Routledge Studies in Corporate Governance

SUPPLY CHAIN MANAGEMENT AND CORPORATE GOVERNANCE

ARTIFICIAL INTELLIGENCE, GAME THEORY AND ROBUST OPTIMISATION

Catherine Xiaocui Lou, Sardar M. N. Islam and Nicholas Billington

ROUTLEDGE

Supply Chain Management and Corporate Governance

Supply Chain Management and Corporate Governance: Artificial Intelligence, Game Theory and Robust Optimisation is the first innovative, comprehensive analysis and analytical robust optimisation modelling of the relationships between corporate governance principles and supply chain management for risk management and decision making under uncertainty in supply chain operations.

To avoid corporate failures and crises caused by agency problems and other external factors, effective corporate governance mechanisms are essential for efficient supply chain management. This book develops a new collaborative robust supply chain management and corporate governance (RSCMCG) model and framework that combines good corporate governance practices for risk management strategies and decision-making under uncertainty.

This model is developed as a principal-agent game theory model, and it is digitalised and computed by Excel algorithms and spreadsheets as an artificial intelligence and machine-learning algorithm. The implementation of the RSCMCG model provides optimal supply chain solutions, corporate governance principles and risk management strategies for supporting the company to achieve long-term benefits in firm value and maximising shareholders' interests and corporate performance while maintaining robustness in an uncertain environment.

This book shows the latest state of knowledge on the topic and will be of interest to researchers, academics, practitioners, policymakers and advanced students in the areas of corporate governance, supply chain management, finance, strategy and risk management.

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Routledge
Taylor & Francis Group
NEW YORK AND LONDON

First published 2023
by Routledge
605 Third Avenue, New York, NY 10158

and by Routledge
4 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN

Routledge is an imprint of the Taylor & Francis Group, an informa business

Library of Congress Cataloging-in-Publication Data
Names: Lou, Catherine Xiaocui, author. | Islam, Sardar M. N., 1950– author. | Billington, Nicholas, author.
Title: Supply chain management and corporate governance: artificial intelligence, game theory and robust optimisation / Catherine Xiaocui Lou, Sardar M.N. Islam and Nicholas Billington.
Description: 1 Edition. | New York, NY: Routledge, 2022. | Series: Routledge studies in corporate governance | Includes bibliographical references and index.
Identifiers: LCCN 2022004406 | ISBN 9781032210391 (hardback) | ISBN 9781032210407 (paperback) | ISBN 9781003266457 (ebook)
Subjects: LCSH: Business logistics. | Artificial intelligence. | Game theory. | Corporate governance.
Classification: LCC HD38.5 .L688 2022 | DDC 658.8—dc23/eng/20220314
LC record available at https://lccn.loc.gov/2022004406

ISBN: 978-1-032-21039-1 (hbk)
ISBN: 978-1-032-21040-7 (pbk)
ISBN: 978-1-003-26645-7 (ebk)

DOI: 10.4324/9781003266457

Typeset in Bembo
by codeMantra

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Figures

Preface

This book develops a robust optimisation decision-support system and an artificial intelligence machine-learning algorithm to determine strategies and operations for the corporate governance and supply chain management game (a principal–agent game) that can provide optimal outcomes for corporations in supply chain management, risk management and firm performance. It achieves this through managing agency problems for optimal decision-making under uncertainty by adopting corporate governance principles and mechanisms.

After recent bankruptcies and financial crises arising from failures in dealing with problems of agency relationships and other external uncertainty factors, risk management is now a priority not only in good corporate governance practices but also in supply chain management across different industries. This raises important questions about how companies should take account of such risk management and resolve agency problems from good corporate governance practices and uncertainties in supply chain management. In some circumstances, principles and policies are difficult to interpret in supply chain operations, are not properly exhibited in strategic plans and cannot be broadly applied for the long-term benefit of the company. These provide the need for a new effective framework and a corresponding model that can address the issues of agency problems, risks and uncertainty by considering corporate governance in supply chain management. At present, no satisfactory study addresses the above issues. The existing discussions on the relationships between corporate governance principles and supply chain management are not explicitly based on game theory and robust optimisation foundations.

The recent trend in decision-support system modelling is to integrate analytics (analytical modelling) and intelligent systems to make decision-making and analysis more robust and accurate (Sharda, Delen & Turban 2021). Mathematical and statistical methods of artificial intelligence (especially that of machine learning) have not been adopted to study the issues of the relationships between corporate governance principles and supply chain management and for risk management and decision-making in supply chain management.

To overcome these deficiencies in the existing literature, this book develops a new collaborative robust supply chain management and corporate governance (RSCMCG) framework that adopts a principal–agent game theory framework and incorporates good corporate governance practices for risk management strategies and decision-making under uncertainty. This is implemented by an artificial intelligence RSCMCG model and algorithm to support strategic decision-making under uncertainty. It shows the superiority of applying the artificial intelligence in robustness and optimality for pursuing better supply chain performance by incorporating good corporate governance practices. The artificial intelligence RSCMCG model is applied to a hypothetical case study and is compared with other methods to present its superior results and application.

Despite the limitations of some results, the RSCMCG model provides mechanisms and incentives for minimising agency problems through optimal supply chain solutions and risk management strategies that support the company to achieve long-term benefits and maximise shareholders' interests while maintaining robustness in an uncertain environment. As the model is developed as an artificial intelligence algorithm, it is superior and more effective for risk management and decision-making and can be integrated with possible automated enterprise resource planning intelligent systems. This book also investigates the impact of good corporate governance practices on the company's financial performance.

This book provides a practical guide and an artificial intelligence algorithm for supply chain managers making decisions under uncertainty when managing operations and risks. It provides a machine-learning algorithm framework and methodology for those who wish to further explore incorporating supply chain management with corporate governance for improved supply chain management and financial performance and integrating this machine-learning algorithm in the possible automated enterprise resource planning.

This book makes the following significant contributions, among others, to knowledge in the areas of supply chain management and decision-making and risk management in supply chain operations:

1 This book provides the first innovative, comprehensive analysis and analytical robust optimisation modelling of the relationships between corporate governance principles and supply chain management for risk management and decision-making under uncertainty in supply chain operations.
2 This book provides the first artificial intelligence and machine-learning algorithm in risk management for supply chain management in relation to decision-making under uncertainty in supply chain operations.
3 This book provides a new comprehensive analysis and analytical robust optimisation modelling of, and an artificial intelligence and machine-learning algorithm for, the relationships between corporate governance principles in supply chain management under uncertainty and company's financial performance.

Acronyms and abbreviations

ASX	Australian Securities Exchange
CCP	Chance-constrained programming
DP	Deterministic programming
EBIT	Earnings before interest and taxes
ERM	Enterprise risk management
GCG	Good corporate governance
ISRATIO	inventories to sales ratio
LHS	Left-hand side
LP	Linear programming
M&M	Modigliani & Miller
RHS	Right-hand side
ROA	Return-on-assets
ROE	Return on equity
SCM	Supply chain management
SCMFP	Supply chain management with financial planning (model)
SCOR	Supply chain operations reference model
SOCP	Second-order cone programming
RSCMCG	Robust supply chain management and corporate governance (model)
UK	United Kingdom
US	United States
VAR	Value at risk

Definitions of decision variables and parameters in the proposed model

$B(t)_{safejk}$	safety inventory level for distribution centre *j* for item *k* at time period *t*
$CAP(0)_{fac_k}$	manufacturing capacity of a factory to produce item *k* at the beginning
CAP_{INVjk}	inventory capacity of the distribution centre *j* for item *k*
$CAP_{QTR_{mn}}$	capacity restriction at shipping line from *m* to *n* during time period *t*

$CAP_{QTR_{k_{mn}}}$	capacity restriction for item k at shipping line from m to n at time period t
$CAP(t)_{fac_k}$	manufacturing capacity of a factory to produce item k at time period t
$C^{CG}(t)_{AC}$	reduced agency cost because of GCG at time period t
$C(t)_{AC}$	agency cost at time period t
$C(t)_{ALL}$	total cost includes supply chain operational expenses and agency cost in this study at time period t
$C(t)_{Bc}$	bonding cost at time period t
$C(t)_{inv}$	inventory cost at time period t
$C(t)_{MA}$	manufacturing cost at time period t
$C(t)_{MA_k}$	total manufacturing cost for item k at time period t
$C(t)_{MA^{\exp and}}$	expenses on the expansion of the new production line at time period t
$C(t)_{MA^{\exp and}_k}$	expenses on new production line expansion for item k at time period t
$C(t)_{Mc}$	monitoring cost at time period t
$C(t)_{Rc}$	residual cost at time period t
$C(t)_{TR}$	transportation cost at time period t
$CoS(t)_{year}$	cost of sales at time period t
$c(0)_{invjk}$	inventory cost per unit of item k in distribution centre j at the beginning
$c(0)_{MA_k}$	manufacturing cost per unit of item k at the beginning
$c(0)_{sold_k}$	sold price per unit of item k at the beginning
$c(0)_{TR_{k_{mn}}}$	shipping cost per unit of item k from place m to n at the beginning
$c(t)_{invjk}$	inventory cost per unit of item k in distribution centre j at time period t
$c(t)_{MA_k}$	manufacturing cost per unit of item k at time period t
$c(t)_{MA^{\exp and}_k}$	unit cost of new production line expansion for item k at time period t
$c(t)_{sold_k}$	sold price per unit of item k at time period t
$c(t)_{TR_{k_{mn}}}$	shipping cost per unit of item k from place m to n at time period t
$D(t)_{M_k{}^i}$	demand for item k from the market M^i at time period t
$D(t)_{M_k{}^i}{}^{(s)}$	demand for item k from the market M^i at time period t for scenario s
$EBIT(t)$	earnings before interest and taxes at time period t
FC_{new}	investment into fixed assets at time period t
$i(t)_{IrD}$	interest rate of company's long-term debt at time period t
$IT(t)_{year}$	inventory turns at time period t
$\overline{Inv}(t)$	quarterly average inventory at time period t

$K(t)_{D/E}$	maximum allowed debt-to-equity ratio at time period t
$k(t)_{safe}$	safety inventory level ratio at time period t
LA_{qMA_k}	labour required to finish packaging item k at time period t
$Lev(t)$	leverage at time period t
$P(0)_{qMA_k}$	packaging capacity for production k at the beginning
$P(t)_{qMA_k}$	packaging capacity for production k at time period t
R_{rm_k}	the availability limitation on the raw material provided for item k
$R(t)_{DE}$	debt-to-equity ratio at time period t
$R(t)_{la_k}$	labour available for producing item k during time period t
$R(t)_{sale}$	revenue at time period t
$R(t)_{ROA}$	return on asset ratio at time period t
$R(t)_{RG}$	revenue growth rate at time period t
$R(t-1)_{sale}$	revenue at time period $t-1$
r_{MA_k}	annual increasing rate of manufacturing cost per unit for item k
r_{pac_k}	the annual increasing rate of packaging capacity
r_{PR}	corporate tax rate during time period t
r_{capfac_k}	annual increasing rate of manufacturing capacity for item k
r_{invj}	annual increasing rate of inventory cost per unit at the distribution centre j
$r_{TR_{mn}}$	annual increasing rate of transportation cost per unit at the shipping line from place m to n
r_{sold_k}	annual increasing rate of sold price
$TA(t)$	total assets at time period t
$TD(t)$	total debt at time period t
$X(t)_{invj}{}^{(s)}$	ending inventory of the distribution centre j at time period t for scenario s
$X(t)_{invjk}$	ending inventory for item k of the distribution centre j at time period t
$X(t)_{qMA_k}$	production quantity of item k at time period t
$X(t)_{qMA_k{}^i}$	quantity of material i for item k at time period t
$X(t)_{rm_k}$	raw material requirements from manufacturing factories for each item k at time period t
$X(t)_{rm_{ki}}$	raw material i required for item k at time period t
$X(t)_{sold_k}$	sold quantity of item k at time period t
$X(t-1)_{invjk}$	ending inventory of the distribution centre j for item k at the time period $t-1$, equal to starting inventory of the distribution centre j at time period t
$X(t-1)_{invj}{}^{(s)}$	ending inventory of the distribution centre j for item k at the time period $t-1$, equal to starting inventory of the distribution centre j at time period t for scenario s

$Y(Ex-t)_{qMA_k}$	expansion quantity decision for the production line to produce item k at time period t
$Y(t)_{qMA_k}$	final manufactured quantity of item k after production line expansion at time period t; it equals to $X(t)_{qMA_k}$ if there are no expansions in production line plan
$Y(t)_{qTR_{mn}}$	total shipping quantity amount from place m to n at time period t
$Y(t)_{qTR_{k_{mn}}}$	shipping quantity of item k from place m to n at time period t after extension
$Y(t)_{qTR_{k_{mn}}}{}^{(s)}$	shipping quantity of item k from place m to n at time period t after extension for scenario s
$Y(t)_{qTR^i{}_{k_{mn}}}$	shipping quantity of item k from place m to n by shipping agent i at time period t
Z_1	penalty factor for the over-capacity manufacturing
Z_2	penalty factor for the unsatisfied demand
$Z_2{}^{(s)}$	penalty on the scenario s that has unsatisfied demand
$Z(t)_{CA}$	current assets; refers to liquid assets such as cash, inventories or accounts receivable at time period t
$Z(t)_{CL}$	current liabilities; refers to short-term liabilities such as accounts payable or payroll at time period t
$Z(t)_D$	dividends paid to shareholders at time period t
$Z(t)_E$	equity refers to the value of shareholders' interests in the firm at time period t
$Z(t)_{FA}$	fixed assets; refers to illiquid assets such as plants or equipment at time period t; intangible assets, such as customer goodwill or a cadre of superior design engineers, among the fixed or current assets are not included here
$Z(t)_{Inv/CA}$	investment from current assets at time period t
$Z(t)_L$	long-term debt; refers to long-term bank loans or bonds at time period t
$Z(t)_{PR}$	after-tax profits at time period t
α_{i_k}	the coefficient for item k produced by factory i
β_{i_k}	the coefficient for item k has been shipped through shipping agent i
$\delta(t)_{D/E}$	the rate of agency cost to total cost from debt-to-equity ratio at time period t
$\delta(t)_{ITR}$	the average industry ratio for inventory turnover at time period t; or the targeted inventory turns ratio that the company sets for time period t
$\delta(t)_{IRG}$	the average industry revenue growth ratio at time period t
$\delta(t)_{Lev}$	the upper line of leverage from company management during time period t
$\delta(t)_{ROA}$	the rate of agency cost to total cost from ROA ratio at time period t
$\gamma(t)$	reducing rate of agency cost at time period t

$\kappa(t)_{inv}$	the maximum rate of investment from the current asset at time period t
$\lambda(t)_{EB/L}$	the times in which $EBIT(t)$ is as large as $i(t)_{IrD} * Z(t)_L$ at time period t
$\lambda(t)_{WC}$	minimum working capital available to the company as a function of current liabilities during time period t
$\theta_{k_{mn}}$	the proportion of total shipped amount for each shipping line from place m to n of item k
$\xi(t)_{ISRATIO_k}$	ISRATIO (operating margin) of the company associated with item k
$\xi'(t)_{ISRATIO}$	ISRATIO (operating margin) of the average industry level
Δ	denotes the change of the variable during the time period
$\Delta Z(t)_{FA}$	change amount on the fixed asset at time period t
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1 Introduction

Integrated supply chain management (SCM) entails holistic supply chain network decision-making for an integrated scheme with multiple operational procedures and divisions. In particular, risk management serves an indispensable role in the decision-making process—it is connected to other critical corporate governance factors, such as financial management, through shared risk exposure and interactive relationships within an intricate corporate structure (Ai, Brockett & Wang 2013). As companies increase in size, the synergetic complexity of their governance increases both internally and externally, with no individual component insulated. Such relationships and corporate systems can be conducted with efficiency and optimality; however, they can also be highly vulnerable to catastrophic failures such as world financial crises and other agency and information asymmetry problems and risks. To avoid corporate failures and crises caused by agency problems and other external factors, good corporate governance (GCG) mechanisms are essential for efficient SCM. One of the ultimate goals of corporate governance is to maximise shareholders' interests while maintaining a company's long-term interests, with risk management playing an indispensable role. Motivated by these challenges, this book integrates SCM, corporate governance and risk management strategies for GCG practices by applying an optimisation framework to a hypothetical company's decision-making process for the purpose of maximising long-term profit.

Corporate governance practices and risk management strategies need to be incorporated into an integrated supply chain model. The model should be designed to maximise company profit and manage risk by incorporating corporate risk management strategies such as reduced agency cost as a proxy of GCG practices in supply chain operations. This is followed by the application of robust optimisation to accommodate uncertainty.

To improve decision-making under uncertainty in the management of a company's supply chain, this book first presents a systematic SCM and corporate governance framework (robust supply chain management and corporate governance [RSCMCG] framework) suitable for assisting managers with making strategic decisions about integrating SCM with risk management. Second, this book constructs an integrated mathematical

DOI: 10.4324/9781003266457-1

optimisation model correlating SCM as one aspect of corporate management with financial management and risk management. This model features many material flows of the supply chain: production, inventory, warehousing, distribution and marketing, as well as financial management such as balance-sheet analysis. Finally, the model is solved by using a novel robust optimisation approach. As an application, this model is to be used to assist one hypothetical company with decision-making in an uncertain environment and provide a stable, risk-averse solution that minimises risk while maximising profit.

Research background

As many companies have developed a global market and collaborative supply chain networks, SCM has become an essential part of company governance, with optimal supply chain operations significantly improving company profit. For example, using an interactive approach for analysing an optimisation model, Procter & Gamble was able to save over $200M[1] (Camm et al. 1997). Cerester, Europe's leading manufacturer of wheat and corn-based starch products, implemented an optimisation modelling system that increased average daily production by 20%, leading to annual benefits in excess of $11M (Rajaram & Jaikumar 1999).

Although well-developed supply chain systems have demonstrated their success in resolving a range of business problems, risk and uncertainties in the environment may lead to business failure. For example, in March 2000, an unexpected strike of lightning hit a semiconductor manufacturing facility owned by Philips Electronics and made the plant shutdown for several weeks. This plant was the sole source of critical semiconductor devices used by Ericsson to produce handsets, but there were no contingency plans in place to find alternative devices, costing Ericsson $400M in lost revenue (Labbi 2004). Further, because of weaknesses in addressing risk, in 2008, Lehman Brothers Holdings Inc., the fourth-largest investment bank in the United States at that time, declared bankruptcy on 14 September (Mamudi 2008). This was caused by their failure to find a buyer during the financial crisis, which was triggered by a series of bank and insurance company failures. Subsequently, global credit markets came to a standstill and required unprecedented government interventions. Samuelson and Marks (2006) warned that because of these unnecessary costs arising from risk, risk management is becoming a pervasive part of big business. Consequently, the need to address risk and uncertainty at the decision-making stage of strategic planning has become increasingly important given that corporations are profit-pursuing enterprises with goals that include growth, efficiency and profit maximisation (Merna & Al-Thani 2005).

As a result of frequent bankruptcies and financial crises arising from failures in dealing with agency conflict problems and other external uncertainties, risk management is now a priority in GCG practices. The Committee on the Financial Aspects of Corporate Governance (1992, p. 11) described the role of corporate governance in good firm performance as follows:

> The country's economy depends on the drive and efficiency of its companies. Thus the effectiveness with which their boards discharge their responsibilities determines Britain's competitive position. They must be free to drive their companies forward but exercise that freedom within a framework of effective accountability. This is the essence of any system of GCG.

This range of financial crises and corporate failures across different industrial companies has raised the need to consider corporate governance in SCM, especially for risk management, to manage uncertainties during decision-making processes, which is the focus of this book. The strategic planning of the hypothetical company designed by this book will also balance the conflict between supply chain managers and company shareholders—conflict caused by their different interests—to achieve long-term benefits while keeping operations optimal and practical. Specifically, it aims to achieve sound decisions by integrating corporate governance and SCM for risk management using robust optimisation under uncertainty.

This chapter first provides an overview of the main areas relevant to this study (SCM, corporate governance and risk management) together with the limitations of the existing research. It then discusses the objectives of conducting this research, clarifies the research type and proposes three main research questions. Next, it presents the conceptual framework used in this book. It explains the robust optimisation methods applied in the study and introduces the simulation software implemented to solve the problems and the data sources for the hypothetical case study. Finally, it states the research contribution and introduces the structure of the book.

Introduction to supply chain management, corporate governance and risk management

To discuss the integration of SCM, corporate governance and risk management in an optimal plan for better supply chain networks, this section provides an overview of SCM and relevant corporate governance and risk management. Analysing the background and context of these areas establishes a comprehensive framework for their integration in decision-making under uncertainty.

Supply chain management

In the fast-growing global market, good SCM has become essential for developing sound corporate strategies. SCM has a scheme of operational chains that include flows of materials, information and cash throughout the process, from raw material suppliers to component manufacturers, final assemblers, and distribution to warehouses and retailers. In this process, multiple inventories are coordinated before they ultimately reach customers (Gass & Harris 2001). The effective management of integrated supply chains requires conscious and continuous efforts from all participating companies. These companies also rely on the suppliers and customers who work together to optimise the creation, distribution and support of an end product (National Research Council 2000). As Zaremba et al. (2003) explained, the aim of the supply chain is to link different functions and entities within and outside the company, joining together a large number of partners and customers—these include manufacturers and parts suppliers, logistics suppliers, wholesalers and retailers.

To maximise the holistic value to achieve competitive advantages, the supply chain is actively managed by a firm or group of firms to operate in the most effective and efficient way (Bozarth & Handfield 2005). For example, decisions are required regarding how many manufacturing plants are needed, where to increase the number of manufacturers and in what area they should be located for maximum convenience and minimum cost.

An integrated SCM configuration includes not only operational management but also financial management, where the capital value is the most direct way to measure performance. By integrating financial management in the supply chain, the firm can increase its value and reduce its costs to gain competitive strength. Here, cashflow is used as an indicator to assess whether the strategic planning of SCM is efficient (Stock & Lambert 2001).

Interaction between corporate governance and supply chain management

Supply chain performance refers to a firm's operational performance, and it plays a key role in creating firm value. While GCG practices can improve firm performance (Wang & Sami 2011), an investigation into the ways in which GCG practices can be integrated into SCM to improve a company's long-term decision-making, even under uncertainty, will be of value.

According to Stone, Hurley and Khemani (1998), corporate governance refers to the rules and incentives under the direction and control of company management to maximise profitability and achieve long-term value for the firm and its shareholders. A company's corporate governance structure influences several aspects of its business model, including setting company goals and establishing how to meet them, monitoring and assessing risk, and optimising performance (Australian Securities Exchange [ASX] Corporate Governance Council 2007). This structure also plays a key role in determining the cost of capital in the current global capital market (Brown & Gørgens 2009).

There are three mainstream theories for corporate governance: stewardship theory, agency theory and market theory (Calder 2008). In relation to the SCM of this study, agency theory is applied to improve supply chain operations management. Agency theory deals with principal–agent problems and conflicts of interest between managers (agencies) and shareholders (principals) in the company (Calder 2008). Although both supply chain managers and the board work for the same company, they have different views on company decision-making because of information asymmetry and different perspectives. Supply chain managers are responsible for SCM implementation, reflected as the physical flow and relevant assets of the company and their interests based on annual profits, which can lead to short-term decision-making. Conversely, the board is responsible for corporate governance mechanisms and long-term company benefits. As a result, conflicts of interest can arise between managers and the board that may obstruct the development of the company. These inconsistent interests between the agency and principals can lead to agency cost. In fact, these types of agency cost regarding cooperative efforts can arise in any situation (Jensen & Meckling 1976), particularly in the context of supply chains. This agency cost includes monitoring the expenditures of principals, the bonding costs of agents and residual loss of the company, all of which arise from the divergences between agent and principal. This creates risks in company governance that must be managed at the beginning of decision-making (see Figure 1.1).

An important aspect of the agency problem is risk aversion, which leads to residual loss. Managers normally have a risk-averse preference that may lead to lower profits caused by conservative investment decisions (Drever, Stanton & McGowan 2007). For example, in supply chain operations, a manager could choose a lower risk production plan for waste expense that then creates a shortage in supply. Company projects that bring in higher

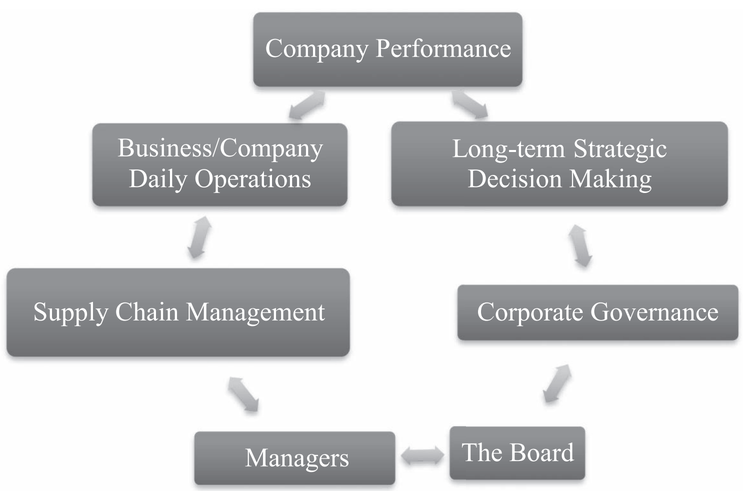

Figure 1.1 Company governance with SCM.

profit normally have higher risk and a probability of failure, leading to the concern of how to balance risk and profit to create an acceptable risk profile. Here, an effective way to measure and model a risk–profit relationship is through mathematical modelling that technically works out stable, optimum solutions. This kind of modelling can address potential problems that may occur because of the separation of management and ownership in the company and clarify how this agency issue can be incorporated into the strategic decision-making process.

Risk management and decision-making under uncertainty

The ASX Corporate Governance Council (2007) states that effective corporate governance structures encourage companies to create value through entrepreneurialism, innovation, development and exploration and to provide accountability and control systems commensurate with the risks involved. According to ISO 31000:2009 (International Standards Organisation 2009), risk management is a process that includes identifying, assessing and prioritising risks that affect the uncertainty of objectives, which is followed by a coordinated and economical application of resources to minimise, monitor and control the probability and/or impact of unfortunate events or to maximise the opportunities' realisation. In ideal conditions of risk management, a prioritisation process is followed in which risks with the greatest loss and highest probability of occurrence are handled prior to those with less loss and lower probability of occurrence. However, although such prioritisation can be very difficult and costly, risks should be under control regardless, with trade-offs between risk management and profit goals considered at the strategic planning stage.

Risk is defined as a chance or possibility of danger, loss, injury or other adverse consequences (Moore 2004). In relation to management accounting and corporate financial management, which are applied in the Chartered Institute of Management Accountants' official learning system, risk is considered a condition in which there exists a quantifiable dispersion in the possible outcomes of any activities (Collier & Agyei-Ampomah 2008). Risk may come with uncertainties, but although they are related, they are not the same (Mun 2010). Uncertainty refers to the variables that are unknown and changing, whereas risk is more structural, with the assigned probability distribution of performance measures (Aven & Renn 2010). That is, risk may be estimated as the possibility of loss in the researched objective, and it is seen as the outcome of uncertainty. Conversely, risk can become an opportunity if uncertainties are well managed and return with good results. However, whether a probability distribution can be applied objectively in real life is arguable (Aven & Renn 2010). Even if the simulated distribution function dovetails well into historical data, it is not certain to follow the same trend in the future. Therefore, as risk should not be distinguished as separate from uncertainties, modelling under uncertainty in SCM can capture the changeability and vitality of the real world, thus attracting researchers' interests. Incorporating risk management into company governance can yield subsequent results in value creation while reducing the costs of financial distress, thus maximising value from volatility in the firm's environment (Léautier 2007).

Limitations of existing studies in supply chain management, corporate governance and risk management

A diverse range of studies have developed models for SCM practice, mainly focusing on the areas of operational management and networking performance while paying more attention to instant achievement and short-term benefits. As a result, most optimal supply chain models have developed features aiming at solving and handling short-term operational planning that are seldom useful for long-term strategic planning. These studies are examined in detail in Chapter 2. However, currently, no satisfactory study has addressed the issues discussed in the above sections. The existing discussions of the relationships between corporate governance principles and SCM are not explicitly based on the game theory foundation.

The recent trend in decision-support system modelling is to integrate analytics (analytical modelling) and intelligent systems to render decision-making and analysis more robust and accurate (Sharda, Delen & Turban 2021). Mathematical and statistical methods of artificial intelligence (especially that of machine learning) have not been adopted to study the issues of the relationships between corporate governance principles and SCM and for risk management and decision-making in SCM.

As corporate governance is concerned with a company's long-term benefits, the impact of its factors on company performance has been well investigated using regression models in a range of studies. Similar studies have investigated the significant role that risk management can play in the decision-making of a company's supply chain process. However, these studies have not paid much attention to the integration of SCM and corporate governance, nor to the interactive impact of SCM and corporate governance on a company's long-term profit. Reviewing the literature reveals an apparent deficit in theories and methodologies that connect corporate governance principles with SCM models in decision-making, especially in relation to the area of risk in a global and integrated fashion. Company practice has tended to isolate decision-making processes by assigning corporate governance tasks to people sitting on the board while leaving SCM decisions to technicians, resulting in significant lags in communications and inefficiency in business decisions.

