and potential research and development areas.

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