As the main purpose of corporations is to accumulate capital to enable high-cost business ventures to be undertaken, risk management becomes a significant issue (Gaffikin 2008). However, previous studies have seldom considered the uncertainties present at the strategic decision-making stage in a company's SCM. As most companies use inadequate cost-minimisation methodologies, they tend to have inaccurate information when identifying their profit-maximising global production and distribution plans.

Applying robust optimisation from the Mulvey mean-variance and penalty function in the objective function is limited in its computational burden and is consequently prevented from having a wider application. Instead, this study considers a profit and equity maximisation model to evaluate decisions explicitly. In particular, this book investigates issues governing the hypothetical company and focuses on modelling supply chains with GCG practices concerning risk management to maximise profits and minimise risks, aiming to achieve optimal strategies satisfying stability and efficiency in management. Consequently, though quite challenging, it is worthwhile at the margin to integrate SCM with corporate governance for risk management.

Research objectives

The objectives of this book are to develop decision-support systems and artificial intelligence to formulate the strategies and operations of the corporate governance and SCM game that can provide optimal outcomes for corporations in SCM and firm performance through managing agency risks and other forms of risks for optimal decision-making under uncertainty by adopting corporate governance principles and mechanisms.

Risk management has always been a key governance issue (Calder 2008), and although an optimal supply chain system can help firms save costs, the failure to manage risk effectively can easily defeat this objective. Previously, researchers have identified corporate governance factors such as financial data and agency cost, relevant data for both influences on company performance and interaction relationships. These have been separately discussed using numeric models or investigated through econometrics methods. However, these factors have not yet been quantified in strategic planning for the standardisation and optimisation of risk management, particularly in SCM. In this context, incorporating GCG practices for risk management strategies into the supply chain model can develop a better supply chain network for the company and improve the company's performance.

This research focuses on risk management strategies for stable internal development of the company and external network collaborations among supply chain partnerships for long-term benefit while considering decision-makers' risk appetite and tolerance factors through optimisation modelling. The risk-based analysis framework of a supply chain is proposed later in this chapter (see 'Conceptual framework') and discussed in detail in Chapter 3. Through risk management, managers can make strategic decisions with risk aversion for the company to prevent financial loss in uncertain environments. Therefore, this book aims to develop a comprehensive framework for using risk management in the integration of SCM and corporate governance. The primary research objective is to build an integrated optimal SCM model that incorporates GCG practices for risk management strategies into formulations for dealing with uncertainties through a robust optimisation approach. The book's other objectives are as follows:

1. Establish a novel systematic and sustainable framework that integrates corporate governance and SCM for risk management. In particular, GCG practices and principles are considered in this framework.
2. Develop the proposed framework into an integrated model, including operational factors and cashflow in an uncertain supply chain environment. The supply chain risk management strategies have been combined in the model to manage the fluctuating environment in the supply chain.
3. Examine and analyse parameters and uncertainties that affect decision-making to achieve GCG and stable supply chain performance. Specifically, factors such as agency cost and risk aversion are incorporated into the objective function of balancing the cost and profit while bringing in decision-makers' risk preferences and constraints that reflect optimal risk management strategies.
4. Solve the problems using a robust optimisation approach conducted through the simulation developed in the Risk Solver Platform
5. Apply the proposed model to solving decision-making problems in a hypothetical case study to provide a robust optimal solution for company decision-making and corporate strategy recommendations. Comparisons in output results and solutions between the proposed model with deterministic optimisation and simulation optimisation approaches are also examined.
6. Provide a robust model framework for decision-making and present the way in which the model framework can improve the company's supply chain performance and corporate governance and enhance broader industry performance.

In a compressed form, we can state that this book aims to achieve the following:

1. Develop novel conceptual, theoretical and numerical frameworks and models based on game theory to analyse issues of corporate governance and supply chain relationships for risk management and decision-making under uncertainty in supply chain operations
2. Develop machine-learning models to design GCG in SCM and corporate performance relationships
3. Design more effective corporate governance principles and mechanisms that use game theory foundations and artificial intelligence and

machine-learning methods to enhance SCM, leading to the improved financial performance of corporations
4 Develop possible future artificial intelligence and machine-learning algorithms and models for emerging automated corporate governance and supply chain systems.

Research type and research questions

To achieve the above objectives, this study employs a combination of qualitative and quantitative methods in a predictive and exploratory manner. First, the interrelationships among SCM, corporate governance and risk management are explored to develop a new collaborative framework. Following the integration of these three areas, an optimal robust supply chain model incorporating GCG practices (RSCMCG model) is proposed to make better decisions and improve company supply chain performance. A hypothetical case study using both qualitative and quantitative mathematical methods is then employed to present the solutions and outputs achieved by the proposed model.

Based on the theories and previous research found in the literature, this research develops a new framework and quantitative model for decision-making under uncertainty in the supply chain industry. The use of a predictive approach through an optimisation model deduced from the proposed RSCMCG framework is shown to improve supply chain performance. In using an exploratory research approach based on a hypothetical case study to explore and examine this new framework for future applications in SCM, existing theories and concepts are used as the basis for a combination of quantitative modelling methods and qualitative analysis to improve SCM decision-making for corporations.

This study is designed to answer the following research questions:

1 How can SCM be integrated into GCG practices for risk management in a systematic framework to achieve an improved supply chain system for a company?
2 How do the risk management strategies and robust optimisation method help the company reach its sustainable long-term profit target?
3 How can decisions be made under uncertainty using the proposed RSCMCG model framework for the company?

Conceptual framework

The study combines the framework of SCM and corporate governance theories to answer the research questions. The study objective is to integrate supply chain issues with GCG practices based on agency theory and game theory, therefore achieving the robustness of effective supply chain performance and long-term benefit to the company. The main goal is to maximise equity and shareholders' interests under the guidelines of SCM and corporate governance theories.

This research aims to build a supply chain framework from the resource-based view, agency theory, game theory and network perspective. In the context of the supply chain networks, the study follows the framework of the resource-based view and network perspective to optimise the structure of the supply chain network and operations. It works on the best value for the entities in the chain network by considering the optimal resources arrangement and participant capabilities. Agency theory helps identify reward structure and cultural competitiveness to ensure alignment among participants' interests in the whole supply chain instead of participants acting only according to their own benefit.

The new proposed framework in this study is derived from supply chain operational networking management, relevant corporate governance, financial and accounting practices from risk management strategies, and corporate financial management perspectives. Specifically, from the SCM perspective, corporate risk management strategies from agency theory, game theory and managerial practices (e.g., diverse suppliers, alternative shipping lines and safety inventory) are applied. From a corporate finance and accounting practices perspective, equations and constraints are included to manage the relationships between corporate financial management and supply chain operations and work interactively to improve firms' strategic planning. In particular, regarding this interrelationship, the financial planning decisions relevant to supply chain operations are incorporated with risk management in accounting practices. Financial policies are also included in the discussion of the principal–agent problem. The principles and practice used to reduce agency cost and protect the company from financial crises are investigated and quantified into the proposed optimal planning model. By incorporating risk management strategies and corporate financial management into the basic SCM model through robust optimisation, this study has developed an integrated robust SCM and corporate governance model: the integrated RSCMCG model.

The proposed RSCMCG model framework (see a basic framework in Figure 1.2) aims to combine the physical flow with the financial flow and to integrate manufacturing, distribution, inventory and marketing processes to achieve a comprehensive SCM framework. At the same time, GCG is incorporated into the model framework under the guidance of agency theory. GCG practices support the firm in reducing risk and increasing firm value, and these elements are quantified into the proposed model through risk management and corporate financial management strategies. The supply chain risk management and corporate governance risk management strategies are incorporated into the supply chain model constraints to deal with the uncertainties in the supply chain environment and achieve better supply chain performance. Meanwhile, the corporate financial management constraints in the model framework will help incorporate the

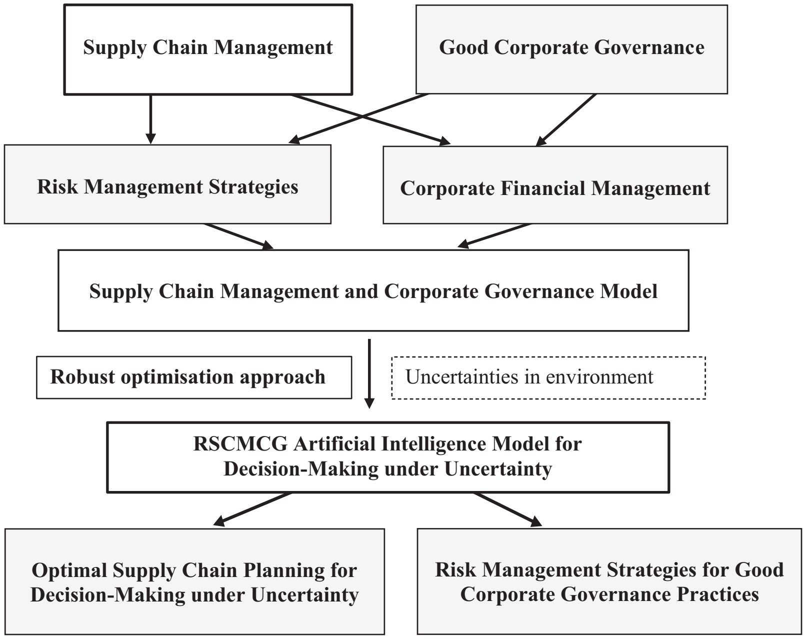

Figure 1.2 RSCMCG framework for making optimal decisions under uncertainty and risk management strategies.

good corporate financial management policies and thereby improve supply chain performance. The robust optimisation method is applied to solve the uncertainties in the problem to maintain stability and optimality and to obtain a competitive optimal solution. Applying the RSCMCG model with the above considerations achieves the solutions and risk management strategies for the company's strategic supply chain planning.

More details on methods and model simulations are given in Chapters 3 and 4. Further presentations of the model framework's application are illustrated in Chapter 5 through a hypothetical case study. The output from this modelling framework can be used for optimal decision-making under uncertainty and to provide risk management strategies for improving SCM performance.

A robust optimisation model that incorporates corporate governance for risk management in an integrated supply chain

Optimisation modelling and robust optimisation

This study uses an optimisation model to solve the problems of supply chain planning under uncertainty. Optimisation modelling applications are normally known as operations research—models are designed for industrial application purposes, focusing on production schedules, inventory planning or transportation arrangements. Specifically, in terms of uncertain environments and managing risk in optimal circumstances, robust optimisation is regarded as the method that generates the most stable solutions for dealing with uncertainty.

Robust optimisation is an optimisation modelling approach that is used to deal with uncertainties in risk management and decision-making. As discussed by Kouvelis and Yu (2010), there are five reasons for using robust optimisation. First, it considers the uncertainties and responds positively. Second, it forecasts the values of uncertain parameters that do not occur in most environments. Third, it can generate decisions in unique, non-repetitive situations, which are common in fast and dynamic environments. Fourth, risk management is averse in nature. Lastly, it recognises that even though decision environments are fraught with data uncertainties, decisions can be evaluated prior to the data being confirmed (Kouvelis & Yu 2010). Drawing on Kouvelis and Yu's discussion to address the concerns of this study, the reasons for selecting robust optimisation as a methodology are as follows:

1. In the general context of SCM, the robust optimisation method can deliver robust results that are not sensitive to changes in the environment.
2. Robust optimisation can be used in specific supply chain areas, such as transportation and logistics, where a stable system is required.
3. Solutions provided by robust optimisation are suitable for use in almost all scenarios that may occur in the same case. By contrast, a general optimisation model may be suitable for finding an optimal solution in a case with a certain scenario but may not be feasible for a case in which circumstances have changed.

More discussions on the superiority of robust optimisation are given in Chapter 2, and the methodology is justified further in Chapter 3.

An integrated supply chain management model with artificial intelligence robust optimisation

Based on the proposed integrated supply chain operational and financial planning framework combined with corporate governance factors for risk management purposes, this study presents an RSCMCG model. This model is designed to support company decisions in relation to complex supply chains, risk management and financial planning in uncertain environments, taking decision-makers' risk preferences into consideration.

The fundamental SCM structure of the proposed RSCMCG model is based on the classical supply chain models and decision-making techniques of Shapiro (2007) and Ragsdale (2012). It also considers the financial situations and management presented in the models of Carleton, Dick and Downes (1973) and Kirca and Koksalan (1996). Subsequently, the study investigates the specific advanced quantitative methodologies used for dealing with uncertain environments and their applications in supply chain networks such as stochastic programming and robust optimisation (Bertsimas & Sim 2003; Bertsimas & Thiele 2004; Tang 1990). The proposed model further incorporates corporate governance risk management aspects from the corporate risk management framework of Léautier (2007).

The modelling exercise has also developed this model (RSCMCG model) as a machine-learning model to study corporate governance in SCM and corporate performance relationships. This has been undertaken to design more effective corporate governance principles and mechanisms that use game theory foundations and artificial intelligence and machine-learning methods to enhance SCM, thus leading to the improved financial performance of corporations. This will help develop possible future artificial intelligence and machine-learning algorithms and models for the emerging automated corporate governance and SCM systems.

This study extends previous research and models by integrating GCG practices for risk management strategies into the objective function and constraints of a supply chain network model. The specific target and constraints consider shareholders' interests and sustainable company profit while maintaining operational management. Equity, earnings before interest and taxes (EBIT), fixed assets and long-term investment are chosen as proxies to represent firm value, shareholders' value and company benefit. The GCG practices incorporated into the RSCMCG model constraints can be divided into supply chain operational networking risk management practices and relevant corporate financial and accounting practices for corporate governance performance. Consequently, it will improve supply chain performance and enhance its sustainable benefits and long-term operations. The model is designed to manage risks that may cause the future failure of firms by assisting the company's decision-makers with planning their long-term strategies.

The RSCMCG model constraints are briefly listed below:

1 Definitional supply chain operation and financial constraints
2 Supply chain operational constraints of manufacturing functions, shipping balance, mass balance, inventory expense and marketing
3 Financial planning constraints include financial balance, funds flow, investment balance and expansion expense
4 GCG practices constraints for optimal supply chain operational management from the risk management strategies perspective, including supply chain specialised agent governance, risk management strategies for supply chain operational system and SCM performance measures policy

5 Corporate finance and accounting practices for corporate governance performance constraints, consisting of internal control policy (debt-to-equity constraint, investment policy, debt service management, working capital policy and leverage constraint), principal–agent problem and GCG performance measures policy.

The proposed model framework for integrated supply chain and corporate governance for risk management is finally realised using robust optimisation. A hypothetical case study conducted under the 'D Norm' uncertainty set in robust optimisation constraints is used to examine the influence of uncertainties on the model's implementation. A risk-aversion perspective of the decision-makers' preference is thereby incorporated into the model through uncertainty set constraints. Risk preference can also be achieved through the utility objective function using a risk coefficient presented in Chapter 4. By changing the value of the risk coefficient, the decision resulting from different risk preferences can then be presented. Finally, the solution from balancing the minimum risk and maximum equity can be achieved.

Simulation and data collection

Simulation software

Operational supply chain optimisation modelling is often conducted using enterprise management software such as the IBM ILOG CPLEX Optimizer, which requires separate platforms for implementation. Conversely, for accounting practices and capital budgeting, Excel Solver is applied in most industrial companies and solves simple linear deterministic optimisation models. The separation between supply chain optimisation and accounting optimisation can result in difficulties when undertaking a comprehensive interpretation of results. This study applies the Risk Solver Platform to solve this problem.

The Risk Solver Platform is add-in software in Excel that is designed for solving a range of problems (including those with uncertainties) by applying methods such as optimisation modelling, simulation modelling or the decision tree method. For dealing with problems with uncertainties, the Risk Solver Platform 11.5 version has been upgraded to combine a robust optimisation approach from its previous version, which can be used in practice. To conduct the proposed RSCMCG model and to seamlessly connect supply chain physical flows with cashflows for a hypothetical case study, this study implements the experiments under the Risk Solver Platform in an Excel spreadsheet using a suitable algorithm, thereby generating the corresponding solutions.

The numerical implementation of the applied principal–agent game theory model for corporate governance and SCM is done as a robust optimisation artificial intelligence/machine-learning model for corporations using some hypothetical data. A search artificial intelligence algorithm is used to implement this principal–agent game model by Excel.

Data collection

The proposed conceptual framework and model in this study are explained and analysed through a hypothetical case study, with the data obtained from two resources, including secondary data and experimental data. The secondary data are collected from business cases for assisting the production of different scenarios under randomly assumed uncertainties. The experimental data are simulated through the random generator method in the Risk Solver Platform.

As holistic supply chain networks and financial planning are highly complex, public financial reports only contain the financial aspects of the company, not the details of its operations. As previous studies have mainly focused on the optimisation of supply chain processes separately, they have used individual models or combined certain procedures that have not included all the supply chain networking in one holistic model. In this context, this study combines secondary data and simulation data with different scenarios based on empirical cases from previous research to achieve a reasonable stream of data.

Contributions and implications of this study

Contributions of the new theoretical framework and model

Competitive global economics has called for sound strategies in collaborative supply chain networks, while frequent bankruptcies and financial crises call for GCG practices and risk management. However, before this study, the integration of the interrelationships among SCM, corporate governance and risk management, especially through a robust optimisation model framework, had not been addressed in the literature. The current study fills this gap by developing an optimal supply chain framework integrated with corporate governance in relation to risk management through the robust optimisation approach (RSCMCG model) based on managerial and financial perspectives.

This comprehensive framework has integrated the physical and financial flows of supply chain networks that are formatted as constraints and variables in the model. Corporate governance factors and GCG practices for risk management have been quantified and incorporated into the model to support strategic decision-making under uncertainties. For example, the agency cost, which plays an important role in measuring corporate governance performance, is modelled into the constraint of the proposed supply chain optimisation model. In this study, reducing the agency cost of agency problems through the model could help reduce the total cost of supply chain operations, combined with the satisfaction of demand based on risk management strategies provided by the RSCMCG model, eventually enhancing the company's long-term reputation. Moreover, the decision-makers' risk-aversion factor can also be incorporated into the proposed model through robust optimisation to achieve a stable, optimal solution.

The sustainable optimal solutions and risk management strategies provided by the proposed RSCMCG model framework have been further proven to improve SCM performance and can be applied to specific cases in the future. In particular, incorporating optimal supply chain strategies and GCG practices can reduce supply chain operational expenses and agency cost while providing risk management strategies through the robust optimisation approach, mitigating possible risks in the uncertain environment. It can eventually increase long-term profit for the organisation and long-term benefit for the shareholders. Applying the proposed model can achieve a robust optimal solution while generating a rational and comprehensive analysis based on the holistic range of constraints and rules to support managers making strategic planning decisions for their companies.

Contribution to the knowledge

This book contributes to the knowledge in the areas of SCM and GCG in the following ways:

- By integrating risk management and financial management into supply chain processes and incorporating corporate governance practices (including internal policies in enterprise and external regulatory surroundings) through robust optimisation, this study brings a novel theoretical systematic framework to SCM and global decision-making research.
- The study offers an extended understanding of corporate governance, corporate finance, and accounting practices and risk management in supply chain networks. By incorporating quantified normative GCG principles into the supply chain model, the effectiveness of GCG practices is addressed in the SCM to achieve long-term benefit for the company and shareholders' interests.
- In answer to the main research questions, this study proposes an integrated robust model for optimal SCM, including material and cash-flow processing, while considering the effect of corporate governance related to risk management (RSCMCG model). This fills a gap in the SCM modelling literature to help enterprises achieve GCG in strategic planning for SCM. Exploring a suitable approach to solve the robust optimisation model provides a new vision to achieve robustness in similar problems.

This study proposes a new model framework for SCM that incorporates corporate governance strategies into an integrated supply chain operational model with financial management. The study formulates the decision variables and constraints for constructing a company's supply chain operation system. The specific target and constraints consider shareholders' interests and sustainable company profit while maintaining robust operational management. Expenses in the main supply chain operational procedures and risks controls are taken into account, and a robustness objective is developed for the strategic planning decision-making of the company's SCM.

This study also makes the following significant contributions, among others, to the knowledge of SCM and decision-making and risk management in supply chain operations:

1. This is the first innovative, comprehensive analysis and analytical robust optimisation modelling of the relationships between corporate governance principles and SCM for risk management and decision-making under uncertainty in supply chain operations.
2. This is the first artificial intelligence and machine-learning algorithm in risk management for SCM in relation to decision-making under uncertainty in supply chain operations.
3. This is a new, comprehensive analysis and analytical robust optimisation modelling of, and an artificial intelligence and machine-learning algorithm for, the relationships between corporate governance principles in SCM under uncertainty and company's financial performance.

Contributions to the practice

Optimal SCM strategies for firm managers are proposed through the RSCMCG model and comprise production decision-making (how to arrange manufacturing), distribution (delivery scheme, distribution methods and transportation control), optimal placement of inventory (safety stock levels, the capacity of inventory) and marketing strategy (demand satisfaction). The model works on minimising the operating costs of manufacturing, transportation and distribution. One of the important bridges between SCM and corporate governance is risk management. The model helps reduce and hedge the uncertainties that may come from financial markets, project failures, legal liabilities, credit risk and accidents. In this way, the optimal output strategy will become an effective tool for providing performance measurements for a company.

By improving decision-making in production, distribution and optimal placement of inventory strategies, efficient corporate governance strategies are proposed to manage risk in SCM and maintain long-term benefits for an organisation. This study contributes to the long-term profit of a company and enhances shareholders' interests while dealing with corporate risk and optimising present operational supply chain systems to support managerial decisions.

Summary and structure of the book

This research shows that by incorporating GCG practices for risk management strategies that have been formulated using an integrated robust optimisation model approach, the company can achieve stable supply chain performance and manage risks for long-term benefits. This section details the structure of this book.

Chapter 2 investigates the development of areas relevant to this research, including SCM, corporate governance, risk management, optimisation modelling and decision-making under uncertainty. It also discusses the limitations of the existing literature in terms of developing a suitable framework for this study.

Chapter 3 presents the conceptual framework of this book and proposes a new integrated SCM framework that incorporates corporate governance for risk management (RSCMCG framework) based on agency theory and game theory. It then explains the integration and interaction of SCM and corporate governance for risk management. The chapter presents and briefly discusses the research problems and questions from a theoretical viewpoint. Next, it introduces and justifies the robust optimisation methodology applied in this research. It explains the specification of the RSCMCG model framework and justifies the choice of software and data collection method. This chapter also presents the validation and superiority of the framework.

Chapter 4 introduces the development of a new artificial intelligence robust optimisation model under the integrated SCM framework that incorporates corporate governance for risk management (RSCMCG). This chapter specifies the mathematical models and interprets corporate governance policies and risk management strategies using constraints and the robust optimisation modelling approach, including presentations of settings for the robust optimisation approach in the Risk Solver Platform.

Chapter 5 presents the application of the proposed model in a hypothetical case study with a specified mathematical model, which simulates by the Risk Solver Platform to present and explain the results. More analyses and outputs are further addressed by comparing the proposed RSCMCG model with the other two approaches: deterministic optimisation and simulation optimisation.

Lastly, Chapter 6 discusses the implications of the study and presents the contributions it makes in the areas of SCM, corporate governance, decision-making under uncertainty and risk management. It also discusses the theoretical and methodological implications of this study. This book concludes by proposing directions for future research.

Note

1 $200M stands for $200 million; the same symbol notation applies for the entire study.

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2 Supply chain management, corporate governance, risk management and optimisation modelling

Introduction

Since the 1900s, well-developed supply chain systems have successfully solved a range of business problems. In the fiercely competitive world of global trading, supply chain systems can help in making decisions that may lead to the success of a business. Supply chain systems refer not only to a chain of one-to-one partnerships, or business-to-business relationships, but also to a network of multiple businesses and relationships (Lambert & Cooper 2000). An integrated supply chain network is an essential element of a company in terms of managing external governance. A company can save significant costs by using an interactive approach to analysing an optimisation model that considers corporate governance.

With the growth in both the width and depth of the supply chain industry, there is a demand to integrate good corporate governance (GCG) practices not only in company governance structures but also in supply chain networks to improve supply chain performance. Recent studies show that adopting GCG practices has a significant positive impact on a firm's performance. This is evidenced in both developed countries with long histories of promoting corporate governance principles (McKnight & Weir 2009) and developing countries such as China (Fu 2010; Wang & Sami 2011). This study considers the metrics measuring GCG and their associated relationships with firm performance indicators. GCG has been proven to have a positive impact on firm performance and valuation. Conversely, failures in risk management and corporate governance can easily lead to ruin. This study presents research on incorporating GCG practices into supply chain management (SCM) and examines their impacts on supply chain networks and performance.

This chapter investigates the contemporary development of SCM, corporate governance, and risk management and their interrelationships. It first reviews SCM, including research and development of theories and models. It then presents the development of corporate governance and critical issues relevant to this study. Next, the chapter addresses the area of risk management in SCM and corporate governance together with risk management modelling and measures. It investigates optimisation models

DOI: 10.4324/9781003266457-2

developed for uncertain environments. Very importantly, the robust optimisation approach and its superiority is compared with other methods. Finally, it states the limitations in the existing literature and the contribution made by this research.

Supply chain management and models

The competition of the world markets is growing into an era of supply chain versus supply chain instead of firm versus firm (Ketchen & Hult 2007). The significance of SCM in a company's governance strategies is emphasised and reflected in well-known multinational firms such as Walmart, Dell and Apple. SCM aims to achieve long-term benefits while managing risks to achieve the best performance and, therefore, the best value for the company.

The concept of SCM was brought into the public domain in 1982 by Keith Oliver, who was a consultant at Booz Allen Hamilton. The following points, which are well established in academia, can help define SCM: it is the process involving raw material procurement, production planning, material sourcing, manufacturing, transportation management, warehouse management, production–distribution and demand management; a good supply chain network would be 'right time, right place, and right production'; broad SCM contains physical flow, information flow and financial flow; the concept of SCM refers more to the management of the network, which needs cooperation and collaboration between the engaged participants. Consequently, trust and agency cost become more important; vertical supply chain decision-making for a company is divided into strategic, tactical and operational planning; important concerns in SCM include lead time, real-time, just-in-time, cost and quality (Bozarth & Handfield 2005; Handfield & Nichols 1999; Jacobs & Chase 2011; Neef 2004).

Supply chain management theories development and research streams for forming a supply chain framework

SCM theories have grown rapidly since the 1990s and have been broadly investigated (Halldorsson et al. 2007; Ketchen & Hult 2007; Lamming 1996). The main streams of SCM theories include the resource-based view, transaction cost analysis, the knowledge-based view, strategic choice theory, agency theory, institutional theory, systems theory, network perspective, performance information risk management system, materials logistics management, just-in-time and material requirements planning. Others areas include theory of constraints, total quality management, agile manufacturing, time-based competition, quick-response manufacturing, customer relationship management, requirements chain management and available-to-promise. Multiple theories have been identified and integrated for effective application to the supply chain industry (Bidar & Islam 2019; Grover & Malhotra 2003; Halldorsson et al. 2007; Ketchen & Hult 2007).

Transaction cost analysis concentrates on the 'make or buy' decision, and its main goal is to maximise performance by minimising the transaction costs within and between organisations. Agency theory focuses on the principal–agent problem and aims for an efficient structure that ensures the best value for the supply chain participants' interests. Networking perspective theory addresses the relationship among the participants and determines whether it should be a strong tie for the reliability or a weak tie for flexibility, depending on what brings the best value to the network. The resource-based view considers the role of assets and capabilities and their contribution to the firm's competitive advantages and performance (Ketchen & Hult 2007). For modelling at the strategic and tactical levels, the importance of resources is emphasised (Shapiro, JF 2007). The resource-based view provides important insights into a firm's resources and implicitly into the construction and use of optimisation models for SCM. Resources in the context of SCM refer to physical resources, human resources, financial resources, information technology resources, marketing resources, organisational resources and legal resources (Shapiro, JF 2007, p. 309). Considering the above theories, the major problems of SCM are resources planning and expenses balancing.

The core performance dimensions for operations and supply chain activities are quality, time, flexibility and cost (Bozarth & Handfield 2005). HL Lee (2004) from Stanford University also proposed '3A' (Agility, Alignment, Adaptability) strategies for modern SCM. Meanwhile, to enhance companies' supply chain performance, modern techniques such as just-in-time, automation, lean production and risk control have also been brought into SCM (Neef 2004).

Based on an online survey of 177 professionals working in the area of SCM in China, the Global Supply Chain Council (merged with the Association for Supply Chain Management [APICS] as APICS Supply Chain Council in April 2014) reported that the major problems with supply chain and logistics in China are high costs and low reliability (Wu 2012). It is essential for logistics providers to avoid waste by improving supply chain plans, information technology systems and warehouse management, according to Thomas Pan, managing director of Menlo Worldwide Logistics, based in North Asia (Wu 2012).

Gartner Inc., founded in 1979, is the world's leading information technology research and advisory company, headquartered in Stamford, United States, and it has built a program that annually identifies global supply chain leaders. It has revealed the top 25 supply chains performance companies over the past eight years (Hofman & Aronow 2012). In 2012, the top five companies out of 298 included Apple, Amazon, McDonald's, Dell and Procter & Gamble. The report featured the following recommendations: continue to build resiliency into supply chain network design and implement a robust risk management strategy, including a 'sense and respond' capability to recover quickly and profitably from disruptions; adopt complexity optimisation strategies to eliminate features, services and network capacity that do not add sufficient value to the customer; and improve responsiveness to customer requirements using a globally architected, regionalised approach to supply chain network design (Hofman & Aronow 2012). The report also mentioned that many of the top 25 companies were affected by natural disasters, such as the Japanese earthquake and tsunami and the massive flooding in Thailand. The capacity to deal with an uncertain environment and risk management is emerging as a crucial factor in the decision-making process.

Despite increasing awareness among industries, the concepts of supply chain networking and management, supply chain risk management and corporate governance are still in their infancy.

Supply chain management procedures

There are different levels for planning and scheduling SCM procedures, including strategic planning, tactical planning and operational planning. Companies have strategic planning for the long term (normally one to three years), tactical planning for the short term (less than one year) and operational planning for daily or weekly periods. Additionally, these different planning levels involve different aspects of a company's operation. For example, with regard to the manufacturing and distribution plans, strategic planning concerns a company's situation with capacities, facilities, locations and resources while tactical planning refers to the aggregate planning, including allocating capacity and resources to product lines, assigning sales regions to distribution centres, developing warehouse workforce requirements and conducting carrier selection processes (Miller & Matta 2008). Operational planning differs from strategic and tactical planning as it is more detailed regarding daily activities. This study focuses on a hypothetical company's strategic planning for its long period (including short- and long-term benefits). Tactical planning and operational planning are considered to a certain extent but are not fully discussed in this book.

The specialised horizontal procedures across a comprehensive supply chain process are divided into several main parts: raw material procurement, manufacturing, inventory, logistics and transportation, marketing and customer services. For raw material purchasing, researchers and organisations have developed different approaches to promote the progress of procurement such as materials requirements planning systems, supplier selection, bill-of-materials, lean production and agile manufacturing. Inventory issues are concerned with holding general costs, shortage costs and demand distributions for products specified at a detailed stock-keeping unit level (Beamon 1998). To improve the inventory status of merchandise, strategies are designed to reduce the cost while satisfying customers' requirements. A typical example is the economic order quantity, which determines the optimum order size for individual inventory items. An optimum order size is one that minimises the total ordering costs and carrying costs (Simchi-Levi, Thorne & Hilton 2009). Logistics and transportation refer to the activities of shipping the production from manufacturing factories to the warehouses, the retailers and, eventually, to the final customer. Specific logistics and transportation activities comprise transportation, warehousing and storage, industrial packaging, material handling, inventory control, order fulfilment, demand forecasting, production planning and scheduling, customer service, facility location, return goods handling, parts and service support, salvage and scrap disposal (Coyle et al. 2012). The main associated decision-making comprises transportation selection and optimising the route and resources, such as warehouses, to achieve cost economies and time efficiency. More recently, system and software innovation and development have attracted SCM industry attention through the application of ERP systems. For example, major software vendors include SAP, Oracle, PeopleSoft and i2Technologies.

Through a comprehensive discussion and exploration of modelling and computing in the supply chain, Voss and Woodruff (2006) determined the specific tasks that need to be undertaken in SCM from long-term, mid-term and short-term views.

Popular SCM issues among industries include distribution networking design, inventory control, purchasing and supply contract management, distribution strategies and systems, integration of supply chain and strategic alliance partners, outsourcing, new product design, customer value, intelligent pricing and double marginalisation (Simchi-Levi, Wu & Shen 2004).

Supply chain management models

In the supply chain industry, common features and problems associated with planning can be modelled and then specified with minor customised modifications for individual companies. To achieve the firm value maximum or cost minimum target, a company needs to design the supply chain system from the very beginning and plan an efficient and effective framework for its implementation. Various methods for modelling the supply chain include conceptual model, graphic model, simulation model, grammatical model, intelligent mode, econometric mode and operations research (Yan, Li & Shi 2008). Optimisation in SCM has been studied for decades using a range of quantitative and qualitative methods such as sensitivity analysis, heuristic analysis and mathematical modelling. Normally, the analysis uses deterministic variables or predicted values for the parameters, which estimate efficient and optimal solutions, assuming all other factors are constant. Optimisation modelling has been extensively discussed and applied in SCM to maximise profits or minimise costs through optimal use of resources.

From the perspective of supply chain decision-making, supply chain operational management has developed two types of models: descriptive models and optimisation models (Shapiro 2007). Descriptive models are designed for a better understanding of functional relationships in the company and include forecasting models, cost relationships, resource utilisation relationships and simulation models, which rely on concepts from a number of disciplines. Optimisation models seek an optimal solution based on the manager's preference by analysing the decision problem through integrating data and data relationships in the supply chain decision database using mathematical programming methods (Shapiro 2007, pp. 10–11). From a purely modelling perspective, the above two model types overlap in their applications. However, supply chain managers need to realise that the descriptive model is necessary but not sufficient if they are seeking effective SCM strategic plans. The optimisation models are essential for effective decision-making in SCM (Shapiro 2007).

JF Shapiro (2007) proposed that supply chain operations can be managed by logistics, production and inventory management from a bottom-up perspective. This is in contrast to other top-down perspectives that refer to high-level strategic issues. In practice, the integrated supply chain process refers to participants who are decentralised. For example, Graves' model was built to manage inventory for decentralised production networks, considering periodic review and base-stock inventory policy, but it had the limitation of assuming total flexibility in diverse production rates at each site (Graves 1988). A comprehensive framework for linking decision and performance in the material–production–distribution supply chain through a series of linked approximate sub-models and a heuristic optimisation procedure was developed by Cohen and Lee (1988). They designed a general decentralised network but limited it to a single manufacturing site. Following this, Garg (1999) extended the idea by developing a more general decentralised but less data-intensive model using the Supply Chain Modelling and Analysis Tool for designing products and processes at a large electronics manufacturer. Garg's model was based on stationary and normally distributed end-product demands, which is also used by other researchers to model decentralised networks (Graves 1988; Lee & Billington 1993) and connect nodes with both information and physical flows. All of the above decentralised network models require inputs from end-product demand and service requirements, bill-of-materials and routing data, and site-specific data. Later, Robinson and Satterfield (1998) designed an integrated configuration that considers the interactions among a firm's distribution strategy, market share and distribution costs while building up an optimal distribution network. Agrawal, Smith and Tsay (2002) described a methodology for managing capacity, inventory and shipments for an assortment of retail products produced by multiple vendors to maximise the retailer's expected gross profit with varied capabilities under demand uncertainty. Raghunathan (1999) and Moinzadeh (2002) assessed the impact of collaborative forecasting and replenishment in a supply chain with random demand. Through a systematic examination of the models in SCM research, Narasimhan and Mahapatra (2004) discussed five supply chain decision models that demonstrate the importance of integrating the decisions across the supply chain with their applications globally.

Financial management is incorporated in the model to integrate physical and financial flows. The classical method for this incorporation is Carleton's (1969) linear programming (LP) model, which features definitional constraints (available for common definition), funds constraints and policy constraints.[1] Warren and Shelton's (1971) model considers four distinct segments—sales, investment, financing and return on investment—and 20 equations of a semi-simultaneous nature, and it was further developed by AC Lee, Lee and Lee (2009).

Cash availability plays a key role in the feasibility of a production plan. A common approach to production planning models is to find a plan that minimises the overall cost while satisfying machine, workforce and demand constraints (Johnson & Montgomery 1974; Nahmias 1993). Kirca and Koksalan (1996) demonstrated simple examples of how production decisions may change based on a company's financial state. Later, they proposed that the production decisions depend on the financial situation and that financial decisions are closely related to production decisions. They also developed and implemented an LP model under high inflation. The model considers every process of material flow with money, including demand, machine capacity, labour, labour expenses, materials, taxes, collections, credits and cashflow (Kirca & Koksalan 1996). A good example of a comprehensive optimisation model for a global supply chain is the Global Supply Chain Model, which is a large mixed-integer linear program that achieves minimum cost while balancing attributes such as time, cost, capacity, duty, taxes and international trade (Arntzen et al. 1995). However, LP under a minimum cost objective function might not be appropriate for supply chain networks. According to JF Shapiro (2007, pp. 7–8), 'the traditional objective of SCM is to minimize total supply chain cost to meet fixed and given demand' and 'total cost minimisation is an inappropriate and timid objective for the firm to pursue when analysing strategic and tactical supply chain plans'. Instead, more ambitious models would seek net revenues maximisation, which equals the gross revenues minus total cost and links to 'financial performance of the firm and strategic decisions about capital investment and divestment of resources' (Shapiro 2007, p. 352). His supply chain model includes corporate financial management. Miller and Matta (2008) discussed a global supply chain model with profit maximisation and transfer pricing to undertake planning at both the strategic and tactical levels.

Measures for supply chain performance

Supply chain operations influence the company's profit and are therefore of relevance to shareholders' interests. At the strategic planning level, supply chain performance is considered in the context of long-term benefit to the company and maximising shareholder returns. While SCM refers to networking and integrating a series of business activities, each sector has its own indicator to measure its influence on supply chain performance. For example, perfect order is applied to measure logistics performance (Bozarth & Handfield 2005).

A diverse range of measurements exist in the supply chain industry, and their use depends on the context in which they are to be applied. Jie, Parton and Cox (2007) contended that trust and commitment can be used to measure the cooperative behaviour in a supply chain. These concepts can be measured by variables such as lead time, cost, capacity, quality, delivery and flexibility. Customer satisfaction, flexibility, information and material flow integration, effective risk management and supplier performance are considered in qualitative analysis of non-financial performance measures, while financial performance measures are used for quantitative analysis. Quantitative measures of supply chain performance have also been summarised in previous studies. For example, measures based on costs include cost minimisation, sales maximisation, profit maximisation, inventory maximisation, inventory investment minimisation[2] and return on investment maximisation.[3] Measures based on customer responsiveness include fill rate maximisation,[4] product lateness minimisation, customer response time minimisation, lead-time minimisation[5] and function duplication minimisation (Beamon 1998). From the firm value viewpoint, there are indicators and critical proxies such as output/input for productivity measures, income per employee, revenue per employee, receivables turnover, inventory turnover and asset turnover as efficiency measures used by Wall Street (Jacobs & Chase 2011).

The 2012 Gartner report discussed earlier in this chapter (see 'Supply chain management theories development and research streams for forming a supply chain framework') used the combination of 50/50 (50% for the financial component and 50% for the opinion component) overall weighting methods into the ranking metrics of the supply chain excellence to investigate the targeted 298 companies. The three financial metrics applied in the ranking were return-on-assets (ROA, net income/total assets), inventory turns (cost of goods sold/inventory) and revenue growth (change in revenue from prior year). The authors explained that the ROA (weighted at 25%) indicated the overall operational efficiency and productivity and revenue growth (weighted at 10%) reflected myriad market and organisational factors while providing some clues as to the company's innovation capability (Hofman & Aronow 2012). They also regarded the inventory turns (weighted at 15%[6]) as one of the few 'real' supply chain proxies shown on a company's balance sheet. The report highlighted the best practices in the leading companies, including the importance of supply chain risk management.

There are value-based drivers of metrics and indicators for value creation performance. Hahn and Kuhn (2011) used economic value-added techniques to measure and analyse shareholder value creation in the supply chain; they further used it at the mid-term level of sales and operations planning through robust optimisation as a value-based performance metric. It is calculated as net operating profit after tax minus the capital charge for the planning period (Hahn & Kuhn 2012b). This indicator has been well developed by combining operation performance and cost measurement. The expected value of perfect information is used to quantify the impact of uncertainty and is calculated as the difference between the objective value of the 'here-and-now' and the 'wait-and-see' approach (Hahn & Kuhn 2012b). To use the expected value of perfect information, the potential states of the outcomes and their corresponding probabilities must be known. It is equal to the minimum expected opportunity loss, calculated by the expected value obtained with perfect information minus the expected value obtained without perfect information, given by maximum expected monetary value (Ragsdale 2007). Other examples of measures in supply chain research include time indicators such as cycle time, weighted activity time, transit time, lead time and manufacturing time (Arntzen et al. 1995).

Findings from a survey of 636 Global 3000 companies reveal the significance in the value of an integrated supply chain and indicate the importance of governance in achieving better supply chain performance (McWatters, Zimmerman & Morse 2008). Setting broad policies and plans for using firm resources is essential and should be integrated into corporate strategy (Jacobs & Chase 2011).

Corporate governance for supply chain management

Corporate governance has brought global attention to the financial sector because of the recent global financial crisis in a range of areas. GCG is regarded as improving company performance. In the supply chain industry, corporate governance has been studied in the context of firm value and financial planning. This study considers the factors and measures required to achieve the benefit of GCG practices.

The major objective of corporate governance is to resolve agency conflicts to design efficient organisations for the principals. Therefore, corporate governance is essentially a game theory problem—it is a principal–agent game. Game theory is the mathematics of strategic interactions among different agents for optimal outcomes in situations when decisions taken by one agent affect the outcomes of other agents' strategies and payoff (Shoham & Leyton-Brown 2009). To resolve agency problems and conflicts of interests effectively for risk management and efficient decision-making, we need game theory and corporate governance–based SCM strategies. The task involves finding mechanisms and strategies to design a game form (S, g) where $S = S_1x, \ldots, Snx$, S_1 = set of agent i's strategies, = corporate outcome/design/corporate governance, g: S is a mapping from S to A where A is a set of actions (following Marschak's [1989] analysis). Game theory models can be in cooperative, non-cooperative, normal form, extensive form, deterministic, stochastic, evolutionary, differential and other forms. This book adopts the game theory model implicit in corporate governance and agency theory, which is principal–agent game theory.

Historical development and theories of corporate governance

In recent years, with the speedy growth in corporation sizes and technologies, companies have developed faults resulting in corporate governance failures. This has ultimately resulted in ascending awareness of corporate governance. Increasing globalisation and rapid advances in information technologies in the market have also prompted global calls for efficient and GCG practices in large multinational companies. In response, O'Donovan (2003, p. 29) redefined corporate governance as 'an internal system encompassing policies, processes and people, which serves the needs of shareholders and other stakeholders, by directing and controlling management activities with business savvy practices, objectivity, accountability and integrity'. She pointed out that sound corporate governance relies on both external marketplace commitment and legislation. A healthy board culture that safeguards company policies and processes is also needed. A number of researchers have given corporate governance considerable domestic and international attention (O'Donovan 2003). For discussions of the crucial issues in corporate governance, see the work by Hassan, Islam and Rashid (2018), Hussin and Islam (2017), Kalyebara and Islam (2014) and Nuryanah and Islam (2015), among others.

There are three main streams of corporate governance theories: stewardship theory, agency theory (a form of game theory) and market theory (Calder 2008). Stewardship theory postulates that people will behave well and in the interests of their shareholders. In particular, it leads to the combined roles of chair and CEO and non-existent or lightweight audit committees. By contrast, agency theory argues that, as employees, company directors will act with rational self-interest and tend to maximise their compensation as agents, doing no more than what is necessary to appease shareholders. That is, they need to be supervised and controlled to ensure that shareholders' best interests are served. Market theory holds that it is not important whether managers consider themselves stewards or agents since shareholders can simply sell their stocks in the market if they do not think they receive sufficient returns for their investment. Market theory appears fatally flawed in the circumstances of inadequate corporate governance (Calder 2008).

Key corporate governance issues pertaining to supply chain management

This study considers the risk management of internal and external control from a corporate governance perspective. Previous studies have considered supply chain and corporate governance issues as aligned with agency cost, trust, contract, transaction cost, compensation for managers, supply chain sustainability and governance. This study focuses on the key issues of corporate governance in relation to SCM, including the principal–agent problem or the principal–agent game, internal control and trust, investigating how they can work for the company to improve supply chain performance.

Agency theory argues that a listed company that has separate ownership and control has principal–agent issues (Jensen & Meckling 1976). According to agency theory, the board takes the role of the principal, looking after the owners' interests, while the managers are responsible for controlling the company's operations. Owners, who are normally shareholders, seek to maximise stock value and long-term profit. The managers, who are implementing the firm's operational decisions based on their own interests, sometimes only try to maximise the company's short-term profit and do not consider the company's sustainable development. However, in practice, because of the separation of ownership and control, the principal who owns the company and targets firm value cannot always know about the managers' operations. Consequently, agency cost exists.

Agency cost consists of two main sources: the costs inherently associated with using an agent and the costs of techniques used to mitigate the problems associated with using an agent or employing mechanisms to align the interests of the agent with those of the principal. Although the effects of agency cost are present in any agency relationship, the term is most often used in business contexts. Agency cost normally contains three elements: the monitoring cost caused by the principal, the bonding cost from the agent and residual losses (Jensen & Meckling 1976).

Many studies have explored the relationship between agency cost and firm performance (Berger & Di Patti 2006; Cyert, Kang & Kumar 2002; Jensen & Meckling 1976; Larcker, Richardson & Tuna 2007; Wang & Sami 2011). More recently, attention has been given to exploring agency problem issues within management accounting, such as how to deal with the agency cost of equity and debt captured by balance-sheet management. The agency cost of equity arises because of the difference in interests between shareholders and management, including the cost incurred by suboptimal decisions and the cost incurred by monitoring management to prevent them from making these decisions. The agency cost of debt arises because of the different interests of shareholders and debt-holders. Assuming that management is in favour of shareholders' interests, studies have been conducted on cutting down the agency cost of equity by linking the incentive compensation of the executive officers with their performance (Cyert, Kang & Kumar 2002). If managers' compensation has been linked to the company's annual profit, this may lead to managers focusing more on the firm's current performance and urging the company to expand its size to increase short-term profit. This risks long-term development because of short-sighted decisions. Instead, the managers' remuneration is linked to the firm's stock price, which could not be realised until a certain period had elapsed after the manager's retirement from their position. Many companies have found this to be an efficient way of balancing the conflict of interest between managers and shareholders (Cyert, Kang & Kumar 2002). Ciliberti, Pontrandolfo and Scozzi (2007) examined the Code of Corporate Social Responsibility SA8000 and addressed the principal–agent problem in supply chain relationships. They also investigated from the perspective of how corporate social responsibility works in the supply chains of small- and medium-sized enterprises (Ciliberti, Pontrandolfo & Scozzi 2008).

One important factor in the modern supply chain managerial conceptual framework is how efficient is the performance of the supply chain network that connects all the partners or participants, such as manufacturer, suppliers, inventory and transportation from initial resources to the final product delivered to the customer. If raw materials are delivered on time, it can ensure that there is no delay in the production process. If demand forecasting is good, there will be less need for stock in storage and reduced inventory costs. To achieve this efficiency, partners need to have a trusted relationship network that will stimulate cooperation and efficient collaboration.

Trust is a significant factor in a well-managed supply chain system, and researchers have explored the relationship between trust factors and SCM performance (Handfield & Bechtel 2002; Ireland & Webb 2007; Jie, Parton & Cox 2007; Kwon & Suh 2004; Welty & Becerra-Fernandez 2001). Factors such as human-specific asset investments, site-specific asset investments, contracts and buyer-dependence play an important role in building the relationship (Kwon & Suh 2004). Other trust proxies include transaction cost variables such as asset specificity, behavioural uncertainty and information sharing, and social exchange variables, including perceived satisfaction, partner reputation and perceived conflict (Kwon & Suh 2004). To build a relationship based on trust, suppliers must invest in site-specific assets and human assets and buyers must judiciously apply contracts to control for relative levels of dependence within the relationship. Different methods, such as regression and structural equation modelling, are applied to explore the influence and extent of trust in the supply chain relationship.

Good corporate governance for better firm performance

Poor corporate governance is regarded as the main reason for the post-financial crisis in Asia (Zulkafli & Samad 2007). Following a number of governance scandals and failures, the incorporation of corporate governance into SCM firms has been brought to managers' attention. To achieve GCG, countries and companies have adopted many strategies. For example, ten GCG principles from the ASX Corporate Governance Council (2007, pp. 10–12) are as follows:

> lay solid foundations for management and oversight; structure the board to add value; promote ethical and responsible decision making; safeguard integrity in financial reporting; make timely and balanced disclosure; respect the rights of shareholders; recognise and manage risk; encourage enhanced performance; remunerate fairly and responsibly; and recognise the legitimate interests of stakeholders.

There are diverse debates about the factors that influence corporate governance. Some have regarded product competition and capital structures as important to corporate governance (Berger & Di Patti 2006; Zulkafli & Samad 2007). Others have viewed corporate and director actions, including corporate governance structure[7] and executive compensation or remuneration, as important factors with significant influence on corporate governance performance (Cyert, Kang & Kumar 2002; Fried & Bebchuk 2006; O'Donovan 2003).

To achieve GCG in SCM for a company, a key issue is to balance different stakeholders' interests and have managers efficiently working for them to avoid principal–agent problems. The manager or director carries responsibility for corporate governance performance in a firm, especially for common-law countries such as the United Kingdom, United States, Australia and Hong Kong (China). These have stock markets with thousands of listed companies dominating the economy (Choong 2009). With regard to this problem, there are many debates about what corporate governance mechanism the company should adopt. Some have argued that ownership and management should be separated so that managers can act objectively without conflict of interest. Some have argued that if a company's profit and long-term benefit are not directly linked to senior managers' compensation packages, it raises the risk that senior managers will be well rewarded regardless of company performance (Choong 2009). The performance of senior managers in terms of executing policies and strategies is critical to establishing and maintaining good control structures to ensure effective decision-making and efficient business processes (Choong 2009). Moreover, a company's corporate governance structure is considered a critical factor that influences corporate governance performance.

In integrated supply chain networks, the principal–agent relationship can be explored even more broadly—for example, the chain director as the principal and other members as agents, the headquarters as the principal and the branches as agents, or the board as the principal and the managers as agents. However, little in-depth research has been undertaken on principal–agent problems in the supply chain area, especially from the perspective of optimisation modelling with GCG practices.

Previously, boards have emphasised the important role of internal control in achieving good firm performance. Internal control is defined by the Committee of Sponsoring Organizations (2013, p. 1) of the Treadway Commission as

> a process, effected by an entity's board of directors, management and other personnel, designed to provide reasonable assurance regarding the achievement of objectives in the following categories: effectiveness and efficiency of operations; reliability of financial reporting; and compliance with applicable laws and regulations.
>
> (cited in Calder 2008, p. 109)

The essential components of internal control systems, according to this definition, are to maximise the reliability and timeliness of information for decision-making. It also informs the need to comply with regulations (Collier & Agyei-Ampomah 2008). To determine internal control policies, the board needs to consider clarifying the risks the company faces, assessing the extent and types of risk the company can bear, quantifying the probabilities of the risks actually occurring, determining the solution to reduce or manage the risks, and assessing the difference between the cost of operating controls and the benefit obtained by managing the risk (Collier & Agyei-Ampomah 2008). Inherently, internal control is related to corporate governance principles and risk management in supply chain operations.

As stipulated by the Committee of Sponsoring Organizations of the Treadway Commission, internal control frameworks have five essential components: risk assessment, control activities, information, communication and monitoring (Choong 2009; Collier 2009). These elements of internal control are globally accepted as guidance for any medium and large organisations. Having internal control systems becomes a prerequisite for listed companies to pursue GCG. Therefore, implementing GCG requires not only financial control but the application of those additional internal control mechanisms.

Internal control legislation that brought radical and dramatic changes to US federal securities laws is the Sarbanes–Oxley Act. In 2002, the United States passed Sarbanes–Oxley, Sarbox or SOX, a federal law, setting new or enhanced standards for all US public company boards (Calder 2008). They attempted to improve corporate governance by paying attention to risk management through internal control mechanisms in corporations.

Previous studies from around the world have attempted to develop corporate governance models, such as the intricate shareholding structures of *keiretsus* in Japan, the heavy presence of banks in the equity of German firms and the *chaebols* in South Korea (Scott 1998). Other countries have also tried to introduce internal control frameworks and systems of risk management into corporate governance. Unfortunately, few have successfully defined structures for these frameworks and systems in an appropriate way (Daelen & Elst 2010).

For strategic decisions, a company board needs to consider the role of internal control in risk management to achieve its business goals (Calder 2008). Management accounting is considered an important factor in relation to the issues of corporate governance in SCM or operations management. Hansen and Mouritsen (2006) examined the challenges of integrated manufacturing in automation, total quality management and just-in-time inventory control from the perspective of management accounting. They also investigated the role of accounting in integrated manufacturing management and discussed the relationship between management accounting and operations management with implications for the future (Hansen & Mouritsen 2006).

Considering the objective and critical problems related to this research, GCG aims to maximise a company's value by maintaining its internal control and use of sound risk management practices in its SCM policies and processes.

Proxies and ratios as corporate governance performance measurement for firm value

This study explores different indices that can be used in consideration of GCG practices to improve SCM. Ratio measurement for financial management is popularly applied in corporate governance categories. For example, the net debt/equity ratio (various debt structure ratios are used to assess the gearing or leverage) and net interest cover (a common measure of long-term solvency) are applied as capital structure measures. Inventory turnover,[8] receivables turnover[9] and asset turnover ratios are used as the indices for asset management or turnover measures. Price/earning ratio and market/book ratio are used for market value measures. The following four ratios are the most widely used of all the financial ratios intended to measure the efficiency of firms in managing operations: profit margin, ROA, return on investment and return on equity (ROE) (Ross 2011). For corporate strategies, the financial performance ratios are classified into five subcategories: profit ratios,[10] liquidity ratios,[11] activity ratios,[12] leverage ratios[13] and shareholder-return ratios[14] (Hill & Jones 2007).

Incorporating GCG practices reduces agency costs (McKnight & Weir 2009). Agency cost measures include sales-to-total assets ratio,[15] interaction of free cashflows and growth prospects, and the number of acquisitions. Agency cost is high when high free cash combines with poor growth opportunities. Growth opportunities are measured by Tobin's Q,[16] which is market capitalisation plus total debt divided by total assets (McKnight & Weir 2009). Other ratios include the optimal agency effort compensation ratio, the ratio of sales-to-total-assets and research and development. The firm's financial performance is measured as net profit, after-tax profit and return on investment.

The proxies used for company governance comprise two streams: cashflow rights and control rights (Claessens et al. 2002). The cashflow rights represent the ownership and show that the actual ownership in a company arises only with investment. Cashflow rights are a proxy for owner investment in a company. Control right shows the stock share, which represents voting rights for the controller. Stock share indicates the return or dividend to shareholders. Stock price and market share reflect shareholders' interests.

Proxies such as capital structure, participation constraints and incentive-compatibility constraints have been constructed as governance variables in the model constraints. The methods applied for this purpose include fixed-effects, instrumental variables and Tobit regressions. Proxies applied for measuring firm value are usually also combined in the model—for example, economic value added (Hahn & Kuhn 2011). Other proxies commonly applied in the accounting aspect of corporate governance include ROA, ROE and EBIT.

The ROA ratio developed by DuPont for its own use is now employed by many firms to evaluate how effectively assets are used. It measures the combined effects of profit margins and asset turnover. It can be calculated as follows:

$$\text{ROA} = \frac{\text{Net Income}}{\text{Sales}} \times \frac{\text{Sales}}{\text{Total Assets}} = \frac{\text{Net Income}}{\text{Total Assets}}.$$

The ROE ratio is a measure of the rate of return to stockholders and also a measure of firm value. Decomposing the ROE into various factors influencing company performance is often called the Du Pont system. The formulation is as follows:

$$\text{ROE} = \frac{\text{Net Income}}{\text{Equity}} = \frac{\text{Net Income}}{\text{Pretax Income}} \times \frac{\text{Pretax Income}}{\text{EBIT}} \times \frac{\text{EBIT}}{\text{Sales}} \times \frac{\text{Sales}}{\text{Assets}} \times \frac{\text{Assets}}{\text{Equity}}.$$

EBIT is the earnings of the firm that are shared between the equity-holders, debt-holders and government in the form of taxation. It is the return to the firm as a whole. EBIT is an indication of a company's ability to service the debt obligation. Inventories to sales ratio (ISRATIO),[17] also known as operating margin, is the ratio measurement of the proportion of a company's revenue left over after paying variable costs of production, which can indicate a company's pricing strategy and operating efficiency. The higher the margin ratio, the better the company's operational performance.

Risk management and models in supply chain management and corporate governance

Risk management and best practice business continuity programs are essential to fostering companies' long-term sustainability. Risk should be managed as a critical element in the decision-making process (Mun 2010). The subprime crisis and the subsequent financial and economic crises intensified the attention on risk management. The collapse of Lehman Brothers and the rescue of large financial institutions by governments all over the world highlighted the unwarranted trust in financial markets and risk management. However, not only did the systems fail to prevent the subprime crisis—although it certainly resembled the savings and loan crisis—but many instruments even aggravated the risks incurred. The level of systemic risk was also much higher than foreseen and the risk appetite of most financial institutions proved insatiable. The problem was no longer restricted to the reliability of financial reporting and the quality of internal control systems but extended to risk management, including the use of risk-mitigating instruments to increase performance instead of limiting risks (Daelen & Elst 2010).

Risk management processes include risk assessment, risk reporting and risk treatment, and these were developed by the Institute of Risk Management in 2002 (Collier & Agyei-Ampomah 2008). Risk assessment involves identifying risks using methods such as brainstorming, scenario analysis, checklists and workshops. Further, it comprises the description and estimation processes. The risk reporting process helps the corporation monitor the operations of the risk management system and risk treatment to understand how to respond to risks, such as with risk control and mitigation, risk avoidance and risk transfer (Collier & Agyei-Ampomah 2008). The investigation in this section is related to the process of risk assessment; risk reporting and risk treatment are discussed in the following chapters.

The remainder of this section discusses risk management in SCM and corporate governance from a framework perspective, including regulations and policies, followed by risk management models and risk measures. The benefit of risk management is briefly discussed at the end of this section.

Risk management in supply chain management and corporate governance

Risk is defined as uncertain consequences, where uncertainty is a result of imperfect knowledge. Risk is normally associated with the probability or possibility of gaining 'expected good results', such as appreciable revenue for a corporation or successful project outcomes for an individual (Hardaker et al. 2004). Uncertainty affects a wide range of decision-makers, such as managers, engineers and others (Kouvelis & Yu 2010). Uncertainty in price, labour and other production costs, as well as in the availability of needed raw material suppliers, complicates the task of production. The classification of decision-making problems among certainty, risk, uncertainty and unknowingness is determined by the players' knowledge of the possible outcomes (McGuigan, Moyer & Harris 2005). Based on the discussion by McGuigan, Moyer and Harris (2005), if each action leads to one set of possible specific outcomes, risk refers to each outcome with a known probability while uncertainty refers to each outcome with its probability unknown. Risk in this study refers to the uncertain environment surrounding the supply chain and the risks associated with operations. In relation to SCM and corporate governance, the main risks include those of supply, operations, demand, security, policy and resources[18] (Manuj & Mentzer 2008a). Businesses can face multiple risks across the supply chain—for example, at the level of supplier, regulatory and compliance, intellectual property, downstream partner behaviour, political and social issues, market demand and economy. Supply chain risk management is adopted as good practice for supply chain governance to minimise the impact on financial strategy and profitability. According to the Turnbull Report, Waters (2011) encapsulated 'Supply Chain Risk Management' in three core elements: identify risks to the supply chain, analyse the risks by prioritising them and their corresponding expected consequences; and design appropriate prevention and mitigation response to each of the risks. Risk management strategies that result in a reduction of losses and the increased probability, speed and frequency of identifying a risk event can improve supply chain outcomes for a company and lead to better performance (Manuj & Mentzer 2008a, 2008b). After a series of scandals and bankruptcies of companies in different parts of the world, concerns with risk management and internal control in corporate governance have come into the limelight. Risk management has been synchronised with corporate governance through legislation such as the Sarbanes–Oxley Act in the United States, Soft Law in South African King II Report and the UK Corporate Governance Code, which operates on a 'comply or explain' basis (Collier 2009). The efficiency of risk management affects shareholders' value in the company. Modigliani and Miller (1958) established the proposition on the basis of the relationship between a firm's value and its financial policies; this was later referred to as the M&M[19] proposition. This proposition has been further applied in the research assuming that if risk management can influence a firm's value by increasing its real cashflow, it could add value by reducing taxes and the cost of financial distress or by facilitating optimal investment (Froot, Scharfstein & Stein 1993; Smith & Stulz 1985). The techniques used to manage risk can be generally categorised as avoidance, reduction, sharing and retention (Dorfman 2007). Risk management has been discussed broadly in previous research, including variance, variability index, probabilistic financial risk and downside risk (You, Wassick & Grossmann 2009). In this book, risk management is the specific area being investigated and integrated into the SCM models as a part of corporate governance.

As addressed in the UK Corporate Governance Code, the main principles of corporate governance are related to leadership, effectiveness, accountability, remuneration and relations with shareholders (Financial Reporting Council 2012). The Code[20] also released the underlying principles of good governance: accountability, transparency, probity and focus on the sustainable success of an entity over the longer term (Financial Reporting Council 2012). 'Recognise and manage risk' is one of the ten essential principles (mentioned earlier in this chapter: 'Good corporate governance for better firm performance') of the Australian Stock Exchange to achieve GCG in corporations (ASX Corporate Governance Council 2003). Enterprise risk management (ERM) is another such example of an integrated framework. According to the Committee of Sponsoring Organizations (2004, p. 16), ERM 'is a process, effected by an entity's board of directors, management and other personnel, applied in strategy setting and across the enterprise, designed to identify potential events that may affect the entity, and manage risk to be within its risk appetite, to provide reasonable assurance regarding the achievement of entity objectives'.

Risk management can be achieved through different methods, but in terms of SCM and corporate governance, it can be considered through frameworks and modelling. From the perspective of a framework, risk management can be achieved through policies and regulations that are formulated based on historical data, qualitative analysis and managers' experiences. From a modelling perspective, risks are quantified in the form of indicators in models, which are then assessed to reach the acceptable risk level of the company. In addition, through modelling, risk control and risk management can be introduced as model constraints and can therefore be built into a company's operational system design. The risk factors can be presented as objective functions of the model and can thus be incorporated into risk policies for managers' risk preference. More details are presented in the following sections.

Risk management models for decision-making

The decision-making exercise is conducted at the start of the year or before a project's implementation. To find a suitable strategic plan and solutions for business activities, the company needs to assume certain conditions to set up a model and make a forecast. However, there are many uncertainties regarding the future. Previously, the uncertainties were formulated using probabilities, such as decision tree and stochastic programming.

Several popular mathematical methods incorporate risk management, including stochastic programming, robust optimisation, Capital Asset Pricing Model, ERM modelling, hedging and derivatives, second-order cone programming (SOCP) and Barra Risk Models. For example, derivatives are applied as a tool for managing risks in the finance area (Chance & Brooks 2010; Panaretou, Shackleton & Taylor 2013).

The first mathematical model for balancing between risk and returning under uncertainty for the portfolio selection problem was the mean-risk model developed by Markowitz (1952), which is based on the foundation of the Capital Asset Pricing Model. It proposed that the key issues to be initially dealt with in the stock and portfolio investment are expected profit and risk. An important goal of risk management in supply chain corporations is to predict and manage future volatility in the value creation process of companies. Value at risk (VAR[21]) was used in the past to measure volatility (Léautier 2007). According to an intuitive definition by Jorion (2001), VAR summarises the worst loss over a target horizon with a given level of confidence under normal market conditions. According to Chance and Brooks (2010, p. 531), VAR 'is a dollar measure of the minimum loss that would be expected over a period of time with a given probability' and 'the basic idea behind VAR is to determine the probability distribution of the underlying source of risk and to isolate a given percentage of worst outcomes'. There are three methods of estimating VAR: the analytical method or variance–covariance method, which relies on a normal distribution[22], the historical method and the Monte Carlo simulation method. There are many advantages to using VAR. For example, banking regulators can use it to measure the risks to their banks and protect their consumers. It is also used to evaluate the performance of managers and traders (Chance & Brooks 2010).

In SCM decision-making, there are numerous risk management streams of discussion. For example, researchers may manage risk from the supply chain procedure controls aspect. This stream explores risk analyses and models that are mainly internal to the supply chain, such as inventory control, transportation and marketing (Aharon, Boaz & Shimrit 2009; Graves, Kletter & Hetzel 1998; Johnson & Montgomery 1974; Moinzadeh 2002; Nagurney & Matsypura 2005; Tang 1990). Another stream studies the methods for managing different supply chain risks such as financial risk, operational risk, information risk, accounting audit risk and human error risk (Brindley 2004; Cavinato 2004; Liu et al. 2009; Manuj & Mentzer 2008a; Ritchie & Brindley 2007; Tang 2006; Tang & Nurmaya Musa 2011; Waters 2011). Some studies focus on the methodologies used to assess and manage risk in the supply chain area, such as VAR, derivative, real options and optimisation programming, depending on their requirements (Estampe et al. 2013; Hahn & Kuhn 2012b; Léautier 2007; Swaminathan & Tayur 2003; Tayur, Ganeshan & Magazine 1999; Tummala & Schoenherr 2011; Wan, Pekny & Reklaitis 2005; Yu & Li 2000). For example, hedging derivatives are usually used by larger firms or firms receiving higher exposures (Léautier 2007).

JF Shapiro (2007) added risk management into data-driven models to support supply chain managers with making decisions under uncertainty.

He briefly discussed supply chain risk management with a focus on the use of real options and reviews the modelling methods from a heuristic perspective. With the dramatic development of the business market, it is necessary to integrate risk management into supply chain networks, not just at a conceptual level but also in mathematical models, to help managers making risk management decisions. Some researchers have already tried integrating risk management into the optimisation models for decision-making. Grossmann worked on risk management in supply chain planning for a global chemical company by incorporating risk measures into the stochastic programming model, trying to solve the uncertainties in demand and freight rate (You, Wassick & Grossmann 2009). This study also mentions the robust optimisation method, which minimises the variance of cost in the objective function. It proposed several ways to address risk management in supply chain optimisation modelling.

Risk management can be achieved by incorporating different elements into the objective function, variables and constraints of optimisation models. Most decision-makers are risk-averse and prefer to incorporate their attitude towards risk into the objective of the strategies (Mulvey, Vanderbei & Zenios 1995). For example, two popular methods for incorporating risk aversion in the objective functions of decision models are mean-variance and related models (Mulvey, Vanderbei & Zenios 1995) and Von Neumann-Morganstern expected utility models (Keeney & Raiffa 1976). The former includes the objective of minimising variance as risk control and combining it with maximising the benefit. The latter holds the expected utility model, which can capture asymmetries in the distribution of the outcome to incorporate risk aversion into the model (Bai, Carpenter & Mulvey 1997). Others, such as minimising the risk probability into the objective function, are also a way to manage the risk in decision-making processes. Risk can be presented in the variables for the model. For example, ratios measuring the activity performance can be selected as variables to show the risk appetite of decision-makers.

There are several popular risk-programming models summarised by Hardaker et al. (2004). These include linear risk programming, which is for a risk-neutral manager and does not account for any non-neutral risk attitude on the part of managers, and quadratic risk programming,[23] which relies on the E, V efficient frontier with E varied over the feasible range and achieves a significant reduction in variance for the sacrifice of relatively little expected income (although it does not include activities for sharing the risk of the firm, such as the purchase of product insurance or the use of derivative markets); MOTAD programming,[24] which replaces the variance constraint of the quadratic risk-programming model with mean absolute deviation of net income; target MOTAD programming,[25] which is related to MOTAD in that it entails a constraint on income deviations with a target level of income; mean–Gini programming; and stochastic programming with chance-constrained programming (CCP).

There are also other model frameworks for coping with uncertainty problems for risk management in SCM—for example, ERM (Ai et al. 2009; Ai, Brockett & Wang 2013; Committee of Sponsoring Organizations 2013; Olson & Wu 2008) and supply chain operations reference (SCOR) models (Supply Chain Council 2010). The ERM modelling process includes identifying major types of risks, choosing appropriate risk measures and selecting a valid modelling approach capable of incorporating key elements. In an example, CCP can be applied as a two-stage model to incorporate corporate risk management and firm's risk appetite using different metric formulations and different choices of desirable risk levels (Ai et al. 2009). A brief summary of studies on risk modelling in the uncertainty of SCM and corporate governance is presented in Appendix 1.

This study considers risk through modelling and uncertainty analysis. Uncertainty leads to risk through its impact on decision-making. Thus, to combine supply chain with risk management, one needs to identify the different types of risks a corporation faces and then categorise them into the various generic forms in which they appear in the area of SCM. The three core categories of corporation risks are credit risk, market risk and operational risk (Chorafas 2008). Considering supply chain procedures and corporate governance policies, the risks considered in the proposed RSCMCG model include operational risks, market risks, financial risks and internal control risks.

Risk measures and indicators for supply chain management

Risk measures can be divided into two categories: dispersion risk and downside risk (Pachamanova & Fabozzi 2010). Dispersion risk measures the amount of dispersion of the returns around the expected portfolio return; therefore, it measures uncertainty in the estimation of the expected portfolio returns. Dispersion risk measures include methods of variance, standard deviation, absolute deviation and absolute moment. Downside risk measures outcomes that fall short of expectations rather than outcomes that exceed expectations (Pachamanova & Fabozzi 2010). However, it cannot be accurately measured by portfolio variance and other dispersion measures. Markowitz (1959) acknowledged this shortcoming in his model and suggested the use of semi-variance to measure downside dispersion risk as an alternative to measuring portfolio risk. Methods for downside risk measures include lower partial moment,[26] semi-variance,[27] Roy's safety-first criterion[28] and quartile-based risk measures[29] (Pachamanova & Fabozzi 2010).

Risk indices have been widely applied to identify risk through quantitative models, such as VAR, hedging and mean-variance, and have been known as descriptors and fundamental betas. For example, the Barra model is a multi-factor regression model where a stock return is modelled using market and industry risk-factor returns and certain underlying factors that are called the Barra risk indices. Using a single VAR number, the Barra Risk Factor Analysis model can measure a security's relative risk (Investopedia 2004). The risk index can be given by descriptors.

Risk policies and regulations of corporate governance can also act as risk indicators in the model. For example, financial risk factors (normally established according to a bank's risk management policies and expressed as ratios or limits) can serve as indicators to indicate what constitutes acceptable risk (Van Greuning & Bratanovic 2009). The debt-to-equity ratio for a bank's borrowers is another example of a risk indicator that expresses level of credit risk. Maximum exposure to a single client is a risk parameter that indicates credit risk in a limited form (Van Greuning & Bratanovic 2009).

Uncertainty exists everywhere. The weather can change suddenly, and equipment can break down for internal or external reasons. Uncertainties in supply chain operations can occur because of unexpected human behaviour or expectations and uncertainty in supply chain environments. For example, in a manufacturing factory, the workers may stop working suddenly, which can cause an order to be delayed, or the warehouse might not have sufficient stock for market contingency demands. Decision-making under uncertainty is essential for good SCM. In particular, the competition of the modern market becomes between supply chain networks, which necessitates incorporating risk management into resources planning optimisation. Consequently, this leads to the application of robust optimisation modelling to supply chain risk management. Researchers' concern for risk management in financial planning has led to the generation of tools such as real option. Similarly, the supply chain industry has SCOR for risk analysis and control in supply chain planning and financial management. Others include economic value added for the mid-term level (Hahn & Kuhn 2011, 2012a) and the expected value of perfect information for quantifying the impact of uncertainty (Hahn & Kuhn 2012a), which are discussed earlier in this chapter ('Measures for supply chain performance').

Benefit from risk management

Risk management practices in a company can support company operations to achieve better performance and value creation. A firm that practises effective risk management can lower costs for shareholders (individually adjusting their personal portfolios), lower taxes by stabilising shareholders' income, reduce the probability of bankruptcy, protect their personal wealth, avoid underinvestment, take speculative positions, earn arbitrage profits and lower borrowing costs (Léautier 2007).

Risk reports are recognised as an important component and are incorporated into the annual reports of international firms, such as Adidas-Salomon AG, Nestle SA and Sony Corporation (Collier & Agyei-Ampomah 2008).

Investigations in theoretical and empirical studies show that risk management can create value by providing a progressive tax structure to minimise taxes and reduce a company's tax burden (Chew 2012). It can also increase a firm's expected net cashflows through the use of risk transformation products to reduce expected tax liabilities when a firm faces a convex corporate tax schedule (Culp 2002). Consequently, risk management can increase shareholders' value in a firm. Further, effective risk management can help a company build an excellent brand reputation, achieving a well-managed supply chain, approaching a good credit rating and eventually achieving profitable and successful company performance (Collier & Agyei-Ampomah 2008).

Incorporating risk management strategies can create firm value from three viewpoints: financial flexibility at minimum cost, enhanced capital allocation and performance management, and leveraging operational and strategic flexibility (Léautier 2007). For example, financial flexibility can be achieved at minimum cost through modelling with three ingredients of the risk management model: unknown timing and magnitude of the investment opportunities faced by a firm, the U-shaped cost of capital with respect to the debt-to-assets ratio and the pecking-order hypothesis.

Methodologies in an uncertain environment

Methods used to manage the uncertain environments of supply chains include game theory, quantitative analysis, LP, computer simulation and intelligence algorithms. As discussed earlier in this chapter ('Supply chain management models'), optimisation modelling is essential for effective supply chain decision-making and, moreover, it can perform policy analysis pragmatically and expeditiously by adding policy constraints, labelled as externalities in economics (Shapiro 2007). This study focuses on the discussion of optimisation modelling. Diverse optimisation programming methodologies have been applied to the supply chain in an uncertain environment, including stochastic dynamic programming, stochastic programming, simulation optimisation and robust optimisation. Optimisation and game theory models are viewed as artificial intelligence/machine-learning models (Russel & Norvig 2013; Wilmot 2019). For artificial intelligence models and algorithms, see Sharda, Delen and Turban (2021) and Russel and Norvig (2016). This section compares these methodologies and justifies the choice of robust optimisation.

Approaches for supply chain management in an uncertain environment

In decision-making problems, there are several classifications based on the conditions of uncertainty, including objective risk, subjective risk and uncertainty. The uncertainties under which decision-making is studied in this research can be demonstrated according to Naylor and Vernon (1969) as follows: 'if the decision maker is unable to calculate (either objectively or subjectively) the probabilities associated with the different action-outcome combinations with which he is associated' and where the probability distribution of action–outcome is unknown.

Business goals are usually set to enhance economic value (Zenios 2007). With respect to SCM, uncertainties exist in procedures or in imperfect information provided by participants. Specifically, a manufacturer may produce items for storage but have no certain demand data from customers for each type of item. Similarly, shareholders do not know whether the stock price of the company will rise or fall in the future. While participants and stakeholders wish to maximise their profit, the asymmetry of information and implementation may consequently lead to a reduction in supply chain value. This can lead to the failure of the business and even to its bankruptcy. How to maximise the value of the entire supply chain while satisfying each participant's expectations, or at least not reducing their profit, is the objective that modern supply chain networks seek to achieve.

Modelling under uncertainty is attracting researchers' interest. Mathematical programming, such as optimisation modelling and simulation modelling, can be used to predict and manage uncertainty. CS Tang (1990) analysed the impacts of different uncertainties in production and demand for the finished product on production planning, inventory control, quality improvement and capacity planning. Requirements planning in multistage production-inventory systems were studied and investigated by considering the stability of production and trade-off between capacity and inventory (Graves, Kletter & Hetzel 1998). Krajewski and Wei (2001) explored the merit of integrated production schedules for reducing the negative effects of schedule revision, and a stochastic cost model was developed to evaluate the total supply chain cost. By using a simulation approach based on optimisation, Jung et al. (2004) studied the safety stock level required for customer satisfaction and proposed the use of deterministic planning and scheduling models. The overlapping approaches to supply chain decision-making under uncertainty include scenario planning, contingency planning, hedging and risk management. Stochastic programming offers a methodology for rigorously implementing and integrating these approaches (Shapiro 2007). Dunbar (1999) discussed the increased focus on the corporate risk manager after the turbulence in the fall of 1998. Christoffersen (2003) explored option pricing and hedging and presented a thorough treatment of risk model evaluation and comparison.

McGuigan, Moyer and Harris (2005) have reviewed the various approaches to decision-making under uncertainty, including expected marginal utility, which is applied to situations where the possible uncertain outcomes related to monetary payoffs have known probabilities of occurrence and the criterion for expected monetary values is given by the decision-maker; prospect theory,[30] which hypothesises that decision-makers prefer risk at wealth levels that are below their current position and become risk-averse above those levels; risk-adjusted discount rate approach, which is usually used in long-term capital budgeting decision-making to deal with the risk associated with future cashflow estimates; decision trees, which are applied when the decision problems involving a sequence of alternative actions and random events need to be analysed; scenario planning; and simulation models for economic decisions.

Sensitivity analysis, which is significantly different from robust optimisation, is typically applied as a post-optimisation tool for measuring the change in the cost of the related optimal solution with a small perturbation in the underlying problem data (Bertsimas & Brown 2009). According to Bai, Carpenter and Mulvey (1997, p. 898), sensitivity analysis is 'the simplest and most well-known alternative. It is a reactive approach for limiting risk and simply measures the sensitivity of a solution to the changes in the input data'. Sensitivity analysis differs from optimisation modelling and simulation modelling through its measurement of a solution's sensitivity when input data changes. However, it does not offer a solution for controlling sensitivity. For this reason, sensitivity analysis may be an inadequate method for dealing with risk in complex decisions. Stochastic LP and robust optimisation are more constructive. They are both superior to sensitivity analysis (Bai, Carpenter & Mulvey 1997). Therefore, sensitivity analysis is not considered in this book.

In 2010, Kouvelis and Yu (2010) proposed the robustness framework, which investigates the critical elements in the robustness approach and input data uncertainty in SCM. The main types of methodologies used for optimisation under uncertainty include dynamic programming, stochastic programming and robust optimisation (Pachamanova & Fabozzi 2010). Simulation modelling is also proposed to deal with uncertain decision-making in SCM.

Optimisation modelling methods for handling problems with uncertainty

This section discusses the four most widely used optimisation modelling programs that deal with uncertain parameters: stochastic dynamic programming, stochastic programming, simulation programming and robust optimisation.

Stochastic dynamic programming

Stochastic dynamic programming is extended to dynamic programming by allowing multiple transition states for a given state and decision. For optimal strategies, managers must consider current and future decisions simultaneously and make decisions in a sequential manner over time

(Cornuejols & Tutuncu 2007). The main idea for this method is to decompose the large, multistage problem into a sequence of smaller optimisation problems, starting from the last stage and proceeding backwards, thereby keeping track of the optimal paths only from any given time period onwards (Pachamanova & Fabozzi 2010).

Whereas deterministic optimisation problems deal with known parameters, in practice, the company needs to deal with uncertain parameters. While some problems can be predicted by taking advantage of the estimated probability distributions, some parameters are known only within certain bounds. These different categories of problems are solved using stochastic programming, and robust optimisation is used.

Stochastic programming

Stochastic programming is one branch of mathematical programming that studies conditional extremum problems under incomplete information, and it was proposed by Dantzig (1955). Practically, stochastic programming is used to solve two types of problems: one is passive stochastic programming, where the numerical features of the performance about the set of matching extremum systems are predicted; the other is active stochastic programming, using methodologies and algorithms for forecasting and managing under risk or uncertainty (Kolbin 1977). Stochastic programming models can be divided into three types based on the way they address the random data: expected value multistage models, mean-risk stochastic models and chance-constrained models (Fabozzi 2007).

The linear stochastic programming model can be obtained by inserting stochastic variables into the Standard LP model—for example:

$$
\begin{aligned}
&\min c(\tilde{\xi})^T x \\
&s.t. \quad A(\tilde{\xi})x = b(\tilde{\xi}) \\
&\qquad\ \ x \geq 0
\end{aligned}
$$

where $\tilde{\xi}$ is a stochastic parameter.

A generic form of a two-stage stochastic linear program with recourse can be formulated as follows (Cornuejols & Tutuncu 2007, p. 256):

$$
\begin{aligned}
\text{Max}_x \quad & a^T x + E\left[\text{Max}_{y(w)} c(w)^T y(w)\right] \\
& Ax = b \\
& B(w)x + C(w)y(w) = d(w) \\
& x \geq 0, \ \ y(w) \geq 0.
\end{aligned}
$$

Note that vector x represents the first stage of decisions made before the random parameter w is observed. The second stage of decisions is made after w is observed $y(w)$. A and b are variables in the deterministic constraints of the first stage for decisions x, whereas $B(w)$, $C(w)$ and $d(w)$ constitute the stochastic constraints linking the recourse decisions $y(w)$ to the first-stage decisions x.

The algorithms and approaches of stochastic programming models are based on different approximations of the problems. Two major approaches are generally chosen to create approximation: aggregating data points and selecting data points (Gass & Harris 2001). Based on aggregating data, Prauendorfer (1994) proposed data-aggregation methods for multistage problems with limited computational results. Selecting data approaches usually generates approximations through sample-based algorithms (Gass & Harris 2001). One method for two-stage problems is the stochastic decomposition algorithm, which updates approximations created in earlier iterations (Higle & Sen 1991). Some deterministic algorithms are used in combination with approximation approaches, such as the L-shaped method, which is suitable in a small number of scenarios (Slyke & Wets 1969). For two-stage stochastic programming problems, the Monte Carlo sampling method is an efficient solution. Multistage stochastic programming problems are solved through nested Benders decomposition and sampling algorithm.

Stochastic programming is popularly used to solve problems in which some of the data may be subject to uncertainty and is appropriate for problems with data progressing over time where decisions need to be made before all the data are available (Gass & Harris 2001). This methodology has been applied in electric power generation, financial planning, telecommunication network planning and SCM. Software products are available to solve stochastic problems, both at special-purpose and general-purpose levels (Ravindran 2009). Software products such as Probabilistic Symbolic Model Checker, MC Queue, @Risk and Crystal Balls focus on Markov process analysis and are applied in the areas of queuing, reliability and telecommunications. For general objectives, programming language-based software products are widely used to solve these problems, such as MATLAB, Maple and Mathematica (Ravindran 2008).

Both multistage stochastic programming and stochastic dynamic programming deal with the same style of problems: dynamic and stochastic. The main distinction between the two is the solution concept. The main emphasis of multistage stochastic programming is on first-stage decisions, while in stochastic dynamic programming it is the decision rule that is of the primary interest (Dupačová, Hurt & Štěpán 2002).

Simulation modelling under uncertainty

For studying and modelling uncertainties in the supply chain environment, simulations are undertaken. Considering this modelling perspective, simulation can be defined as a tool for obtaining performance measurements

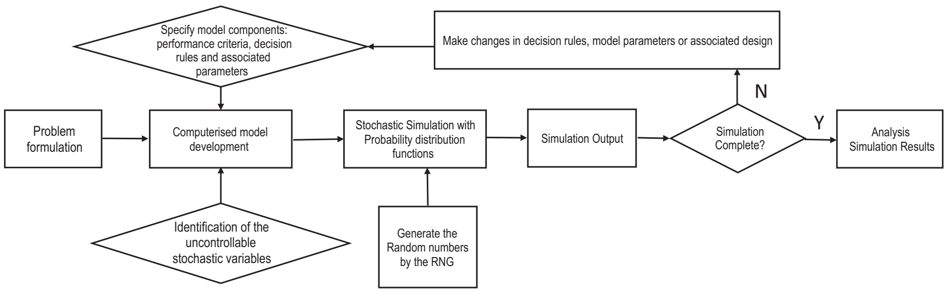

Figure 2.1 Stochastic simulation progress.

about the specific modelled problem by 'running' sampling experiments based on the corresponding mathematical model of the particular problem over a period (Moore, Lee & Taylor 1993). The core components of the simulation method include specification of performance criteria, decision rules, critical system parameters and identifying the relationship between variables (Moore, Lee & Taylor 1993).

After identifying the elements of the model, simulation programming requires that the models be developed in a form that can be analysed by the computer. The general stochastic simulation process is summarised as a workflow framework in Figure 2.1.

There are two critical steps in the simulation operating process: random number generation and determining the probability distributions that characterise the stochastic variables. To proceed with the simulation programming, the first step is to generate random numbers. Here, the random numbers are truly pseudorandom numbers, which can be duplicated and repeated after certain rounds. The procedure is based on arithmetic operations. The examples of older techniques are mid-square and mid-product methods (Moore, Lee & Taylor 1993). After producing a set of random numbers, the system then uses it to generate those that are identified as uncontrolled stochastic variables in objective models. The important component is to choose a proper distribution function to finish the mapping. This step is usually achieved by analysing empirical data through probability distributions, for example, exponential probability density function, uniform distribution and normal distribution. Simulation languages have been developed to perform simulation functions, such as GPSS, DYNAMO, GASP IV and SIMSCRIPT (Moore, Lee & Taylor 1993).

As an extension, simulation programming can be incorporated to support other methodologies. Frequently, it is combined with optimisation modelling for simulation optimisation to help improve system implementation.

Simulation optimisation

Simulation optimisation is the process of finding the best values of some decision variables for a system where the performance is evaluated based on the output of a simulation model of this system, which may have the objective function or constraints in a stochastic way (Ólafsson & Kim 2002). The result is the best solution from the simulated scenarios. The general formulation of the simulation optimisation problem is as follows (Azadivar 1999, p. 94):

$$\begin{array}{ll} \text{Max(Min)} & f(X) = E[z(X)] \\ \text{subject to:} & g(X) = E[r(X)] < 0 \\ \text{and} & h(X) < 0 \end{array}$$

z and r are random vectors representing several responses of the simulation model for a given X, a p-dimensional vector of decision variables of the system; f and g are the unknown expected values of these vectors (their theoretical regression functions) that can only be estimated by noisy observations on z and r; h is a vector of deterministic constraints on the decision variables.

Simulation optimisation is very widely used to deal with uncertainties. Diverse techniques have been developed based on the essence of the feasible region. For continuous decision variables, gradient-based search methods have received the most attention, especially stochastic approximation, which is based on the work of Robbins and Monro (1951) and Kiefer and Wolfowitz (1952). Other methods include sample-path optimisation (Gurkan, Yonca Ozge & Robinson 1994; Shapiro, A 1996) and response surface methodology (Biles 1974; Smith 1976). Conversely, when the underlying variables are discrete, numerous methods can be used to solve the problem. One example is statistical selection, including the approaches of subset selection, indifference-zone ranking and selection, multiple comparisons procedures and decision theoretic methods (Ólafsson & Kim 2002). In addition, there are random search approaches and metaheuristics methods. To be specific, metaheuristics methods include genetic algorithms, tabu search, complex search, simulated annealing and neural networks (Azadivar 1999; Ólafsson & Kim 2002).

However, none of the above can resolve problems with uncertain environments that cannot be measured with probability distributions for feasible solutions while incorporating risk consideration. This study thus turns to robust optimisation.

Robust optimisation and its application

Robust optimisation, which is an extension of stochastic programming, is a more stable and risk-centred optimisation modelling method.

Robust optimisation

For problems with the fluctuating parameters of a model or uncertainty in constraints, robust optimisation has been proposed. Gupta and Rosenhead (1968) and Rosenhead, Elton and Gupta (1972) were the pioneers for the use of the robustness concept, introducing 'robustness' in the mean of favour flexibility in which resources are subsequently available. The key in the definition of a robust solution is the flexibility it allows after the uncertain values become known (Ravindran 2008). The second view of robustness is the degree to which a solution is sensitive to the underlying assumptions, and this was introduced by Mulvey, Vanderbei and Zenios (1995) in the form of a model and solution for robustness using a penalty function. Optimality and robustness play important roles as the essential elements of management decision-making. Robust optimisation can be seen as a complementary alternative to sensitivity analysis and stochastic programming (Cornuejols & Tutuncu 2007).

The robust optimisation method was introduced by Soyster (1973) to deal with uncertainty in LP. Mulvey, Vanderbei and Zenios (1995) further formulated the concept of robust optimisation with a scenario-based approach that aims to find a solution that is close to optimal and is feasible under all the scenario constraints. In their research, solution robustness and model robustness were respectively introduced and analysed. They applied it to the classical diet problem to show how the robust optimisation method performs and produces robust solutions with some costs. In addition, this research has been applied to power capacity expansion, matrix balancing and image reconstruction, air-force airline scheduling, scenario immunisation for financial planning and minimum weight structural design (Mulvey, Vanderbei & Zenios 1995). Later, many researchers applied the robust optimisation method to diverse areas to make systems stable and optimal, for example, portfolio selection optimisation (Fabozzi 2007).

El Ghaoui and his colleagues (El Ghaoui & Lebret 1997; El Ghaoui, Oustry & Lebret 1998) developed robust solutions in problems of least-squares and semidefinite programs. Ben-Tal and Nemirovski (1998, 2002) discussed robust optimisation applications and described a specific linear problem from the NETLIB collection, which was applied in antenna design, truss topology design, and stability analysis and synthesis. Bertsimas and his colleagues explored different uncertainty sets and solutions (e.g., the convex robust counterpart program) and discussed how to structure the uncertainty set to protect the solution for tractable problems (Bertsimas & Popescu 2002; Bertsimas & Sim 2003, 2004). Robust optimisation is more stable and guarantees feasibility for the worst case of the variables. It considers the cost of performance and generally keeps solutions over-conservative to achieve feasibility in the worst situation (Bertsimas & Thiele 2006). Further, researchers have considered risk preference in robust optimisation models (Bertsimas & Brown 2009; Natarajan, Pachamanova & Sim 2009). They have explored the connection between risk measures and uncertainty sets. Bertsimas and Brown (2009) proposed a robust optimisation framework that shows the risk attitude in the form of coherent risk measures, particular distortion risk measures for polyhedral uncertainty sets. A selection of literature in robust optimisation development is briefly summarised in Appendix 2.

Applications of robust optimisation

Many cases and studies have applied robust optimisation in practice. As one of the very early examples, portfolio selection incorporates robustness into its selection solutions and is therefore relatively insensitive to inaccuracies in the input data (Cornuejols & Tutuncu 2007). Increasing numbers of people in either finance or management are studying both theoretical and applicable aspects of this methodology to control or predict uncertainty in business (Cornuejols & Tutuncu 2007; Fabozzi 2007; Kachani & Langella 2005; Lobo 2000). It was proposed for dealing with portfolio selection problems and to find an 'optimal' solution where variables are uncertain with no known probability distributions while considering risk measurement. According to Pachamanova and Fabozzi (2010), robust optimisation refers to 'the incorporation of information about uncertainty sets for the parameters in the optimisation model, and not for specific definitions of uncertainty sets or the choice of parameters to model as uncertain'.

The robust optimisation approach has also been pervasively applied to a range of areas, such as power system capacity planning, chemical industry planning, telecommunications network design, financial planning and optimal inventory planning (Bertsimas & Thiele 2006; Hahn & Kuhn 2012a; Kachani & Langella 2005; Malcolm & Zenios 1994; Mulvey, Vanderbei & Zenios 1995). As a typical example, robust newsvendor problems apply robust optimisation to make a one-shot production purchasing decision about how much to produce of a particular style good facing uncertain demand during its short season. Robust multiperiod production planning problems include different demand periods, production cost functions and inventory carrying cost functions (Kouvelis & Yu 2010). More applications can be found in statistics, learning and estimation. Further examples may be found in engineering, including structural design, circuit design, power control in wireless channels, antenna design, control and simulation-based optimisation.

The favourable trading of expected return with loss probability is the central theme of robust optimisation. Later, following the research on base-stock policies, Bertsimas proposed the robust optimisation approach to manage a supply chain under stochastic demand (Bertsimas & Popescu 2002; Bertsimas & Sim 2003, 2004; Bertsimas & Thiele 2004).

Hahn and Kuhn (2012b) have investigated the robust optimisation application in risk management in supply chains. They developed a framework for integrated value-based performance and risk optimisation by considering physical flows as well as financial performance in supply chains on a mid-term level. Their study considered the model and solution robustness and incorporated it into the objective function to pursue a decision balance depending on the risk preference of the decision-maker.

Bertsimas and Thiele (2004, 2006) proposed a robust optimisation approach to SCM that incorporates a wide variety of phenomena, including demands that are not identically distributed over time and capacity on the echelons and links, and leading to qualitatively similar optimal policies, as in dynamic programming, but outperforming in preliminary computational experiments. They also presented the numerical tractability of the model in the supply chain network and different scenarios, including capacitated and un-capacitated models for the inventory control along with the mathematical formulation, theories and proofs (Bertsimas & Thiele 2004, 2006).

Superiority of robust optimisation

The methods discussed above have their features for solving corresponding problems. However, there are certain limitations to dealing with uncertainties for stochastic programming, simulation modelling and simulation optimisation when compared with robust optimisation.

There are several tactical problems in simulation modelling. First, with respect to the initial conditions, it is for the system to decide whether it should be simulated by assuming the initial situation is empty or that a trial should be taken to build the simulation so that it can be as similar as possible to the practical operating conditions for a start of a run. Second, the decision of how many times the system should run to achieve a stable state situation if a steady state does exist is hard to make (Moore, Lee & Taylor 1993). Moreover, the function of distribution probabilities selected by the simulation system is normally based on managers' experience. For long-term modelling, these factors require the insight and experience of the simulation users, and it will be an individual judgement.

Simulation optimisation takes advantage of simulation, which is a good way of observing a real system, and it has the flexibility to analyse the problems (Taha 2007). However, to make efficient and robust decisions for companies, it is expensive in terms of time and resources. Even if we could simulate every scenario that probably happens, it takes a long time to undertake a full analysis of all potential results. Besides, it is impossible to work out all the possibilities.

Stochastic programming has been applied pervasively in practice; however, it has some deficiencies when dealing with uncertainty (Mulvey, Vanderbei & Zenios 1995), especially when compared with the robust optimisation method. In most cases, stochastic programming needs to obtain the probability distribution of the historical data and may need to split the study into multiple stages. It may also require the feasibility of the solutions from previous stages when dealing with multistage problems. Instead, with robust optimisation, the decision-maker may be able to estimate the flexibility of the recourse variables. Stochastic programming only optimises the first moment and ignores the higher moments of the distribution of the objective value. Further, it does not take the decision-makers' risk-aversion preferences into account. Conversely, robust optimisation formulations replace the probabilistic constraint with a deterministic constraint, requiring the return to be non-negative for any realisation of the returns in a given set known as the uncertainty set (Bertsimas, Brown & Caramanis 2011). Robust optimisation can be formulated as either a second-order cone program or linear program, while the exact stochastic programming is a nonlinear hard mixed-integer program. Robust optimisation formulations can still be solved quickly in large-scale problems, but dealing with stochastic programming is difficult. Stochastic LP optimises only the first moment of the distribution of the objective value, while the robust optimisation approach is able to minimise the higher moments of the distribution (Mulvey, Vanderbei & Zenios 1995). Robust optimisation integrates the methods of multiobjective programming with stochastic programming. It also extends stochastic LP with the introduction of higher moments of the objective value and with the notion of model robustness (Mulvey, Vanderbei & Zenios 1995).

Following the above distinction, robust optimisation also incorporates decision-makers' risk preference into the model. The interaction with the variance term, the risk-aversion parameters and the min-max strategy help reduce the variability while optimising the outcome (Mulvey, Vanderbei & Zenios 1995). By incorporating the risk parameters into the objective function and constraint in the robust optimisation model, decision-makers can incorporate their risk-aversion preferences into the decision-making procedure. Robust optimisation requires the uncertainty sets to estimate the constraints and minimises the variability and costs of the differences. Robust optimisation can be used to deal with erroneous or noise-corrupted data (Bertsimas, Brown & Caramanis 2011). Appendix 3 presents a brief summary table comparing these three methods.

Limitations in the existing literature and motivation

This section presents the limitations in the existing literature, which can be summarised as follows: there has been no previous research exploring an integrated systematic framework for SCM and corporate governance in relation to risk management; the optimal risk management strategies from quantifying corporate governance policies are not effectively built for an integrated SCM framework; few studies have been conducted in an integrated supply chain context using robust optimisation methodology for making decisions under uncertainty. Moreover, mathematical and statistical methods of artificial intelligence (especially that of machine learning) have not been adopted to study the relationships between corporate governance principles and SCM and for risk management and decision-making in SCM.

An integrated systematic framework of supply chain management and corporate governance for risk management

Though many studies have been undertaken on corporate governance factors and their impact on firm performance, there is no systematic framework for integrating corporate governance and SCM. Conceptual characterisation of the corporate governance policies usually presents the regulations or rules for managers to achieve good company performance. Other researchers have conducted surveys or interviews to determine what factors may influence corporate governance performance. However, there is little research on the problem of combining corporate governance factors with an optimal supply chain framework.

In addition, there is a lack of awareness of the metrics and performance measures used in systematic frameworks. Primarily, the metrics applied in supply chain modelling include lead time and inventory turnover, which are actually internally focused logistics management indicators (Lambert & Pohlen 2001). However, logistics management is a part of SCM, as reflected in its definition by the Council of Supply Chain Management Professionals (2015). In this study, the supply chain metrics across the whole operational processes of the corporation are considered and incorporated into a framework.

The synergy between corporate governance and SCM has not yet been widely explored or fully appreciated by managers and those responsible for making major decisions about the company's operation. Conversely, supply chain managers have not effectively articulated the vital role of competitive SCM in enhancing financial performance metrics (Shapiro, JF 2007) and more in corporate performance. This study has investigated this problem and fills the gap by extending the studies of JF Shapiro (2007) and Ragsdale (2012) while taking into account the risk management aspect of corporate governance and supply chains.

Further, previous studies have not given much attention to uncertainty in integrating SCM and corporate governance. They fail to consider uncertainty aspects in both SCM and corporate governance, thus isolating the decision-making process by assigning corporate governance tasks to board members and leaving SCM decisions to technicians. Such a disconnection increases inefficiency in business decisions and creates significant communication lags.

Optimal risk management strategies from quantified corporate governance policies in an integrated supply chain management model

There is little research on the quantification of corporate governance policies and their incorporation into SCM. The scandals about poor corporate governance leading to firm failure raises the importance of effective implementation of corporate governance policies. This study focuses on integrating SCM and corporate governance for risk management by quantifying the key rules and regulations in the optimisation models.

Financial controls used by auditors as key control measures for risk actually focus on short-term profitability. They cover financial ratios, budgets, budgetary reporting and capital investment appraisal (Collier 2009), which looks into income statements and balance sheets from financial reports, therefore forecasting future operations. While the process of financial control does consider the company's future management and application of some quantitative techniques, this practice is limited to short-term or even point estimates based on the subjective judgement of the managers or organisers (Collier 2009; Collier & Berry 2002). By contrast, the non-financial control indicators in a supply chain enterprise, such as operational, information and other control mechanisms, contribute to the company's performance for long-term sustainable benefit (Johnson & Kaplan 1991). It is important for the board reviewing or reporting internal control to ensure that corporate governance is not limited to financial controls (Collier 2009).

However, as discussed above, there have been only a few investigations into the operational aspects of corporate governance in supply chain modelling. Considering all the essential principles of GCG, it is essential to understand these strategies, and the board's statement should disclose how they would manage risk and maximise the business profit in the long term.

Literature shows that few theories and methodologies connect corporate governance principles in SCM models, especially in terms of risk management strategies. Enterprises face various risks, including market risk, credit risk, operational risk and business risk (Labbi 2004). It is important to analyse and manage risk in a global and integrated fashion. Corporations that have the primary goal of accumulating capital to enable high-cost business ventures to be undertaken are becoming more significant with growing industrialisation (Gaffikin 2008). Most companies work based on the findings from cost-minimisation methodologies, which may cause, inaccurately, profit-maximising in global production and distribution plans. Though the supply chain industry has developed risk analysis and models in supply chain planning and financial management, such as SCOR, it has seldom considered the agency problem, nor decision-makers' risk preference.

This study aims to achieve optimal strategies that ensure stability and efficient management by modelling supply chains related to corporate governance to maximise the equity for profit and minimise risk. In this research, factors such as agency cost, risk management and other non-financial factors are integrated into the model to investigate and optimise long-term business profit for the company. Factors such as trust and reputation can be included in the supply chain model as variables or constraints and further influence the supply chain performance.

To manage uncertainties in the supply chain, this research incorporates risk management and achieves GCG by modelling optimal policies and principles in the supply chain model. It contributes to controlling for uncertainty through a robust modelling approach across the whole supply chain.

Limitations of applications of robust optimisation methods on decision-making under uncertainty in integrated supply chain networks

The difficulties of dealing with risk and uncertainty in decision-making have been demonstrated in the literature since the 1950s (Pfaffenberger & Walker 1976). Modelling supply chains in a holistic network context using robust optimisation methods has not been extensively developed, and it is not fully appreciated by operational managers in the context of corporate strategic planning. As discussed earlier in this chapter ('Superiority of robust optimisation'), robust optimisation has distinct advantages over stochastic programming and dynamic programming methods, which have been applied to supply chain cases in the context of capturing the maintenance and stability of the solution and incorporating decision-makers' risk aversion.

Previous studies on the robust optimisation methods applied in SCM have placed more emphasis on optimising the subobjectives of the supply chain procedures, such as logistics planning optimisation. However, in reality, a company manager needs to consider the processes of the supply chain—purchasing, manufacturing, inventory, distribution and transportation—as a whole network. Therefore, for optimal operations decisions, supply chain processes need to be framed in a network manner and constructed into one model. Robust optimisation using mean-variance and penalty function in the objective function may have limited application because of its complex computations. In a risk-aversion preference context, this study deals with the uncertain environment through the robust optimisation method with uncertainty sets. The Risk Solver Platform is used in optimisation mode with Uset, adjustment of the engine and setting up of the cells and optimisation model essentials for faster simulation and to achieve the results.

Contribution and conclusion

This chapter demonstrates that a significant quantity of research has been undertaken on knowledge development in the area of SCM, corporate governance and risk management, respectively. However, there are two major issues in the present circumstances. First, the board, which represents shareholders' interests and makes strategic planning decisions for the company's long-term profit and sustainability, may also sacrifice some short-term gains or increase capital expenditures. Conversely, the company managers who are responsible for the functioning and application of the internal control systems are more willing to plan and implement strategies to achieve sound short-term interests (Fragnière & Sullivan 2007). This might be achieved by cutting the company's costs, particularly when managers' incomes are connected with the company's financial outputs. This contradictory behaviour often results in serious risks to governance that can jeopardise firm development or lead to worse damage. This study is dedicated to developing an integrated framework that coordinates different major parties in the company supply chain network to optimise their interests while maintaining the company's operations and controls in a sustainable manner. This is achieved by managing risk and ensuring GCG policies to cooperate with managing the supply chain.

Second, models that integrate SCM with corporate governance have not been explored deeply and extensively, especially in relation to risk management. To fill this gap, this book focuses on integrating corporate governance policies and risk management to improving the optimal supply chain modelling effort. It assumes that the goal of corporate governance is maximising shareholder profits and maintaining stakeholder interests while guiding the corporation through the design of optimal strategies. It can solve the challenges arising from inappropriate corporate governance that result in weak SCM and poor risk management.

The model includes both material flows that are normally considered in traditional production and inventory modelling and also financial flow. The discussion and analysis of the literature indicates that firms with supply chains consider the implementation of corporate governance policies related to risk management as essential to sustainable and optimal business development.

This research can make several potential contributions. Above all, it has conducted a study on the GCG performance and policies related to supply chain partners. All of the financial crises and failures of large companies point to the necessity of implementing GCG worldwide. It is also included in the ten essential principles of the ASX Corporate Governance Council (2007). It would be a useful and practical contribution to map and incorporate the crucial principles to SCM. Thereby, an essential contribution of this research is to quantify the descriptive principles of GCG. Second, after connecting GCG principles with SCM, this research builds a model that allows for the existence of uncertain elements through robust optimisation. In reality, the only deterministic thing is changeable. To some extent, the way to achieve GCG is to consider uncertainty and manage risk at an early stage of decision-making.

Notes

1 Interest coverage, maximum leverage, refinancing limitation, minimum dividend growth, payout restriction, cumulative payout restriction.
2 Minimise the amount of inventory cost, including product costs and holding costs.

3 Maximise the ratio of net profit to capital that was employed to produce that profit.
4 Maximise the fraction of customer orders filled on time.
5 Minimise the time required to complete the production's manufacturing and fully processed procedure.
6 Its weight in this 2012 report ranking was reduced from 25% in 2010 because of its time-honoured feature.
7 For example, the percentage of externals on the board.
8 Inventory turnover: the higher this ratio is, the more efficiently the inventory is managed; this gives some indication of how fast one company can sell products.
9 Receivables turnover: how fast one company can collect on those sales.
10 Profit ratios: measure the efficiency with which a company uses its resources, such as return on invested capitals, ROA, ROE.
11 Liquidity ratios measure the company's ability to meet short-term obligations, such as current ratio, current assets/current liabilities, quick ratio.
12 Activity ratios indicate a company's efficiency levels in managing its assets, such as inventory turnover, days sales outstanding or average collection.
13 Leverage ratios show the balance between debt and equity, also known as capital structure; the company is termed highly leveraged if it uses more debts than equity, e.g., debt-to-assets ratio, debt-to-equity ratio.
14 Shareholder-return ratios measure the return shareholders earn from the stock holding of the company, such as total shareholder returns, price/earnings ratios, market-to-book value.
15 Sales-to-total assets ratio; higher ratio suggests low agency cost.
16 The ratio between a physical asset's market value and its replacement value.
17 $\text{ISRATIO} = \dfrac{\text{Operating Income}}{\text{Net Sales}}$
18 More general risk categories include business risk, market risk (e.g., inflation risk, interest rate risk), credit risk (e.g., contractual obligation, liquidity risk and derivative risk), special risks of global operations, currency risk, government policy risk and expropriation.
19 Modigliani-Miller Theorem.
20 'The Code' refers to 'the UK Corporate Governance Code'.
21 Sometimes VaR.
22 The information is available through the Risk Metrics Corporation, http://www.riskmetrics.com (Wall Street firm JP Morgan).
23 First proposed by Freund in 1956.
24 First proposed by Hazell in 1971.
25 First proposed by Tauer in 1983.
26 Also called the Fishburn risk measure.
27 Defined as the average of the squared deviations from the mean of all values that are below the mean.
28 The theory behind this is that rather than thinking in terms of overall portfolio risk, the investor first makes sure that a certain amount of the invested principal is preserved; the investor tries to minimise the probability that the return earned is less than or equal to the threshold t.
29 These evaluate volatility in terms of the percentiles of a distribution and are justified from a theoretical point of view in the sense that they are consistent with the preference of risk-averse investors—for example, VAR.
30 Proposed by Kahneman and Tversky (1979).

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3 Conceptual framework and modelling methodology

Introduction

This chapter introduces the conceptual framework of the study, which includes the theoretical structure and procedural flow of supply chain management (SCM). The framework is used to answer the main research question: How can good corporate governance (GCG) practices and risk management be incorporated into the SCM model to improve supply chain performance by resolving agency problems?

Practices and research in the supply chain industry have mainly focused on minimising cost or maximising a company's profit on a short-term operational basis. However, as the incorporation of corporate governance principles for reducing risk and increasing firm value for long-term benefit have seldom been considered, quantifying these principles and practices for risk management strategies into an effective supply chain operations model can be expected to improve supply chain performance.

As addressed in Chapter 1, this study investigates optimal SCM with corporate governance practices to manage the flow of materials, cash and information in the context of an uncertain environment. Therefore, to achieve GCG and profit maximisation for all shareholders, strategic decisions need to be made to manage net value optimally, even under uncertainty. In this situation, a measurement of the effectiveness of corporate governance that includes financial management in terms of the balance sheet becomes an important aspect of an optimisation model for SCM. Further, to enhance the sustainability of corporate governance in an uncertain environment and to minimise the possibility of losing money, risk management in SCM is essential. Operational risk and financial risk are discussed and analysed for suitability and inclusion in the model. Following this, a robust optimisation methodology is applied to construct an integrated model that can be used to determine suitable strategic supply chain planning under uncertainty.

This chapter first presents the conceptual framework for this study together with the research questions and interrelationships between SCM, corporate governance and risk management. Next, it explains the theoretical foundation of this research to build up an integrated robust framework

DOI: 10.4324/9781003266457-3

of SCM and corporate governance. It then discusses the robust optimisation method, its approaches and algorithms for model building and as artificial intelligence algorithms. This section of the chapter also justifies the methodology applied in this study. Next, the chapter addresses the proposed integrated RSCMCG for risk management model framework and summarises the model specifications. Specifically, it details how the RSCMCG framework is used to quantify GCG practices and risk management strategies to optimise SCM, demonstrating the variables, parameters and constraints of the models. It presents the existing computer programming used in similar studies and justifies the Risk Solver Platform chosen for this study. It then justifies and briefly investigates the data sources used and simulated in the hypothetical case study of this research. It presents the measurements and demonstrates the validation of the proposed RSCMCG framework. The superiority of the framework is also discussed in this section. The chapter then concludes.

The conceptual framework of this book

Building on Chapter 2's review of contemporary developments in SCM, corporate governance and risk management, this section presents the conceptual framework used for this research. As SCM has now become a global issue for large corporations in uncertain environments, the building up of an integrated SCM and corporate governance framework for optimally modelling the supply chain of a company's global business is required. This study designs a new framework for large companies to reach their goals in successfully managing their SCM networks.

First, companies need to build up their integrated supply chain models for material flows that consider all participants, along with the operational chain as a whole, as well as cashflows. Generally, integrated networking implementation and collaboration is preferred. For example, manufacturing can be outsourced to partners with low labour costs. This can reduce the cost to economically operate the supply chain. In the meantime, it also mediates the selection of distribution centre locations, transportation selection and schedule arrangement, and different suppliers or provider tasks and chain balancing.

Second, clarification is required for the corporate policies and rules constraining the supply chains of large companies to develop strategic plans for risk management in uncertain environments. Such clarification can provide guidelines for company managers and owners to make decisions for their firms' executive operations while balancing any conflicting interests related to company resources.

Finally, following the proposed framework in this study, companies can determine optimal SCM strategies and practices using a robust optimisation methodology. By including the four main operational procedures of manufacturing, transportation, inventory and marketing in SCM with financial management, this proposed framework and model can be used to successfully analyse resources planning in an optimal and systematic way.

The new framework for integrated supply chain management with corporate governance for risk management

In providing a new framework for improving SCM performance, this study incorporates GCG practices and risk management strategies into an integrated SCM model that can positively influence SCM decisions (see Figure 3.1). This framework allows optimal decisions to be made in an integrated supply chain networking problem, considering operational flow and financial management as well as risk management strategies for GCG practices within and between each business division to pursue long-term benefits for company shareholders. As shown in Figure 3.1, the basic integrated supply chain model comprises manufacturing, distribution, inventory and marketing. GCG practices are incorporated to improve supply chain performance while controlling risk. The framework is based on the following elements: supply chain operational networking management, including manufacturing, distribution, inventory and marketing management practices; GCG practices and issues, including agency problems, game theory and the theory of risk management and corporate finance and robust optimisation model practices including the theory of optimisation and decision-making under uncertainty.

To achieve the goal of long-term benefit for the firm, GCG practices for risk management strategies and corporate financial management practices are formulated into constraints. Risk management strategies comprise the following elements: GCG practices for improving the supply chain operational system, including supply chain specialised agencies and operational risk management[1]; corporate governance performance elements, including internal control and the principal–agent problem; financial planning elements of financial balance, funds flow equation and expansion expense. Financial policies are also included in the discussion of the principal–agent game framework. The principles and practices used to reduce agency cost and protect the company from financial crises are investigated and quantified into the proposed optimal planning model. By incorporating the risk management strategies and corporate financial management into the optimal SCM model, this study has developed an integrated SCM and corporate governance model. To be specific, equity, fixed assets and long-term investment are used to represent shareholders' long-term benefit. The variables in the supply chain operational sector include quantities and unit costs pertaining to inventory and distribution. Similarly, variables are introduced to represent risks in financial areas such as the equity-to-debt ratio. The equations and constraints are structured to quantify the interrelationships among SCM, corporate governance practices and risk management strategies.

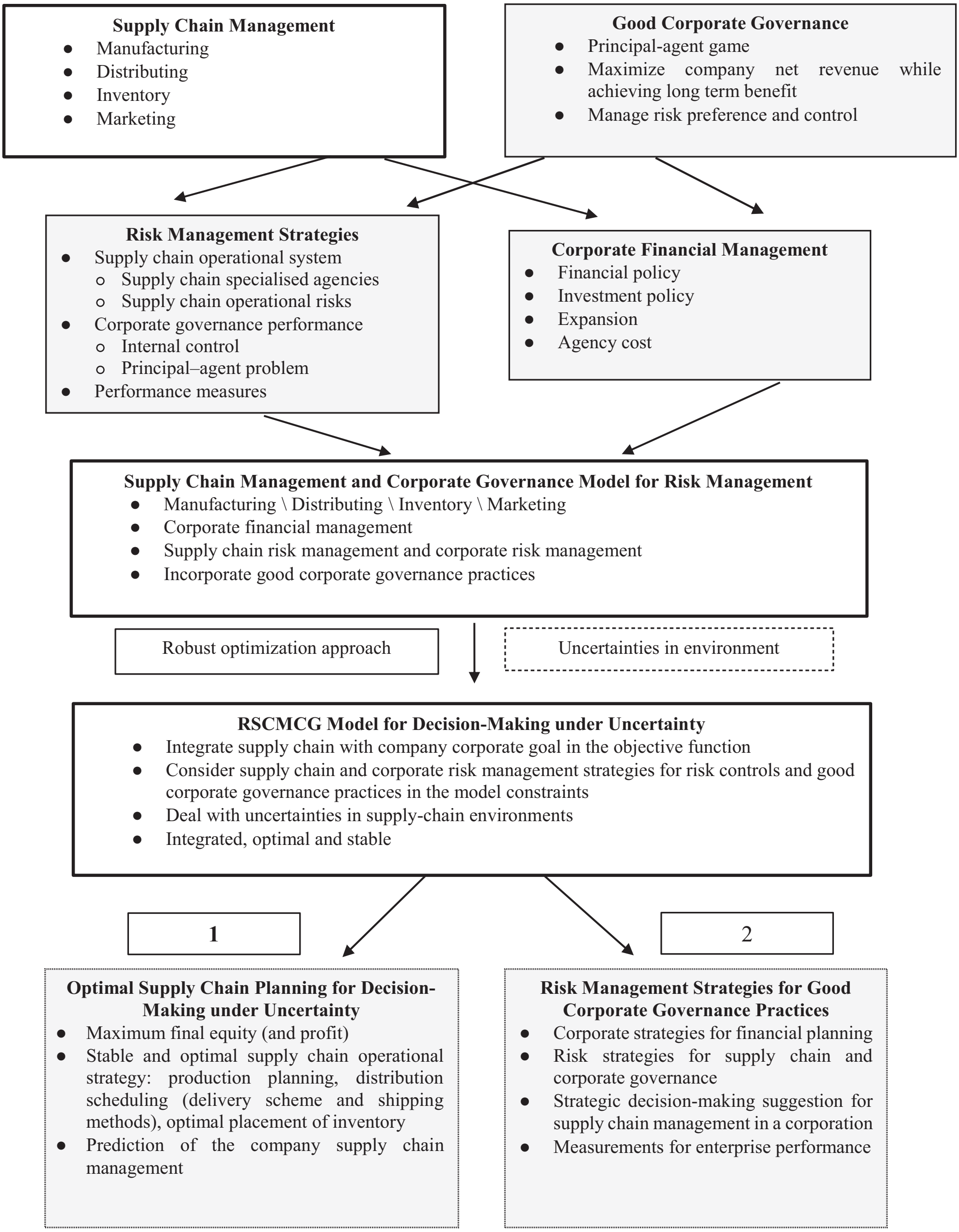

Figure 3.1 Framework for determining optimal decisions under uncertainty and risk management strategies in SCM while considering GCG practices.

The uncertain environment surrounding the supply chain network is considered in the model. The proposed RSCMCG model framework quantifies the uncertainties into the constraint and solves the problems of uncertainties with robust optimisation. Both supply chain risk management and corporate risk management strategies also support dealing with problems of uncertainty.

The model output includes optimal solutions and risk management strategies. Optimal solutions include the objective value of this model, which is the expected final equity at the end of the study period. The optimal solution provided by the proposed model will support achieving the maximum expected equity. To be specific, it will yield the supply chain operations decisions (quantities to produce at each factory, shipping amount on each transportation line and inventory quantities) and financial decisions (the annual debt amount, expenses of company's expansion and investment of the current assets). The second output is the risk management strategies for GCG practices followed by the corresponding solution and targeted equity while considering the uncertain environment. The risk management strategies provide operational and financial policies for better governance and supply chain performance.

Using the robust optimisation model, the optimal decision under uncertainty is achieved. Further, in the hypothetical case study presented in Chapter 5, the impacts of corporate governance and risk management strategies on supply chain operations and their performance are presented and discussed by comparing the solutions and outputs from our robust RSCMCG model framework with three other model frameworks: (1) initial deterministic optimisation supply chain model, (2) deterministic supply chain management with financial planning model (SCMFP model) and (3) SCM with uncertain environment model through the simulation optimisation approach.

The proposed framework supports an examination of the following research questions:

1 How can SCM be integrated into corporate governance related to risk management in a systematic way to achieve an improved SCM system for a company?
2 How can supply chain decisions be made under uncertainty in a company to achieve long-term benefits using the proposed framework?
   a What are the major factors that influence a corporation's decision-making for SCM under uncertainty, and how can these factors be incorporated into an SCM model?
   b How can the GCG practices be incorporated into the supply chain model to support decision-making under uncertainty?
   c How can the solution and the risk management strategies from the model support the decision-making process?

3 How can the robust optimisation method using a corresponding algorithm help the company reach the goal of stable optimal benefit while controlling risk?

The stage framework of this book updates the original work of Voss and Woodruff (2006) by incorporating corporate governance practices into three stages of functional, internal and external integration, respectively (see Figure 3.2 with shaded updates). This informs the direction of this study, which incorporates GCG practices into the procedures of both the internal and external operations of a company to improve SCM performance. It is a stage framework for the evolution of logistics and supply chain that incorporates corporate governance strategies.

Interrelationship between supply chain management and corporate governance for risk management

To answer the above research questions, the first step is to build a procedure for incorporating corporate governance factors into supply chain processes and models.

Issues in SCM generally concern the operational implementation as physical flow, where decisions are made by supply chain managers. Special SCM issues are related to asset management—for example, the selection of plant to implement the manufacturing task and decisions about production quantities, warehouse allocation and safety stock level. Managers in SCM are working on daily operations. Conversely, corporate governance

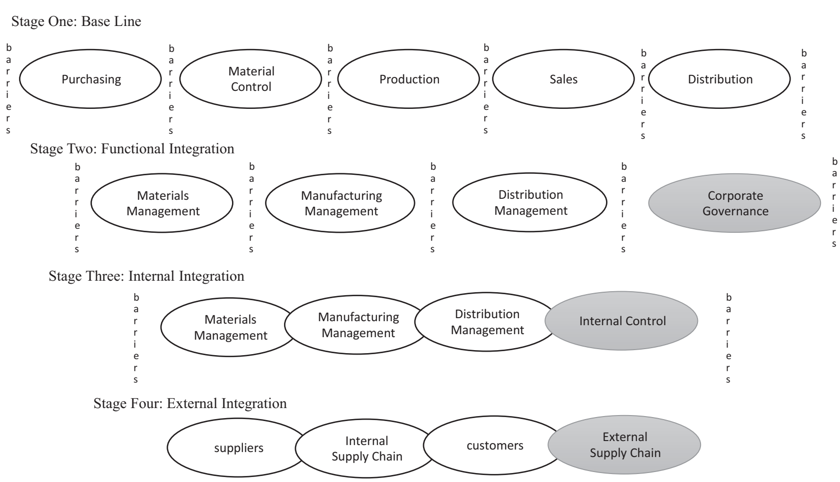

Figure 3.2 Stage framework for evolution of logistics and supply chain incorporating corporate governance strategies.

Figure 3.3 Working flow structure of SCM managers and the board.

mechanisms are discussed and decided by the board. The board determines the policies or long-term strategies for company development. Managers strongly focus on SCM practical operations and the board receives information related to long-term strategies. Managers and the board will often adopt different opinions on strategic decisions because of different responsibilities and asymmetry of information, even though they are both working towards the same goal of maximising company profit. Figure 3.3 shows the structure of the above working system. Nevertheless, all of them influence the company's performance, and the combination of these areas influences performance development.

Financial control has been a key solution for company boards and auditors to control risk over the past few decades. However, it tends to focus on short-term profitability, which considers financial ratios, budgets, budgetary reporting and capital investment appraisal (Collier 2009). These financial elements can be derived from income statements and balance sheets to forecast future operations. While the financial control process does consider a company's future management and the application of some quantitative techniques, the practice is limited to short-term or even point estimates based on the subjective judgement of the managers or organisers (Collier 2009; Collier & Berry 2002).

By contrast, the non-financial control indicators in a supply chain, such as operational factors and information control, contribute to a company's performance in terms of long-term sustainable benefits (Johnson, HT & Kaplan 1991). However, as discussed above, supply chain managers take responsibilities in operational planning while paying little attention to the financial flow and undertaking a relatively little investigation into the operational aspect of corporate governance in supply chain modelling. How do corporate governance factors and principles become incorporated into

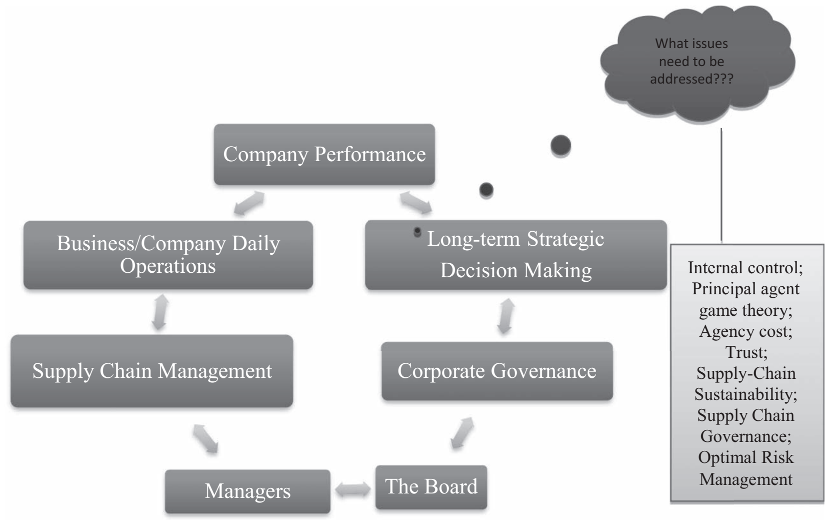

Figure 3.4 Structure of SCM and corporate governance for risk management.

the supply chain model, and what factors or conditions need to be considered in the modelling procedure? In this research, factors such as key operational control, managers' performance and risk management are integrated into the model to consider long-term business planning and profit maximisation. The framework (see Figure 3.4) shows the relationship between supply chain flows (which contain physical flows and cashflows) and corporate governance policies and principles for the purpose of risk management.

To be specific, the relationships among SCM and corporate governance elements from a risk management perspective in financial flows and benefits for shareholders and company stakeholders are presented in Figure 3.5. The performance of SCM is strongly influenced by the corporate governance practices within the financial flow.

GCG can improve supply chain performance through value creation and cost minimisation. For example, the linkage of a manager's remuneration with a company's profit is reflected in the influences of corporate governance on SCM performance (see Appendix 4). The incentive compensation model presents the relationship between wages and managers' unobserved effort. Payments to reward short-term performance fail to provide incentives for long-term value maximisation. This study focuses on how SCM and corporate governance work together to improve the company's long-term strategic decision planning under uncertain factors.

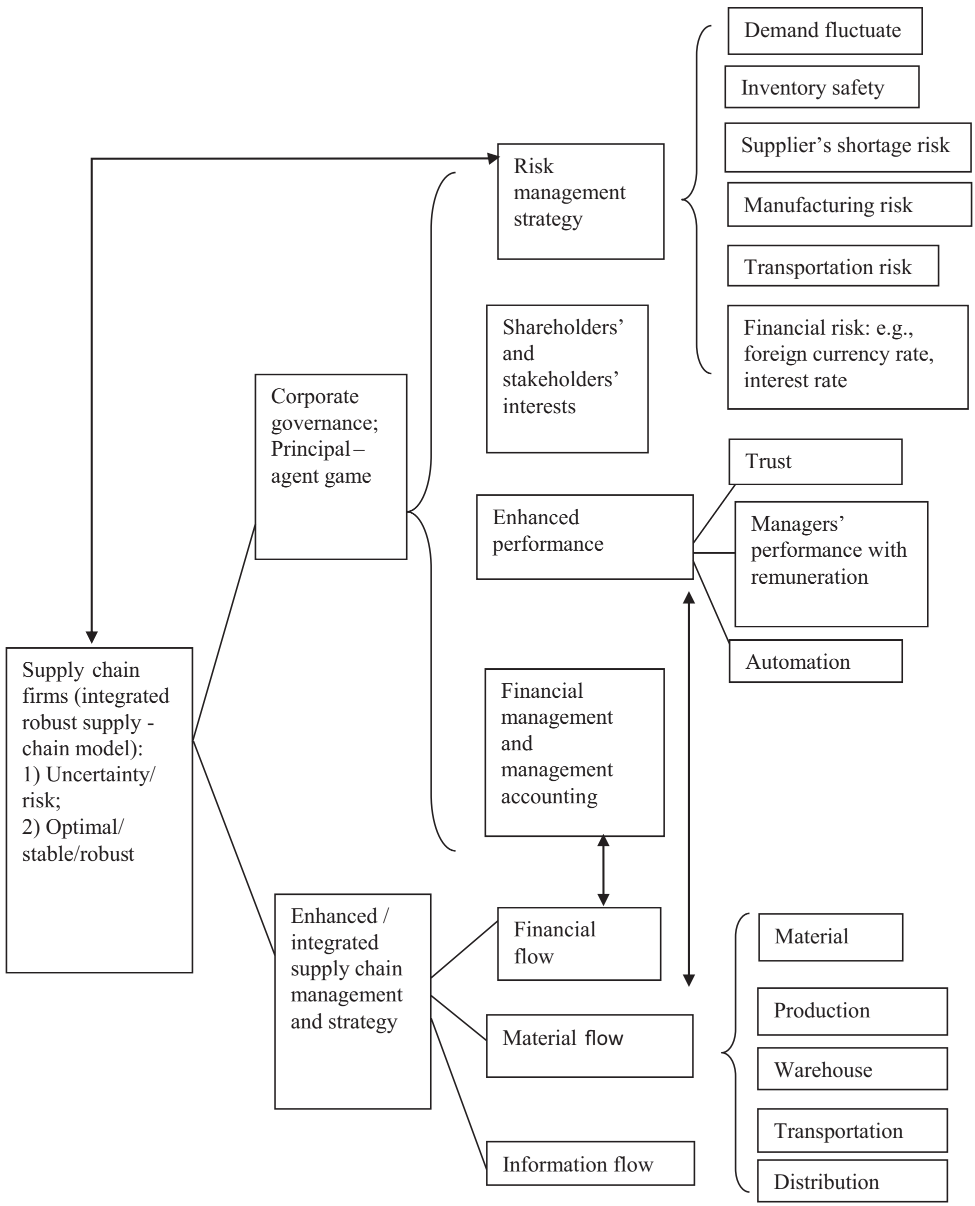

Figure 3.5 Structure framework of interrelationship between SCM and corporate governance in financial flow.

Theoretical foundation: postulates and propositions

To generate an integrated optimal supply chain model, a sound theoretical framework is essential. This section presents the theoretical foundation of this study.

Supporting theories and integrative theoretical framework

The logistics and SCM of companies have developed highly technical systems and networks through mathematical modelling, yielding optimal routines for resources planning. The framework of this study is developed under a postulate that a variety of factors in both the supply chain and corporate governance influence company business performance. How supply chain factors influence a company's decision-making is demonstrated by the resource-based view,[2] transaction cost analysis and agency theory. Agency theory explains how corporate governance practices improve supply chain performance. Theories to be considered also include decision theory, constraint theory and operations research.

In SCM, managers decide operational implementations. As addressed in the agency theory of corporate governance, a main argument in the company is the agency cost issued by the principal–agent problem because of the separation of ownership and control (Jensen & Meckling 1976) that exists between the board and the manager in a company. Corporate governance policies dictate the regulations or rules for managers that ensure good company performance. Previous studies based on surveys and interviews were conducted to determine the factors that may influence corporate governance performance. However, there is little earlier research that quantifies corporate governance factors into an optimal supply chain model. The theoretical framework guiding this study is illustrated in Figure 3.6.

The theories applied to robust supply chain model frameworks in this book include the resource-based view, transaction cost analysis and agency theory. Supply chain optimisation based on the theory of the resource-based view refers to arranging resources along the supply chain in an optimal way, from manufacturing to distribution to retailers to customer service. The resource-based view provides important insights into a firm's resources and implicitly into the construction and use of optimisation models for SCM. The aim of transaction cost analysis is to decrease the cost of transactions in supply chain processes by vertically integrating the organisations. In a robust supply chain network, it is important to have integration among diverse partners. Agency theory requires applying strong communication and cooperation within and outside the supply chain, extending into an external supply chain network relationship.

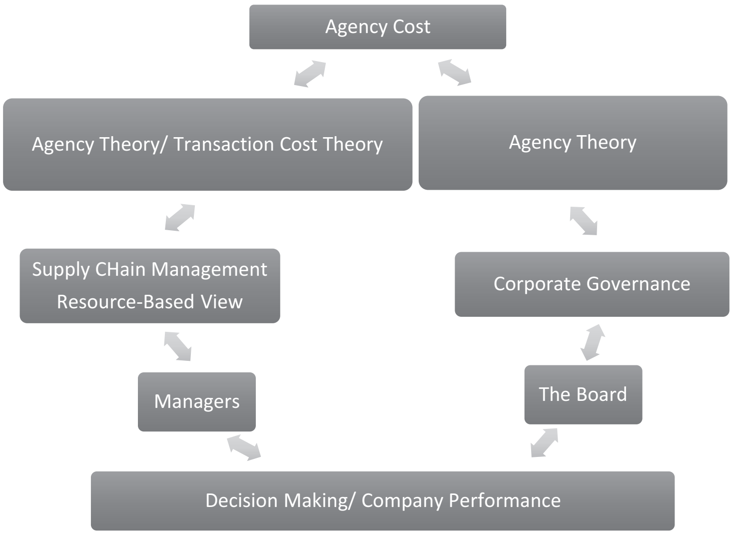

Figure 3.6 Theory framework of the study.

Agency theory: the principal–agent game in corporations and good corporate governance appraisal through efficiency and risk analysis

An agency relationship exists when one or more individuals (called principals) hire others (called agents) to delegate responsibilities to them (Jensen & Meckling 1976). Agency relationships are administrated by implicit or explicit contracts between agents and principals. The assumption of agents' self-interest, which contradicts the principals' interest, is the basis of the agency problem. Companies set targets of minimum agency cost and wish to improve principal–agent problems to achieve optimal company performance.

This research takes a view of agency theory from the perspective of corporate governance to investigate ways to improve management performance. Companies with global supply chain systems have to deal with principal–agent problems not only between managers and shareholders but also with external partners. In a company, the supply chain manager pays more attention to tactical operational planning and practical business implementation, while the board emphasises company development strategies for long-term benefits to shareholders and other stakeholders. Each group in a supply chain plays a significant role in making decisions and influencing company performance. Agency theory plays a significant role in corporate governance and demonstrates that management can be better controlled while balancing the interests of owners and managers. Further, it can be extended to the external relationships in the supply chain network collaborations. The connection and cooperation between participants in the supply chain is another important principal–agent problem. Well-managed specialised external partners will enhance the efficiency of supply chain operations. Therefore, it is very important to consider agency theory, and especially the principal–agent problem, in this integrative supply chain and corporate governance model. This study applies agency theory to the broader supply chain network: for example, this study treats the main company as the principal while delegating some SCM procedures to specialised services/companies as agents. Incorporating this extended principal–agent problem into the RSCMCG framework can improve supply chain performance, which is demonstrated in detail through the specification of the framework in this study.

GCG practices have a positive influence not only on the individual company but also on supply chain networking performance and the broader economy. As discussed earlier, GCG leads to reduced agency cost. This study explores current corporate governance performance influences in the supply chain optimisation process and the risks associated with strategic development.

Risk-based analysis framework of supply chain management and corporate governance

This section discusses the risk management strategies related to GCG practices that are incorporated into supply chain operational and financial management. The proposed risk-based analysis framework for SCM covers the whole supply chain network.

Major risks in a supply chain include environmental risk, operational risk and financial risk. Subcategories include supply risk, inventory risk, transportation risk and marketing risk. The subcategories are taken as an example to present the framework for incorporating risk management strategies for GCG to improve supply chain performance. Consequently, a process to identify prioritised risks is needed for the company. As a result of complexities in finance and management, it is impossible to account for all potential risks. For supply chain risk management, it is essential to define and clarify what risks would be considered and incorporated as priorities by the company. In this book, the focus is on integrating risk management related to corporate governance in SCM modelling. Therefore, it is reasonable and effective to choose key risk factors in the supply chain that link to corporate governance.

Environmental risk is considered by referring to market risk and currency risk. Market risk is the uncertainty caused by fluctuations in the market prices of financial or non-financial assets or volatility in demand (Labbi 2004). Price variance is the main uncertainty when corporations are facing the market. Good management of this risk can result in income stability. To solve this problem, the proposed model uses a financial model of earnings to determine the optimal hedge ratio. It is also a good strategy to diversify suppliers or select different line portfolios to improve risk and return trade-offs. Another vital risk factor of the market is unsatisfied market demand. This study considers the demand as increasing or decreasing each year based on historical data. The risk management strategies in this study use complementary product lines and suppliers combined with safety inventory level to hedge demand volatility. The other optional method is to apply robust optimisation, which can be further considered to include the fluctuating demand in an uncertainty set to develop a stable optimal solution for the model. Additionally, operational risks in SCM include suppliers' shortage, inventory shortage and shipping failure. This study also considers internal control to protect the company from bankruptcy risk, such as the debt-to-equity constraint. For international transactions, currency risks can be further considered. The way to manage this is to purchase or own foreign currency.

The main steps to approach risk management include measurement, strategy development, strategy execution and compliance monitoring (Léautier 2007). Considering SCM with a focus on corporate governance, this study adopts the risk-based analysis framework depicted in Figure 3.7, further taking into account supply chain risk management processes, phases and categories (Aven & Renn 2010; Tummala & Schoenherr 2011).

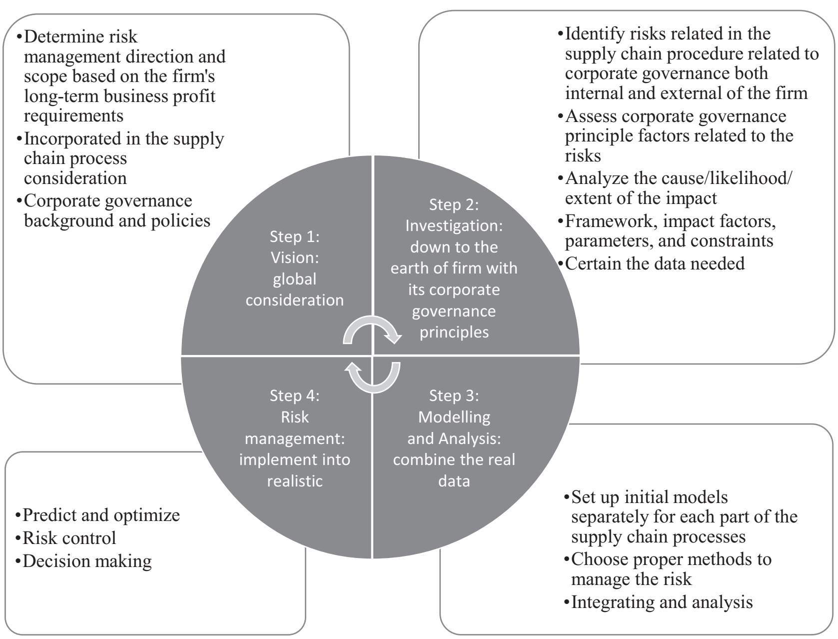

Figure 3.7 Risk management process framework in the context of SCM and corporate governance.

In the first instance, a company needs to define its goal: whether it wants to maximise its profit or minimise its costs. Second, it needs to set the bottom line for operational supply chain performance (restrictions for the operational channel). This will help determine the supply chain performance target and identify risks. Third, it must conduct an in-depth analysis of the current risks it faces, such as stock risk and shipping risk. Fourth, it should determine what strategies it will apply to deal with the risks associated with inventory level, shipping capacity and manufacturing level. Finally, all these risk management strategies are quantified as constraints of the supply chain optimisation model.

Method and application in this study

Optimisation modelling is one of the most popular tools for calculating and analysing key problems to yield superior decision-making results. A number of heuristic analyses and quantitative techniques covering a range of cross-disciplinary topics have been used to achieve optimal SCM (Ben-Tal & Nemirovski 2002). Applying optimisation models to the distribution of resources or to workers' schedules or production plans results in the best designs and economic outcomes. However, there are many obstacles to modelling industry supply chains. One of the critical issues is modelling in an uncertain environment, such as fluctuating demands. Following the reasons presented in Chapter 1 and the justification of the method's superiority offered in Chapter 2, this study uses robust optimisation modelling in the context of uncertainty and risk management. Risk management is incorporated into the model to manage the uncertainties in the planning process. In the context of an uncertain environment, where there is no probability distribution or exact estimation for the uncertainties, this study presents stable optimal solutions for a company dealing with risk management. This section presents the applications of robust optimisation and justifies the application of this method.

Robust optimisation method

To develop a robust optimisation model, variables, objective functions and constraints of the model must be identified following the discussions presented below.

Definition and general formulation for robust optimisation

The general framework of the robust optimisation model is presented below.

$$\begin{aligned} &\text{Max} && f_0(x) \\ &\text{subject to} && f_i(x, u_i) \leq 0, \\ & && \forall u_i \in U_i,\ i = 1, \ldots, m \end{aligned}$$

Here, $x \in \mathbb{R}^k$ is a vector of decision variables, $f_0, f_i : \mathbb{R}^n \rightarrow \mathbb{R}$ are functions and the uncertainty parameters $u_k \in \mathbb{R}^k$ are assumed to take arbitrary values in the uncertainty set $U_i \subseteq \mathbb{R}^k$ (Bertsimas, Brown & Caramanis 2011, p. 470), which are assumed to be closed throughout this research.

The robust linear counterpart of a linear optimisation problem could be written, without losing generality, as follows (Bertsimas, Brown & Caramanis 2011, p. 471):

$$\begin{aligned} &\text{Min} \quad c^T x \\ &\text{subject to} \quad Ax \le b, \ \forall a_1 \in \mu_1, \ldots, a_m \in \mu_m \end{aligned} \tag{3-1}$$

Where a_i represents the *i*th row of the uncertain matrix A and takes values in the uncertainty set $\mu_i \subseteq \mathbb{R}^n$. Then, $a_i^T x \le b_i, \forall a_i \in \mu_i$, if and only if $\max_{\{a_i \in \mu_i\}} a_i^T x \le b_i, \forall i$.

One criterion for the robust optimisation model is addressed as the optimisation models with uncertain data try to reach a good solution for all or most possible realisations of the uncertain parameters (Cornuejols & Tutuncu 2007).

Uncertainty set and robustness: essential elements and main features of robust optimisation

Robust optimisation as the optimisation methodology has two basic elements: objectives and constraints. Compared with other optimisation methods, robust optimisation has uncertainty sets that additionally incorporate uncertainty parameters or conditions. Uncertainties may differ across different cases. Based on the requirements or issues, the model could be set up with distinct uncertainty sets for special purposes. In relation to diverse cases, the robustness varies. More details are provided below.

As concluded in Chapter 2, the uncertainties in robust optimisation models are independent of the decision variables. Different uncertainty forms may exist depending on the setting up of the problem, such as net profit coefficients, uncertain production technology and raw material supply (Kouvelis & Yu 2010). The risk-aversion formulation may appear in the objective function as a risk-aversion coefficient (Pachamanova & Fabozzi 2010), for example, by way of the penalty function or mean variance according to the traditional approaches.

1 Uncertainty set

Depending upon the circumstances of individual cases, there are diverse ways of setting up the uncertainty set. Determinants of an uncertainty set that are appropriate for a particular model as well as the type of uncertainty set that lead to tractable problems are important (Cornuejols & Tutuncu 2007). The sources of uncertainty and the sensitivity of the solution to these uncertainties decide the type of uncertainty set. The size of the uncertainty set is determined by the desired level of robustness (Cornuejols & Tutuncu 2007). The common types of robust optimisation used in the area of finance are categorised into several groups: scenarios, polytopic uncertainty set, interval description and ellipsoidal (Cornuejols & Tutuncu 2007).

I Scenarios: Specifying an uncertainty set by collecting the potential scenarios for the uncertain parameters: $U = \{p_1, p_2, ..., p_k\}$

Robust formulation of the original problem would then include the constraints for each scenario in the uncertainty sets; it finds a solution that satisfies the worst-case scenario in the set (Fabozzi 2007). For this type of robust optimisation group, the key question is how many scenarios (n) from the underlying distribution for the uncertain parameters should be included in the uncertainty set to guarantee that the probability of the constraint being violated in reality will be at most ε? (The answer is $n \geq \frac{N}{\varepsilon\beta} - 1$) (Calafiore & Campi 2005).

II Polytopic uncertainty set: $U = \text{conv}(p_1, p_2, ..., p_k)$.

In this case, the uncertainty sets are p, representing the convex hull of a finite number of scenarios generated for the possible values of the parameters.

III Interval description for each uncertain parameter: $U = \{p : l \leq p \leq u\}$

Confidence intervals, which are encountered frequently in statistics, can be a source of this category of uncertainty sets.

IV Ellipsoidal uncertainty set: $U = \{p : p = p_0 + Mu, \|u\| \leq 1\}$

These uncertainty sets arise from statistical estimation in the form of confidence regions. In addition to their mathematically compact description, ellipsoidal uncertainty sets have the property of smoothing the optimal value function (Cornuejols & Tutuncu 2007).

While these are common types, there are also other popular methods. Bertsimas, Brown and Caramanis (2011) described the uncertainty sets for robust linear optimisation, robust quadratic optimisation and robust discrete optimisation. For instance, robust linear optimisation models have quadratic or ellipsoidal uncertainty, polyhedral uncertainty, cardinality constrained uncertainty and norm uncertainty (Ben-Tal & Nemirovski 1999; Bertsimas, Brown & Caramanis 2011; Bertsimas, Pachamanova & Sim 2004; Bertsimas & Sim 2004).

The above discussions are about uncertainties in the constraints of the model; however, sometimes, uncertainties occur in the objective function. If the original objective function is affected by uncertain parameters, they can be converted into additional constraints $\max_{u_0 \in U_0} f_0(x, u_0) \le t$ by introducing an auxiliary variable t and then minimise t.

2 Robustness

Robustness is an essential and core characteristic of the robust optimisation problem. It can vary depending upon the situations of uncertainty, such as constraints robustness, objective robustness, relative robustness and adjustable robustness (Cornuejols & Tutuncu 2007).

Constraints robustness refers to the uncertainties that exist in the constraints and looks for solutions that are feasible for all possible values of uncertain inputs (Cornuejols & Tutuncu 2007). This type of solution is frequently used in engineering applications. While the objective robustness refers to solutions that will remain close to optimal for all possible realisations of the uncertainty problem parameters, such solutions may be hard to achieve, especially when the uncertainty sets are extremely large. Consequently, an alternative goal for this robustness is to seek solutions whose worst-case behaviour is optimised.

The above two robustness types focus on the absolute measure of worst-case performance and are not consistent with the risk-tolerance levels of many decision-makers. Therefore, instead, the worst case is measured relative to the best possible solution under each scenario, which is known as relative robustness (Cornuejols & Tutuncu 2007).

A solution to the optimisation model may be defined as solution robust or model robust according to different situations (Mulvey, Vanderbei & Zenios 1995). It is solution robust if it remains 'close' to optimal for all scenarios of the input data and model robust if it remains 'almost' feasible for all data scenarios.

Approach and algorithm of robust optimisation

There are different approaches for methods used depending on different study targets. For example, Pachamanova and Fabozzi (2010) summarised the optimisation problems into three types where stochastic programming could be used to address the presence of uncertain input data: expected value objective function, chance-constrained and mean-risk stochastic models. This section presents three classical models for stochastic programming, followed by robust optimisation models.

Three classical models of stochastic programming for the foundation of robust optimisation

There are three classical approaches for stochastic programming that provide an origin for robust optimisation: the mean-risk model, the recourse model and the chance-constrained model (Ravindran 2009).

1 Mean-risk model

The first mathematical programming model of uncertainty was Markowitz's (1952) mean-risk model for the portfolio selection problem, which is symbolically presented as follows:

$$\max_{x \in X} \; px - \lambda x'Vx, \text{ where } X = \left\{x \geq 0 : \textstyle\sum_i x_i = 1\right\}$$

2 Recourse model

The two-stage recourse model is $\min \left\{ f(x) + E\left[\min_{y \in Y(x)} \{\Phi(y;x)\} \right] \right\}$ (Dantzig 1955), where the underlying mathematical program is linear:

$$\min \left\{ cx + E\left[\min\{\Phi(y;x) : y = d - Dx\} \right] : Ax \geq b \right\}$$

Φ penalises over-and under-satisfaction of joint constraints $Dx + y = d$. Let y^k denote the second-stage variable for the scenario k. Then, the entire recourse model can be presented as one mathematical program: $\min cx + \sum_k s_k C^k \left|y^k\right| : Ax \geq b, y^k + D^k x = d^k,$ for $k = 1,\ldots,K$, where s_k is the probability that scenario k prevails and K is the number of scenarios. C^k is a linear penalty of the magnitude of y^k. Replace the absolute value with the difference of the positive and negative part: $y^k = u^k - v^k$. Then, the LP recourse model is given by the equation

$$\min cx + \sum_k s_k C^k \left(u^k + v^k\right) : Ax \geq b \; y^k + D^k x$$
$$= d^k, \left(u^k, v^k\right) \geq 0, u^k \geq y^k, v^k \geq -y^k, \; \textit{for } k = 1,\ldots,K$$

3 Chance-constrained model

The chance-constrained model can be formed as Max $cx: x \in X$, $P(Dx > d) \geq \alpha$, where $\alpha \in [0,1]$. This allows controlling for the constraint certainty level (Charnes, Cooper & Symonds 1958).

Main forms of the robust optimisation method

There are three main robust optimisation methods: Soyster's (1973) robust linear optimisation model, Ben-Tal and Nemirovski's (2002) model, and Bertsimas and Sim's (2004) model.

1 Soyster's robust linear optimisation model

Soyster (1973) proposed the robust linear solution, which solved linear programs by replacing the uncertain parameters with their worst scenarios to find the 'safest' solution.

$$\text{Max } c^T x$$

$$\text{subject to} \sum_{j \in J} \tilde{a}_{ij} x_j \le b_i, \forall i \in I, \tilde{a}_j \in K_j$$

$$x_j \ge 0, \forall j \in J$$

with uncertainty existing at $\tilde{a}_{ij}$. The robust counterpart of this problem presents the uncertain parameters with their worst cases and turns into a deterministic linear problem:

$$\text{Max } c^T x$$

$$\text{subject to} \underset{\tilde{a}_j \in K_j}{\text{Max}} \left\{ \sum_{j \in J} \tilde{a}_{ij} x_j \right\} \le b_i, \forall i \in I$$

$$x_j \ge 0, \forall j \in J$$

This robust optimisation approach solves the uncertainty problem while keeping the linearity of the problem. However, it keeps the optimality from the solution and turns out to be too conservative.

2 Ben-Tal and Nemirovski's robust optimisation model

The uncertainty in the problem is noted as $\tilde{a}_{ij} \in \left[\overline{a}_{ij} - \hat{a}_{ij}, \overline{a}_{ij} + \hat{a}_{ij} \right]$. $\overline{a}_{ij}$ is the nominal value of the uncertainty parameter $\tilde{a}_{ij}$. This group of robust optimisation can be formatted as follows:

$$\text{Max } C^T X$$

$$\text{subject to} \sum_{j} \overline{a}_{ij} x_j + \sum_{j \in J_i} \hat{a}_{ij} y_{ij} + \Omega_i \sqrt{\sum_{j \in J_i} a_{ij}^2 z_{ij}^2} \le b_i,$$

$$-y_{ij} \le x_j - z_{ij} \le y_{ij}, \ \forall i, j \in J_i$$

$$X \ge 0, \ Y \ge 0$$

This method was presented by Ben-Tal and Nemirovski (2002) and improves the conservative problem of the Soyster model. However, it increases the complexity of the algorithm and cannot control the balance of solution robustness and feasibility. Under this form, the probability that i constraint is violated is at most $\text{Exp}(-\Omega_i^2/2)$.

3 Bertsimas and Sim's robust optimisation model

To improve the problem of balancing the solution for robustness and feasibility, Bertsimas and Sim (2004) proposed a new robust optimisation approach to deal with the uncertainty problems. Consider a problem with data uncertainty Min $c'x : Ax \le b, 1 \le x \le u$. Matrix A is subject to uncertainty in data:

$$\mathrm{A} = \left\{ A \in \mathbb{R}^{m \times n} \middle| a_{ij} \in \left[\overline{a}_{ij} - \hat{a}_{ij}, \overline{a}_{ij} + \hat{a}_{ij} \right], \forall i, j, \sum_{(i,j) \in J} \frac{\left| a_{ij} - \overline{a}_{ij} \right|}{\hat{a}_{ij}} \le \Gamma \right\}.$$

The robust problem then formulated as follows:

$$\begin{aligned} &\text{Min } c'x \\ &s.t.\ Ax \le b, \ \ \forall A \in \mathrm{A} \\ &1 \le x \le u \end{aligned}$$

Applying this format of robust optimisation balances the robustness and linearity and also keeps the probability of breaking the constraints optimality in $\Phi\left(\frac{\Gamma_i - 1}{\sqrt{n}} \right)$.

The main approaches to robust optimisation

There are a few approaches to robust optimisation problems, such as mean-variance methods (Mulvey, Vanderbei & Zenios 1995), minimax regret in the form of $\min_{x \in X} \max_{k} \{z^k - c^k x\} : D^k x \ge d$ for all $k = 1, \ldots, K$ (Ravindran 2009) and the worst-case method, which can be mathematically presented as $\min_{x \in X} \max_{c} cx : Dx \ge d$ for all $\left[D\ d \right]$. Here, the mean-variance methods are presented for further application in this study.

Robust optimisation can be considered in the form of model and solution robustness using a penalty function. Introducing a penalty function into the objective function in Mulvey's robust optimisation model distinguishes it from others in dealing with uncertainties (Mulvey, Vanderbei & Zenios 1995). This approach is able to incorporate the risk measure and decision-makers' preference into the planning model. Unlike the recourse model, the robust model could penalise risk, as in the Markowitz model, without requiring scenarios to be defined (Mulvey, Vanderbei & Zenios 1995, pp. 265, 266).

$$\min \sigma(x, y_1, \ldots y_s) + \omega \rho \ (z_1, \ldots z_s)$$

$$Ax = b$$

$$B_s x + C_s y_s + z_s = e_s, \ \text{for all} \ \ s \in \Omega$$

$$x \ge 0, y_s \ge 0 \ \ \text{for all} \ \ s \in \Omega$$

$$x \in \Re^{n_1}, y \in \Re^{n_2}$$

ω incorporates the risk preference of decision-makers; $\rho(z_1,...z_s)$ is the penalty function, while $\sigma(\cdot)=\sum_{s\in\Omega} p_s\xi_s$. With multiple scenarios, the objective function $\xi = c^T x + d^T y$ becomes a random variable taking the value $\xi_S = c^T x + d_S{}^T y_S$, with probability p_S.

This method comprises two parts: the expectation and measure of risk. Risk is presented as variance of the realisation of each scenario to the expected value and is penalised for the disturbance of the stability of some constraints. The first part, including mean and variance, makes sure that the solution is located close to the mean/centre of all the scenarios' solutions; the second part of the penalty function $\rho(z_1,...z_s)$ minimises the deviation of the optimal solution from the scenario's solution, which is used to penalise violations of the control constraints under some of the scenarios. The weight ω is used to derive a spectrum of trade-off solutions for model robustness. This approach addresses the robustness from two aspects: solution robustness, which means the optimal solution remains 'close' to optimal for any realisation of the scenario $s \in \Omega$, presented in the first term $\sigma(x, y_1,...y_s)$; and model robustness, which means the solution remains 'almost' feasible for any realisation of scenario s (Mulvey, Vanderbei & Zenios 1995). In the worst-case analysis, the model minimises the maximum value and the objective function is defined by $\sigma(\cdot) = \text{Max}_{s\in\Omega}\xi_s$.

This book provides a robust optimisation approach with expected utility function in Chapter 4. Uncertainty sets and robust counterpart approaches are informed by the Bertsimas and Sim (2003, 2004) model framework. The model framework is applied to balance the robustness between risk and optimality in the objective function. The Mulvey method is used to incorporate the risk measures and aversion into the current model (Mulvey, Vanderbei & Zenios 1995).

Solutions and algorithms of robust optimisation

1 The counterpart of robust optimisation

Duality theory states that the optimal objective function value will be the same as the value of the primal (maximum) problem (Pachamanova & Fabozzi 2010). The robust counterpart optimisation problems could be projected from different uncertainty sets with diverse optimisation problems. To solve optimisation problems, normally it is efficient and tractable to deal with their dual problems. The robust counterparts of the original robust optimisation problems have no uncertainty variables and are solved through a deterministic optimisation method (Pachamanova & Fabozzi 2010).

For normal LP or quadratic programming, if they are convex problems, they can be classified as SOCP. SOCP is a problem class that lies between LP and semidefinite programming. It can be solved very efficiently by primal-dual interior-point methods (Lobo 2000). SOCP general form is as follows:

Minimize $f^T x$

subject to $\|A_i x + b_i\| \leq c_i^T x + d_i,\ i = 1,\dots,N$

where $x \in \Re^n$ is the optimisation variable and the problem parameters are $f \in \Re^n, A_i \in \Re^{(n_i-1)\times n}, b_i \in \Re^{n_i-1}, c_i \in \Re^n$ and $d_i \in \Re$ (Lobo 2000). The norm appearing in the constraints is the standard Euclidean norm. According to Bertsimas, Brown and Caramanis (2011), the norm-based model, including D Norm, yields an equivalent problem with corresponding dual norm constraints, which can be formulated as a linear problem. To be specific, the l_1 and l_∞ norms generate linear optimisation problems, while the l_2 norm results in a second-order cone problem. With the uncertainty set $U = \{A \mid \|M(\text{vec}(A) - \text{vec}(\bar{A}))\| \leq \Delta\}$, where M is an invertible matrix, $\bar{A}$ is any constant matrix and $\|\cdot\|$ is any norm; therefore, the previous problem is equivalent to the following problem (Bertsimas, Pachamanova & Sim 2004):

$$\text{Min} \quad c^T x$$

$$\text{subject to} \quad \bar{A}_i^T x + \Delta \left\|(M^T)^{-1} x_i\right\|^* \leq b_i, i = 1\dots,m,$$

where $x_i \in \mathbb{R}^{(m\cdot n)\times 1}$ is a vector that contains $x \in \mathbb{R}^n$ in entries $(i-1)\cdot n + 1$ through $i \cdot n$ and 0 everywhere else and $\|\cdot\|^*$ is the corresponding dual norm of $\|\cdot\|$.

The general robust counterpart form for the Bertsimas and Sim model noted earlier in this chapter ('Main forms of the robust optimisation method') is presented below (Bertsimas & Sim 2004):

$$\text{Min } c'x$$

$$s.t. \sum_j \bar{a}_{ij} x_j + q_i \Gamma + \sum_{j:(i,j)\in J} r_{ij} \leq b_i, \forall i$$

$$q_i + r_{ij} \geq \hat{a}_{ij} y_j,\ \ \forall (i,j) \in J$$

$$-y \leq x \leq y$$

$$1 \leq x \leq u$$

$$q \geq 0, r \geq 0, y \geq 0$$

Applying this format of robust optimisation balances the robustness and linearity and keeps the probability of breaking the constraints optimality in $\Phi\left(\frac{\Gamma_i - 1}{\sqrt{n}}\right)$.

2 Algorithm

Optimisation algorithms differ depending upon the circumstances of the original problems. For LP problems, the simplex algorithm and interior-point methods are applied to find the solutions. For constrained nonlinear optimisation, Karush–Kuhn–Tucker conditions and Lagrange multipliers are used for feasible solutions. For integer programming problems, algorithms include branch-and-bound, branch-and-cut routines and heuristics. Randomised search algorithms have simulated annealing, tabu search and genetic algorithms (Pachamanova & Fabozzi 2010). A genetic algorithm is a particular option in several popular software packages for optimisation, such as Premium Solver and Palisade's Evolver. Conic optimisation tools have different types of programming, such as SOCP and semidefinite programming, and they apply algorithms including heuristic, branch-and-bound, interior-point methods, genetic algorithm and decomposition.

The efficiency of an algorithm—for example, the number of steps and elementary operations it takes to solve a problem of a given size—is also one of the criteria used in the decision-making processes. The size is determined by the number of operations needed to solve the problem, which is related to the number of decision variables and the number of constraints.

Justification of the methodology applied in this study

The above models proposed to deal with risk management are fitted in their corresponding situations and environment. For example, in the ERM modelling framework, CCP is used for risk management in financial decisions because it captures the critical components of ERM in a natural way (Ai et al. 2009).

This study uses a robust optimisation method supported by LP. In reality, situations are sometimes not linear. But nonlinearity in variables or constraints can make solutions harder or can complicate problems. Supply chain models are an approximation, and they are used to guide the company in decision-making.

The superiority of robust optimisation and its comparison with different methods, including dynamic programming, stochastic programming and simulation optimisation, are presented in Chapter 2. In this research, robust optimisation is chosen to achieve three modelling benefits. First, this research analyses decision-making under uncertainty and aims to maximise long-term business benefits through modelling. Robust optimisation can achieve these simultaneously. Second, this model should be used at the very beginning of the strategic stage when decisions are made for the long-term benefit of the company, and it, therefore, requires the methodology to be robust and stable. Third, robust optimisation might be exploited in an approach similar to the CCP model (Ai et al. 2009), when the firm does not possess good information about some pertinent factors. To fit uncertain environments proposed in this study, where the firm does not possess good information about some elements and factors in the supply chain process or environment, robust optimisation is employed. In addition, more risk management strategies with corporate governance practices are incorporated into the models.

The bullwhip effect amplifies demand variability between downstream and upstream. Reducing this effect has the potential of reducing cost and improving company profit. Robust optimisation delivers the optimal solution where demand is uncertain and, compared with other solutions applied in an uncertain environment, such as stochastic programming, it is computationally manageable (Bertsimas, Brown & Caramanis 2011). Moreover, to balance the robustness and optimality, this study applies Mulvey's method and Bertsimas' model framework to manage the integrated supply chain and financial planning with corporate governance considerations to achieve risk management while maintaining optimality (Bertsimas & Sim 2004; Mulvey, Vanderbei & Zenios 1995).

The proposed new robust supply chain management and corporate governance model framework and specifications of model elements

This study formulates a framework for a corporation to maximise its value through supply chain operations, financial management and corporate risk management within each division and the interdependencies between these factors. The optimisation problem is constructed through quantifying GCG practices into the risk management strategies of the supply chain optimal model to incorporate the variety of synergetic relationships within supply chain procedures and corporate structures. The proposed model is a principal–agent game theory model and incorporates the interests, goals and strategies of both the principal and agent into its structure. The model mainly answers two questions: how can corporate governance be integrated into the supply chain model, and what is the impact of this integration on improving the performance of the supply chain? In the proposed model framework, SCM consists of raw materials procurement, manufacturing, inventory, transportation and marketing. Raw materials procurement considers how to reduce cost based on a composite of their capability and transportation cost. Manufacturing focuses on producing goods on time while reducing cost. Inventory aims to maintaining low stock levels while keeping enough on hand to meet demand. Transportation needs to be well arranged to obtain optimal routines. Marketing concentrates on selling and managing demand to generate revenues. Based on these considerations, this study presents the model framework with its key elements, objective function and constraints.

Key elements of the proposed new model framework

This study's optimisation framework highlights the incorporation of SCM and corporate governance practices across diverse business divisions and presents an artificial intelligence and machine-learning algorithm. In this situation, there are two sets of decision variables: operational decision variables such as production quantity, shipping lines division and warehouse stock level; and financial decision variables such as reduced cost, objective coefficient, allowable increase and decrease amount.

Artificial intelligence and machine learning: Lexico (n.d.) defines artificial intelligence as 'The theory and development of computer systems able to perform tasks normally requiring human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages'.

Wikipedia provides the following discussions of machine learning: machine learning is a subset of artificial intelligence and is a study of computer algorithms that seeks to make predictions or decisions. Machine-learning algorithms build mathematical models, including optimisation models, from data experience. 'The study of mathematical optimisation delivers methods, theory and application domains to the field of machine learning' (Wikipedia 2021).

Following the above tradition, a computational mathematical model (a computer system) has been developed and used as artificial intelligence and machine-learning algorithms for decision-making and predicting the optimal specifications and strategies in the areas of study in this book. There are two main streams of constraints for risk management strategies in the model: supply chain risk management and corporate risk management modelling. Supply chain risk management supports the management of risks in supply chain procedures. These strategies maintain company stability in a fluctuating environment. Corporate risk management can add firm value by optimising capital structure and hedging ratios (Léautier 2007). Consequently, it is applied here by considering elements in the financial structure and optimal ratios, such as the ratio of sales-to-total assets and inventory turnover.

Principles for GCG addressed by the ASX Corporate Governance Council (2007) (discussed in Chapter 2, 'Good corporate governance for better firm performance') can be incorporated into the model framework. For example, the principle of 'respect the rights of shareholders' is recognised through maximising shareholders' wealth, including EBIT and equity as an objective function. The principle of 'recognise and manage risk' is achieved through risk indicators. The principle of 'encourage enhanced performance' is explored through risk management strategies and the robust optimisation approach to improve supply chain performance by way of robustness and optimality while managing risk. Measures of performance are included in the constraints, such as ROA and ISRATIO. The following sections present the details of the study in this area.

Objective function for the objective value and connections

This study seeks to improve supply chain performance through GCG practices that focus on risk management.

The final goal of the model is to maximise equity value. GCG practices set the maximisation of equity as the objective function. Creating shareholders' value is commonly considered the paramount business goal (Young & O'Byrne 2001). Maximising shareholders' long-term benefits is considered the objective of a strategic planning model. The goal of operational management is minimising cost or maximising profit, but it is only for short-term operational profit. For long-term benefit, the company must not only take care of its operational cost and sales profit but also pay attention to corporate risk management strategies and the relationship between operations and corporate finance. In this study, equity is chosen as a measure for long-term benefit. The final equity of the targeted period is taken as the objective value.

Equity also builds up the connection of corporate governance with supply chain operations through EBIT. EBIT links SCM through revenue and cost of operational chains while it connects to corporate governance through the balance sheet (financial statement reflecting company governance). EBIT is incorporated into the objective function and equity is considered through the interrelationship between EBIT and long-term debt and dividend to shareholders. The definitional equations for supply chain operations and financial management are presented in Chapter 4 ('Constraints of the robust supply chain management and corporate governance model', Section A).

Constraints for integrated supply chain with good corporate governance practices

Constraints for the proposed model framework are divided into those for integrative SCM and financial management and those for GCG practices covering management in the supply chain.

Supply chain management and financial management

1 Supply chain operational equation constraints

Supply chain operational constraints are formed from the operational policies for important SCM procedures. All the major processes—manufacturing, shipping, inventory and marketing—are considered in the model framework; expenses associated with each procedure, different shipping line options and mass balance are considered across the whole supply chain network participation. The interactions and collaborations among participants are reflected through constraints. The main purpose of these constraints is to set up an integrated supply chain operations management system. Chapter 4 presents details of the mathematical form ('Constraints of the robust supply chain management and corporate governance model', Section B.1).

2 Financial planning constraints

This study connects the supply chain operational system with financial management by incorporating financial elements into strategic planning, such as current liabilities, long-term debt, current assets, fixed assets and equity (Ross 2011; Shapiro 2007). Current liabilities refer to short-term liabilities such as accounts payable or payroll. Long-term debt refers to long-term bank loans or bonds. Current assets address the liquid assets of the company such as cash and inventories. Fixed assets are non-liquid assets such as plants or equipment. Equity refers to the value of shareholders' interests in the firm. Part of the basic financial management structure in SCM is drawn from Shapiro's (2007) model in his *Modeling the supply chain*. Chapter 4 presents details of the mathematical form ('Constraints of the robust supply chain management and corporate governance model', Section B.2).

The experimental data can be obtained from the balance sheet in the financial report. The main financial planning concerns in this book are to stabilise financial balance and achieve healthy funds flow and positive investment. These financial planning constraints also demonstrate the interactive relationships of financial elements in corporations.

Corporate governance strategies in constraints

A core research question of this study is how GCG practices can be incorporated into the SCM model for decision-making to improve supply chain performance. This is assessed from the perspective of two main aspects: (1) supply chain operational risk management and agency problems and (2) financial management and corporate risk management. As a result, this study examines and formulates GCG practices and incorporates risk management into the supply chain system through model constraints and variables, as presented below.

1 Supply chain risk management strategies: GCG practices for supply chain operations management

From the perspective of agency theory, this study first addresses the principal–agent problem existing in a broader supply chain network and improves it by employing a specialist agency scheme in the governance of suppliers. Second, it investigates risks in each supply chain operational procedure and manages them by incorporating supply chain risk management strategies in the constraints—for example, capacity restriction in manufacturing and distribution risk strategies. The failure of risk management in operations may lead to unsatisfactory demand management, thereby ruining the company reputation. To incorporate risk management into the early stage of strategic planning, the constraints quantifying these risk management strategies in the planning model framework are required. Chapter 4 presents these constraints ('Constraints of the robust supply chain management and corporate governance model', Section C.1).

Further, supply chain performance measures, including ROA, revenue growth (change in revenue from a prior year) and inventory turnover, are incorporated into the model constraints for performance reflection on corporate governance incorporations. According to Hofman and Aronow (2012), ROA indicates overall operational efficiency and productivity, while revenue growth reflects the myriad market and organisational factors providing some clues to innovation. Inventory turnover is one of the few 'real' supply chain proxies shown on a company's balance sheet.

2 Corporate finance and accounting practices for corporate governance performance

A company's corporate governance performance influences its value and long-term profit for shareholders. These influences are considered from the perspectives of internal control and external control. GCG practice suggests that a company needs to comply with the business and regulatory environment (Farrar 2008). International control is 'established in order to provide reasonable assurance of effective and efficient operation, international financial control and compliance with laws and regulations' (Collier & Agyei-Ampomah 2008, p. 143).

Internal control as a constraint in the current study is reflected in the capital structure (debt and equity), investment decisions, management of bankruptcy risk and reputational risk. The policy for the capital structure is determined by the risk attitude of the companies' managers. They can have diverse construction of debt and equity. The policy incorporating debt holds managers accountable for generating cash to meet interest and principal obligations. Investment in supply chain system development is considered for long-term benefit and managed according to the company's capability. Bankruptcy risk is one of the biggest concerns for company shareholders and stakeholders. To protect the company from this risk, this model brings in a debt service constraint and a leverage constraint to support a healthy operational system. Reputational risk as discussed here refers to the protection of supply chain processes and keeping the operational chain and the financial chain stable in an uncertain environment. Corresponding constraints are delivered through the whole model framework, such as supply chain risk management strategies detailed in the previous section. This section presents reputational risk as managing working capital such that it meets customer requirements. Financial performance ratios discussed in Chapter 2, 'Proxies and ratios as corporate governance performance measurement for firm value', such as debt-to-equity ratio, are also transformed into constraints, which can help improve a company's financial performance.

In this study, GCG principles are incorporated through constraints that ensure the profitability and sustainability of the company's operating activities while reducing agency costs such as benefits from debt financing. Agency cost is one of the important components for measuring corporate governance performance. High agency cost leads to more risks, and such cost is considered in the optimal supply chain model. The risks may lead to a loss in the trust of the company in the market. The implementation of GCG practices can reduce agency cost. Agency cost is accounted for in the supply chain system. Agency problems in the supply chain system are reduced by increasing company trust and reputation in the market. For GCG performance, measures are incorporated as constraints in the model framework. As discussed in Chapter 2 ('Proxies and ratios as a corporate governance performance measurement for firm value'), ISRATIO is a ratio for measuring the operating efficiency of the company. A GCG and SCM system for a company requires a healthy operating margin that enables the company to pay for its fixed costs such as interest on the debt. The ratio is incorporated into the model framework to maintain a healthy operation and management system for the company.

Simulation and programming

Recent times have seen significant awareness of and progress in computational optimisation. Optimisation software has been deeply explored and widely used for both research and real-world application. Software categories are divided into optimisation solvers and optimisation modelling languages (Fabozzi 2007). According to Fabozzi (2007, p. 334),

> An optimization solver is software that implements numerical routines for finding the optimal solution of an optimization problem. Optimization modelling languages have emerged as user-friendly platforms that allow the users to specify optimization problems in a more intuitive generic fashion, independent of the specific algorithmic and input requirements of optimization routines.

Typically, optimisation languages automate the underlying mathematical details of the optimisation model formulation for solving the optimisation problem.

Existing tools for modelling uncertainty

For optimisation models, available computer platforms include MATLAB and IBM SAP. Popular software modelling languages include AMPL and GAMS. Widely used optimisation solvers are spreadsheet programs such as Microsoft Excel and Corel Quattro Pro. Other popular software programs include GPSS, ROME and AIMMS. Professional optimisation tools have been developed for specific purposes. For example, for modelling uncertainty in finance, there is SeDuMi, SDPTS, MOSEK and AXIOMA risk models (Cornuejols & Tutuncu 2007). To solve the SOCP problem, SeDuMi (computational research at Lehigh) or SDPT3 (MATLAB software for semidefinite-quadratic-LP) can be applied efficiently, as they are well designed for this type of problem.

Justification of the chosen software

In this research, optimisation solvers are applied to solve the new problem and model. The study aims to obtain the optimal and robust result to compare the performance of the old model with that of the new model.

For the proposed model, this study uses the Risk Solver Platform, as this integrates well with other commonly used business software programs. Modelling in the Risk Solver Platform offers a range of functions for a variety of model types, including Monte Carlo simulation, decision trees, powerful conventional optimisation, simulation optimisation and stochastic optimisation, with capabilities of up to 8,000 decision variables to deal with large-scale problems. It is offered by Frontline Systems Inc. and can be upgraded for further development. This platform is especially helpful for the purpose of risk analysis and optimisation. Moreover, it is visible and accessible for management accountants who are working on decision planning with spreadsheet modelling in Excel.

Introduction of Risk Solver Platform applied for optimisation model with uncertainty

1. Cell formulation and coding

   The cell functions are formulated based on the case needed and conditioned by the rules and scenarios. The main tool tabs of the applied software in this study are listed in the Risk Solver Platform function. The Risk Solver Platform can be found in the upper right corner of the tab options after installing the program.
2. Modelling: Solver options and model specifications

Brief instructions are presented below. Further details based on the models and cases presented in this study are explained subsequently in corresponding chapters. The main components are 'Model', 'Platform', 'Engine' and 'Output'.

a Model

This component is designed to set up the objective, constraints and variables for the model. There are five sections in the main frame: 'sensitivity', 'optimisation', 'simulation', 'decision trees' and 'input data'. This study uses the 'optimisation' section and the 'simulation' section. In the 'optimisation' section, the objective, variables (normal and recourse), constraints (normal, chance, bound, conic and integers) parameters and results are presented. The 'simulation' section contains uncertain variables, uncertain functions for the objective function, statistic function, correlation matrices and parameters. In this section, under the main frame, there is also the model diagnosis and variables–functions–dependencies tables to define more details for the proposed model.

b Platform

In this component, the implementation details are presented. There are seven sections that are updated as required: 'optimisation model', 'simulation model', 'decision tree', 'diagnosis', 'transformation', 'default bounds' and 'advanced'. In this study, the 'optimisation model', 'simulation model' and 'transformation' sections are defined based on different case situations. It starts with analysis in the 'optimisation model' and relates to the 'transformation' section.

The 'Optimisation to Run' function can support multiple parameterised optimisations of the problem. If an optimisation parameter is defined in a cell to be varied from a to b and is selected as the right-hand side (RHS) of a 'return threshold' constraint in the model, and the number set in this item is (say) *n*, the Risk Solver Platform would solve *n* number of optimisation problems. The 'reports' and 'charts' buttons on the menu are then used to examine results across all *n* optimisation problems.

'Solve Uncertain Models' has selections of 'Simulation Optimisation, Stochastic Transformation, Stochastic Decomposition, Automatic' to choose the method applied to deal with the uncertainty in the problem. For example, 'Simulation Optimisation' can handle nonlinear and non-smooth models but is also the slowest and least reliable. 'Stochastic Transformation' works only with linear models with uncertainty and uses stochastic programming or the robust optimisation method to solve the problem. 'Stochastic Decomposition' can deal with problems of uncertainty and recourse variables but does not support chance constraints or objectives depending on uncertain variables. To apply this, it must have recourse variables contained in uncertain constraints.

In the Risk Solver Platform, 'Stochastic Transformation' in the 'Transformation' section is active only if the last step of the problem sets 'Stochastic Transformation' in 'Solve Uncertain Models'. The options include 'Deterministic Equivalent, Robust Counterpart and Automatic'. Applying this option to determine the platform will solve the uncertainty problem by transforming the optimisation model with uncertainty into a conventional optimisation model without uncertainty or into the deterministic equivalent model (used in stochastic LP) or a robust counterpart model (as used in robust optimisation) (Frontline Solvers 2013a). If set into the default choice, 'Automatic', it will use the deterministic equivalent form if it includes recourse decisions and no chance constraint. Otherwise, it will use the robust counterpart form. In the same section, select 'Chance Constraints Use' to determine the norm, which measures distance. It is used to constrain the size of the uncertainty set in the robust counterpart model. The options include 'L1 Dorm, L2 Norm, L Inf (infinity) Norm or D Norm (the default)'.

In the 'Simulation Model' section, 'Use Interactive Optimisation' will ask for the selection from True or False. Set this option to 'True' to run an optimisation automatically whenever a change is made to the spreadsheet. This study sets it as 'False' to leave it unchanged until the run button is pressed. Then select 'Number of Threads' from 'False or True'. This option defines the number of threads of execution to be used for optimisation problems. This study sets 'False' for the hypothetical study later, meaning the number of threads should be determined automatically. The solver may use as many threads as this study has processor cores and allocates the threads for different purposes to achieve the fastest solutions.

c Engine

This component is for selecting the program engine to be used to solve the model. Engines available are Standard LSGRG Nonlinear Solver Engine, Standard LP/Quadratic Engine, Standard Evolutionary Engine, Standard Interval Global Engine, Standard SOCP Barrier Engine and Risk Solver Engine.

The Standard LP/Quadratic Engine finds optimal solutions to problems of simple linear constraints with linear or quadratic objective functions.

The SOCP Barrier Solver solves problems where objective and constraints are all-linear or convex quadratic functions of the variables. It also solves problems with a linear objective, linear constraints and second-order cone constraints. This differs from the LP/Quadratic Solver, which only allows the objective function to be quadratic (Frontline Solvers 2013b).

The Nonlinear GRG and LSGRG solvers find optimal solutions to problems where the objective and constraints are all smooth functions of the variables. They can be used on problems with all-linear functions, but they are much less effective and efficient than the LP/Quadratic Solver or the Solver Barrier Solver on such problems.

The Evolutionary Solver usually finds good solutions to problems where the objective and constraints include non-smooth or discontinuous functions of the variables—that is, where there are no restrictions on the formulae used to compute the objective and constraints.

d Output

The 'Output' component presents the results of the solving process and analysis if the procedure is unsuccessful or the problem is infeasible or for other problems.

3 Risk Solver Platform specified options for the cases

Under the 'Option' choice, the sections of simulation, optimisation, general, tree, bounds, charts, markers and problem are defined.

Under the 'Simulation' tab, choose 'Sampling Method' from Monte Carlo, Latin hypercube and Sobol RQMC. This study selects 'Latin hypercube', since Latin hypercube sampling is a statistical method for generating a sample of plausible collections of parameter values from a multidimensional distribution. The sampling method is often used to construct computer experiments. Another alternative option can be the Monte Carlo method. If this sampling method is applied, it generates numbers through the chosen Random Number Generators directly to obtain sample values for the uncertain variables (Psi Distribution functions) in the model. Then, choose from the options of Park-Miller, Combined Multiple Recursive Generator (CMRG), WELL and Mersenne Twister. Though computer-generated numbers are never truly 'random' (since they always follow an associated algorithm, being called pseudorandom numbers), the Random Number Generators can quickly generate a sequence of numbers that are close to being statistically independent. This can test the model in a simulated practical problem and improve the model if necessary before it can be applied to real cases. For choosing a generator, the length of the period and the degree of statistical independence achieved within the period will be considered and a trade-off will be reached based on the particular problem. This study applied CMRG of L'Ecuyer, which has a period of 2^{191} and excellent statistical independence of samples within the period. For the remaining tab settings, follow the standard steps.

Justification of data collection

This section discusses the criteria used for data collection. It justifies the data collection process applied in this research and presents the details of the data collection for the hypothetical case study.

The proposed model framework targets a global company with its own settled partners, and its physical chain involves procedures of manufacturing, inventory and transportation. The model framework aims to optimise the company's supply chain system with each stage, assembling plans while meeting the requirements of both specific company policies and customer demand. Potential outputs of the proposed plan include production quantity from the inventory; production quantity from manufacturing, including those satisfying demand (excludes the amount from inventory) and others required to meet the safety inventory; selected transportation type and routine; and cost for the whole supply chain.

As Calantone and Vickery (2009) stated, many empirical studies in SCM are based on the analysis of primary data. Typical methods for collecting primary data include research surveys/questionnaires, direct observations and case interviews. Another data resource is secondary data, which are publicly available. Applying secondary data removes the individual intention from the researcher. Moreover, many studies have applied machine-generated data, such as random data simulated for stochastic programming purposes (Kuchler & Vigerske 2010).

The aim of this study is to build up a new framework of strategic planning with SCM and corporate governance under uncertainty, and develop a corresponding mathematical modelling. The research concentrates on how to apply and improve the proposed new framework for the company through a robust optimisation approach. The focus is on the theoretical contribution of the framework and the corresponding optimal mathematical model. A hypothetical case study is taken as an example for application and an explanation is provided for how the model can work in industrial cases. Practical solutions for real companies can be achieved by incorporating specific company details of operational and financial issues in future applications. The current study uses simulated data based on heuristic data and historical experience. Operational supply chain data are seldom publicly available and are hard to obtain. Meanwhile, the purpose of the numerical case in this study is to explain how the model can be applied in practice and what results and implications can be achieved by using this model to create strategies in a company.

Based on the above discussion, the data for the hypothetical case study applied in this study are from two main resources: secondary data (case examples from previous studies such as Shapiro [2007] and Ragsdale [2012] and from industrial ratios) and simulated data. Data that cannot be obtained from public reports are simulated based on reasonable assumptions from previous studies. More details about data collection are presented in Chapter 5, 'Data collection and specify input data for the hypothetical case'.

Validation of the framework for generalisation and superiority of the model

Measurements

According to a popular management saying, 'what gets measured gets done' (Morin & Jarrell 2001). Developing a better supply chain network framework that considers GCG practices requires a good measurement and criteria system. An important criterion applied in this study is robustness in strategic decision-making for shareholders' long-term wealth creation, which combines strategic decision-making and robustness from various criteria for firm performance measures. To choose a suitable measurement, other criteria applied in this study are accuracy, which takes account of the amount and timing of future cashflows and relevant risks; performance measurement; complexity, which checks the measure to calculate and communicate with relevant stakeholders; and organisational levels (Morin & Jarrell 2001).

Shareholder value addition, which is defined as a corporate value less the value of debt, is recognised as a good metric to measure company performance (Morin & Jarrell 2001). The aim of this study is to achieve the best value for the long-term benefit of the company and shareholders' interests; therefore, the shareholder value addition is used to measure the efficiency of company performance. This study uses equity to represent shareholders' interests and impact on the company's long-term benefit. Using maximisation of equity as the objective function, this study aims to achieve maximum shareholders' value while improving company performance. This study also incorporates agency ratios such as ROA, ROE and the company performance measure ISRATIO into the constraints to further improve the RSCMCG model framework.

The two aspects of GCG practices—risk management and value creation—are incorporated into the supply chain network model. For a supply chain model to manage risk, it is important to set up the appropriate proxies or indicators for them. In addition, the decision strategies to manage the risks are incorporated as constraints in an optimal supply chain model.

Validation and verification

Verification is the process of examining the model's internal consistency to ensure that it is computationally correct and does not contain errors of both omission and commission. Validation is to ensure its external or representational correctness. Two validation approaches may be used: validation by construct and validation by results (McCarl & Spreen 1997).

According to McCarl and Spreen (1997, pp. 18–22), validation by construct is justified by one of several assertions about modelling: the right procedures were used by the model builder; trial results indicate the model is behaving satisfactorily; constraints were imposed that restrict the model to realistic solutions; the data were set up to replicate the real-world outcome.

Validation by results involves five steps: first, a set of real-world outcomes and the data causing that outcome are gathered; second, a validation experiment is selected; third, the model is set up with the appropriate data, the experiment is implemented and a solution is generated; fourth, the degree of association between model output and the real-world outcome is tested; and, finally, a decision is made regarding model validity (McCarl & Spreen 1997, pp. 18–23). Parameter outcome sets show that the model should contain outcome parameters, which reflect the behaviour of the observed objective system or environment. A good model needs to have the outcome parameter(s). Five general validation experiments are the feasibility experiment, the quantity experiment, the price experiment, the prediction experiment and the change experiment (McCarl & Spreen 1997).

A validation test can be descriptive, analytical and experimental. After discussing the validation process, McCarl and Spreen (1997) suggest the steps for conducting validation tests: first, adjust the model variables, equations/constraints and data to reflect the validation experiment; second, run the model and obtain the solution; finally, evaluate the solution.

Further, validations of the model and result can be undertaken at the descriptive and analytical levels. The descriptive level is 'the attainment of the objectiveness of the model, the appropriateness of the model structure and the plausibility of the results'; the analytical level is 'the characteristics of model solutions and the robustness of the results' (Islam & Mak 2006). The details of validation for the model of this study are presented in Chapter 5, 'Plausibility of the robust optimisation approach and results: Generalisation'.

Superiority of the proposed framework

This study proposes a new framework for decision-making under uncertainty through robust optimisation by integrating SCM with corporate governance (RSCMCG). This new framework, followed by models, extends the existing literature and methods in the following ways:

1. It proposes an integrated framework for SCM with GCG practices for risk management strategies, such as suppliers' relationship and allocation, manufacturing package capacity, safety stock and demand satisfaction reputation.
2. It brings corporate financial management into supply chain planning for improving performance and decision-making considerations—for example, debt limitation, equity and debt balancing and long-term investment decisions.
3. It develops a robust optimisation approach for the proposed framework, improved with risk preference considerations and stable strategies.

4 It concludes with a robust optimisation supply chain model by integrating corporate governance and provides strategic solutions for operational planning and financial planning from a new view of risk management.

Conclusion

This chapter discussed SCM and corporate governance theories and set the theoretical framework for this study. It also examined the interaction between supply chain and corporate governance from the perspectives of risk management and decision-making. An integrative conceptual framework was proposed for combing supply chain operational procedures with corporate governance factors to improve firm performance. The relationship between risk management and corporate governance with respect to SCM was discussed to understand how to combine both factors in an integrated model. The proposed RSCMCG framework connecting supply chain and corporate governance is shown in Figure 3.1. Chapter 4 further presents the considered parameters, variables and constraints and computations of the model in a mathematical format for the numerical implementation of the model and as the computational intelligence used in this book.

The following framework discussion is a detailed description of the methodology. It investigates the concept of robust optimisation applied in this study and the incorporation of risk management into constraints. Robust optimisation is a mathematical method applied in this study. Its basic foundations, forms, approaches and algorithms are introduced. More application examples are provided to show the flexibility and robustness of the method. The justification for the methodology applied in this research is also given. This is followed by the quantification framework and specified details for modelling, which are the foundation for modelling supply chain and corporate governance into a mathematical form.

The computer programming of the solver platform and data sources from different resources are also discussed to briefly introduce the way they are implemented. The Risk Solver Platform is used for its practical realisation of robust problems. Various parameters, variables and constraints are identified, conceptualised and measured. Finally, the validation process and superiority of the proposed RSCMCG framework are presented.

Notes

1 Including manufacturing, distribution, inventory and marketing.
2 These theories are discussed in Chapter 2, 'Supply chain management theories development and research streams for forming a supply chain framework'.

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4 Robust optimisation model for supply chain management and corporate governance

Introduction

Following the proposed conceptual framework for integrating supply chain management (SCM) and good corporate governance (GCG) practices for risk management and methods in the previous chapter, this chapter presents a robust optimisation model for supply chain management and corporate governance (RSCMCG) and corresponding solutions for supply chain decision-making under uncertainty.

The RSCMCG model is a principal–agent game theory model as it represents the interests, goals and strategies of both the principal and agent by the objective function (the objectives of the principal) and constraints (the requirements of the principal from the agent, conditions on the behaviour of the agent, the mechanisms for resolving the agency conflicts, the agent's own constraints on SCM, etc.) of the model.

Details of the mathematical presentation of the model for the proposed integrated supply chain decision-making framework are presented and discussed, as are the elements of the RSCMCG model for being an artificial intelligence algorithm. Here, the policies and rules of relevant financial planning and GCG practices are incorporated into a supply chain operation system to improve supply chain performance.

Starting with a supply chain deterministic optimisation model, this study investigates the requirements for an integrated SCM that provides an optimal solution for strategic planning in which GCG policies and principles are linked to the operational aspect of the company's supply chain networking. Considerations including supply chain risk management strategies, agency problems, sustainable development and long-term benefit are quantified and incorporated into the model using variables, objective functions and constraints. Following this, a robust optimisation model (RSCMCG) is built to solve the supply chain problems under uncertainty and thus to improve supply chain performance with robustness and optimality.

In this study, physical and financial flows of a supply chain network are integrated into an optimisation model, taking into account shareholders' long-term interests for strategic decision-making in an uncertain

DOI: 10.4324/9781003266457-4

environment. Regarding the materials domain, the proposed model draws constraints of manufacturing, inventory, transportation and market into an integrated network to capture the solution for the operational quantities of production and shipping as well as goods in safety stock. GCG practices, including supply chain risk management and corporate financial practices such as consideration of the agency problem and internal control, are incorporated into the model constraints. Measures on corporate governance performance, such as ROA, are incorporated into the constraints to improve supply chain performance. This study further develops the RSCMCG model by considering the uncertainties in the supply chain environment, such as packaging coefficients in manufacturing procedures, and by incorporating decision-makers' risk preference.

This chapter addresses the proposed model framework in mathematical format and with a corresponding narrative. It first introduces the background for the targeted problems. Next, it illustrates the details of the proposed RSCMCG model, including the objective function, and the constraints for supply chain operations and financial management together with GCG practices for risk management strategies. It then updates the RSCMCG model with concerns in uncertainties through a robust optimisation approach and presents the corresponding algorithm and simulation. The chapter is then summarised.

Problem background and statement of the model

This section introduces the background of the proposed integrated robust SCM and corporate governance for risk management (RSCMCG) model framework. The proposed RSCMCG model framework is constructed by extending the supply chain basic model and framework from Shapiro (2007) and Ragsdale (2012). The proposed model is also influenced by Williams (2013), who provided guidance regarding the use of constraints for productive capacity, raw materials, marketing, material balance and quality of the productions.

Overall, this study is dedicated to building a model that integrates all the processes of supply chains: procedures of production, inventory, distribution, transportation and marketing. The purpose of the model is to give decision-makers a sound basis for strategic planning in the firm. This study concentrates on incorporating corporate governance strategies into the supply chain model through a robust optimisation method; it does not explore details of each process in depth. For example, in a discussion of the manufacturing plan, this study pays more attention to the performance by considering the machinery capacity as a whole parameter instead of considering every single-node performance for each manufacturing line (Lee & Billington 1993). This model focuses on the key issues regarding constraints for strategic-level decision-making; the objective is to maximise the final equity of the company, which is of interest to shareholders.

Problems that the model investigates include the following: identifying production sites, manufacturing quantities and the level of outsourcing, if necessary; determining optimal safe inventory level, a function of considering the demand, its replenishment lead time and the service level; making decisions about transportation needs and alternatives from the supply chains; handling financial matters regarding investment decisions on expansions and debt; determining the strategies for risk management as it relates to factory closure, transportation failure and fluctuation of packaging coefficients.

The assumptions for the targeted RSCMCG model framework are as follows: people behave rationally; the model follows the features of a choice-based system; people have risk partiality. Assuming that decision-makers are risk-averse, then their certainty equivalent for a given risky prospect is less than its expected value. It averages the utilities associated with monetary values (Samuelson & Marks 2006).

The targeted supply chain system for a company has the following features: different production plants for alternative manufacturing purposes, with separate capacity limitations; the supply chain frame has a transportation system to ensure that shipping volumes do not exceed production; it combines make-to-order and make-to-stock systems to complete orders immediately; it is assumed that the safety stock is held for the inventory of downstream participants, such as distribution warehouses and retailers; overtime hours are positive or zero; shipping costs for raw materials are allocated to suppliers and not included in this model; duties and tariffs are based on general industrial rules; the focus is on uncertainty in the supply chain operational system; therefore, not all types of uncertainties are included in the model. The purpose of this study is to improve supply chain performance supported by GCG practices.

In the proposed RSCMCG model, preconditions are represented by choice-based approaches, which are superior to rule-based approaches because they explore the space of possible decisions to produce better decisions (Shapiro 2007, p. 560). In a choice-based model, sets of feasible consequences are described by constraints on elements of the supply chain process, such as ordering requirements, goods details, obtainable resources and transportation restrictions (Shapiro 2007). Mathematical methods and optimisation algorithms are used in this context to find optimal solutions for decision-making preferences.

Integrated robust supply chain management and corporate governance model for risk management

The research considers corporate planning from strategic and tactical perspective. At the strategic level, the company in the global supply chain industry needs to combine the corporation's visions and policies, such as corporate governance structure and shareholders' interests, into the development strategy of the next three years or more. Therefore, the decision-maker needs to employ a framework that considers not only the supply chain industry environment but also corporate governance factors. At the tactical level, with the help of well-developed theories and guidelines, this research includes the analysis of a corporation's corporate governance elements, which are then quantified into the supply chain model through optimisation modelling.

The objective of this modelling exercise is to maximise company profit. For a supply chain operation company, strategic planning decisions include production allocation decisions, machine scheduling decisions, transportation choices and distribution decisions, inventory strategies, marketing strategies and financial management. This model is also presented as a principal–agent model, which focuses on simple and generalised principal–agent problems with agency cost.

The RSCMCG model is developed as an artificial intelligence and machine-learning algorithm following the standard formats and practices of the literature in these areas, such as:

1 This model is a new computerised model implemented by a search algorithm in Excel for developing an artificial intelligence/machine-learning algorithm for applications in SCM, as this type of model has not previously existed.
2 The model and algorithm address a set of complex relationships in the area of study in this book.
3 The model is being developed and used for decision-making (optimal supply chain strategies and corporate governance mechanisms), doing a task (risk management) and predicting the performance of the supply chain operations and corporate governance relationships.
4 The findings of the RSCMCG model are generated for the general implications of the issues discussed in the book.
5 Generalisation, the out-of-sample testing, overfitting and similar types of issues have been addressed by formal model validation exercises.
6 General hypothetical data have been used to create the algorithm and learning in the model.

This section proposes incorporating GCG practices into an optimal supply chain model and demonstrates the detailed specifications. Viewing SCM networking as a collaborative relationship, it has a core company taking the key coordinating role and cooperating closely with its partnerships that involve manufacturing, shipping, inventory and marketing. The efficient interactions with partnerships in this network become an important element in achieving better supply chain performance and reducing inefficiencies (McWatters, Zimmerman & Morse 2008). The idea in this study is to apply GCG practices and risk management strategies to SCM via a numerical model that has broad application to supply chain networking.

Objective function of the robust supply chain management and corporate governance model

The objective function of this RSCMCG model incorporates GCG practices and financial planning for the purpose of risk management. Four of the essential principles proposed by the ASX Corporate Governance Council (2007) are included in the model: respect the rights of shareholders; recognise and manage risk; encourage enhanced performance; and recognise the legitimate interests of stakeholders. Following these principles, the supporting theories are agency theory and stakeholder theory. GCG principles achieve robust results that are not sensitive to changes, especially from the perspective of the supply chain, while bringing in decision-makers' risk preferences together with corporate governance policies towards risk. Equity as a proxy of shareholders' interests represents long-term benefit for shareholders in the company. The maximum of shareholders' long-term benefit is considered the objective of the strategic planning model. Therefore, this study sets equity as the objective, which connects with supply chain operations through EBIT in the definitional supply chain operational and financial equations. Mathematically, this is presented as follows.

Objective function:

$$Max\ f(equity) = Z(t)_E = Z(1)_E + \sum_t \left[\Delta Z(t)_E\right] \tag{4–1}$$

where:

f(equity): equity value of the firm
$Z(t)_E$: equity; refers to the value of shareholders' interests in the firm at time period t
Δ: refers to the change of the variable during the time period

The GCG practices are reflected in this objective function. GCG ensures the fulfilment of the return to shareholders, which is reflected as the maximisation of equity. GCG ensures the fulfilment of the return to debt-holders, which includes minimisation of the financial distress and bankruptcy risks and is reflected as long-term debt $Z(t)_L$, the return for debt-holders in the equation for obtaining the equity (see Equation 4–4 for details).

Constraints of the robust supply chain management and corporate governance model

This section presents the constraints included in the proposed model. Some are not considered in the hypothetical case study in the next chapter (these are the equation numbers with asterisks).

A. Definitional supply chain operational and financial equations
The objective function is subject to the following constraints:

$$Z(t)_{CA} + Z(t)_{FA} - Z(t)_{CL} - Z(t)_{L} - Z(t)_{E} = 0 \qquad (4\text{–}2)$$

$$\Delta Z(t)_{CA} + \Delta Z(t)_{FA} - \Delta Z(t)_{CL} - \Delta Z(t)_{L} - \Delta Z(t)_{E} = 0 \qquad (4\text{–}3)$$

$$\begin{aligned}\Delta Z(t)_{E} &= Z(t)_{PR} - Z(t)_{D} \\ &= (1 - r_{PR})[EBIT(t) - i(t)_{IrD} * Z(t)_{L}] - Z(t)_{D}\end{aligned} \qquad (4\text{–}4)$$

$$Z(t)_{PR} = (1 - r_{PR})[EBIT(t) - i(t)_{IrD} * Z(t)_{L}] \qquad (4\text{–}5)$$

$$\begin{aligned}&\Delta Z(t)_{CA} + \Delta Z(t)_{FA} - \Delta Z(t)_{CL} - \Delta Z(t)_{L} \\ &\quad - (1 - r_{PR})\left[EBIT(t) - i(t)_{IrD} * Z(t)_{L}\right] + Z(t)_{D} = 0\end{aligned} \qquad (4\text{–}6)$$

where:

$Z(t)_{CA}$: current assets; refers to liquid assets such as cash, inventories or accounts receivable at time period *t*
$Z(t)_{FA}$: fixed assets; refers to illiquid assets such as plants or equipment at time period *t*. Intangible assets, such as customer goodwill or a cadre of superior design engineers, among the fixed or current assets are not included here
$Z(t)_{CL}$: current liabilities; refers to short-term liabilities such as accounts payable or payroll at time period *t*
$Z(t)_{L}$: long-term debt; refers to long-term bank loans or bonds at time period *t*
$Z(t)_{E}$: equity; refers to the value of shareholders' interests in the firm at time period *t*
$Z(t)_{PR}$: after-tax profits at time period *t*
$Z(t)_{D}$: dividends paid to shareholders at time period *t*
$EBIT(t)$: EBIT at time period *t*
r_{PR}: corporate tax rate during time period *t*
$i(t)_{IrD}$: interest rate of company's long-term debt at time period *t*
Δ: denotes the change of the variable during the time period

More explanations for the above financial definition constraints are presented in Section B.2. From Equation (4–4), the objective function (4–1) is updated as follows:

$$\begin{aligned}Max\ f(equity) &= Z(t)_{E} = Z(1)_{E} + \sum_{t}\left[\Delta Z(t)_{E}\right] \\ &= Z(1)_{E} + \sum_{t}\Big\{(1 - r_{PR}) \\ &\quad \times \left[EBIT(t) - i(t)_{IrD} * Z(t)_{L}\right] - Z(t)_{D}\Big\}\end{aligned} \qquad (4\text{–}1')$$

EBIT in this function connects supply chain operational procedures with financial planning. It is calculated by the difference between revenue on sales and all the supply chain costs, including manufacturing cost, inventory cost, transportation cost and agency cost. Agency cost, C_{AC}, which affects the principal–agent problem, is taken into account and depends on the company's policy and strategy. Mathematically, *EBIT* is expressed in the following form:

$$EBIT(t) = R(t)_{sale} - \left[C(t)_{MA} + C(t)_{Inv} + C(t)_{TR}\right] - C(t)_{AC} \tag{4-7}$$

where:

$EBIT(t)$: EBIT at time period *t*
$R(t)_{sale}$: revenue at time period *t*
$C(t)_{MA}$: manufacturing cost at time period *t*
$C(t)_{inv}$: inventory cost at time period *t*
$C(t)_{TR}$: transportation cost at time period *t*
$C(t)_{AC}$: agency cost at time period *t*

In this equation, R_{sale} is the revenue on sales calculated from each market and depends on the individual sale price. C_{MA} is calculated from the multiplication of unit manufacturing cost and corresponding produced quantity. Similarly, transportation cost C_{TR} and inventory cost C_{inv} are generated. C_{AC} is considered in the context of agency cost applied under GCG practices. Symbolically, at time period *t*, it can be presented as follows:

$$R(t)_{sale} = \sum_{k}\left[X(t)_{sold_k} * c(t)_{sold_k}\right] \tag{4-8}$$

$$C(t)_{MA} = \sum_{k} C(t)_{MA_k} = \sum_{k}\left[c(t)_{MA_k} * X(t)_{qMA_k}\right] \tag{4-9}$$

$$C(t)_{TR} = \sum_{k}\sum_{m,n}^{M,N}\left[Y(t)_{qTR_{k_{mn}}} * c(t)_{TR_{k_{mn}}}\right] \tag{4-10}$$

$$C(t)_{inv} = \sum_{k}\sum_{j}\left[c(t)_{invjk} * X(t)_{invjk}\right] \tag{4-11}$$

where:

$R(t)_{sale}$: revenue at time period *t*
$X(t)_{sold_k}$: sold quantity for item *k*
$c(t)_{sold_k}$: sold price per unit for item *k* at time period *t*
$C(t)_{MA}$: manufacturing cost at time period *t*
$C(t)_{MA_k}$: total manufacturing cost for item *k* at time period *t*

$c(t)_{MA_k}$: manufacturing cost per unit for item k at time period t
$X(t)_{qMA_k}$: production quantity of item k at time period t
$C(t)_{TR}$: transportation cost at time period t
$Y(t)_{qTR_{k_{mn}}}$: shipping quantity of item k from place m to n at time period t after extension
$c(t)_{TR_{k_{mn}}}$: shipping cost per unit of item k from place m to n at time period t
$C(t)_{inv}$: inventory cost at time period t
$c(t)_{invjk}$: inventory cost per unit of item k in distribution centre j at time period t
$X(t)_{invjk}$: ending inventory for item k of the distribution centre j at time period t

The extension of the optimal supply chain model using GCG practices is reflected in the supply chain component and corporate governance for the risk management component. The supply chain component includes the supply chain operational system and financial planning, while the corporate governance for risk management component has GCG practices for supply chain operations and corporate governance performance policies including internal control and the principal–agent problem.

B. SCM and financial management equations
B.1 Supply chain operational equation constraints
This section discusses constraints on supply chain operations, including manufacturing, shipping balance, mass balance, inventory and marketing equations.

1 Manufacturing function

The manufacturing balance equation is defined for obtaining the manufacturing cost amount, and it equals the unit cost multiplied by production quantity, presented in Equation (4-9). The unit cost is given by the manufacturing factory while the production quantities are decision variables from supply chain planning. To manage the marketing risk mentioned in C.1, this study also considers the indexation in manufacturing cost, which is recoded as r_{MA_k} to manage the marketing risk of raising cost. Therefore, the manufacturing cost Equation (4-9) is updated as follows:

$$
\begin{aligned}
C(t)_{MA} &= \sum_k \left[X(t)_{qMA_k} * c(t)_{MA_k} \right] \\
&= \sum_k \left[X(t)_{qMA_k} * c(0)_{MA_k} * \left(1 + r_{MA_k}\right)^{t-1} \right] \qquad (4\text{-}9.1)
\end{aligned}
$$

where:

$C(t)_{MA}$: manufacturing cost at time period t
$X(t)_{qMA_k}$: production quantity of item k at time period t
$c(t)_{MA_k}$: manufacturing cost per unit for item k at time period t
$c(0)_{MA_k}$: manufacturing cost per unit for item k at the beginning
r_{MA_k}: annual increasing rate of manufacturing cost per unit for item k

A further investment decision for production line expansion is considered. A company's production line expansion decision depends on investment availability and the profits earned in the previous year.

$$Y(t)_{qMA_k} = X(t)_{qMA_k} + Y(Ex - t)_{qMA_k} \quad \text{(4-12*)}$$

where:

$Y(t)_{qMA_k}$: final manufactured quantity of item k after production line expansion at time period t; it equals $X(t)_{qMA_k}$ if there are no expansions in production line plan
$X(t)_{qMA_k}$: production quantity of item k at time period t
$Y(Ex - t)_{qMA_k}$: expansion quantity decision for the production line to produce item k at time period t

Considering the increasing rate of unit manufacturing cost in Equation (4-9.1) and investment extension decision in Equation (4-12*), an updated equation for the manufacturing cost definition constraint Equation (4-9) is as follows:

$$C(t)_{MA} = \sum_k C(t)_{MA_k}$$

$$= \sum_k \left[c(0)_{MA_k} * (1 + r_{MA_k})^{t-1} * Y(t)_{qMA_k} \right] \quad \text{(4-9.1'*)}$$

where:

$C(t)_{MA}$: manufacturing cost at time period t
$C(t)_{MA_k}$: total manufacturing cost for item k at time period t
$c(0)_{MA_k}$: manufacturing cost per unit for item k at the beginning
r_{MA_k}: annual increasing rate of manufacturing cost per unit for item k
$Y(t)_{qMA_k}$: final manufactured quantity of item k after production line expansion at time period t; it equals $X(t)_{qMA_k}$ if there is no expansion in production line plan

2 Shipping balance

From manufacturing to the market, different shipping lines complete the distribution task.

$$\sum_{k}\sum_{m,n}^{M,N}\theta_{k_{mn}}Y(t)_{qTR_{k_{mn}}} = Y(t)_{qTR_{mn}} \quad (4\text{–}13)$$

where:

$\theta_{k_{mn}}$: the proportion of total shipped amount for each shipping line from place m to n of item k

$Y(t)_{qTR_{k_{mn}}}$: shipping quantity of item k from place m to n at time period t

$Y(t)_{qTR_{mn}}$: total shipping quantity amount from place m to n at time period t

Considering the increasing rate of shipping cost per unit in each year, Equation (4–10) for the expense on transportation is therefore updated as follows:

$$C(t)_{TR} = \sum_{k}\sum_{m,n}^{M,N}\left[Y(t)_{qTR_{k_{mn}}} * c(0)_{TR_{k_{mn}}} * \left(1 + r_{TR_{mn}}\right)^{t-1}\right] \quad (4\text{–}10.1)$$

where:

$Y(t)_{qTR_{k_{mn}}}$: shipping quantity of item k from place m to n at time period t after extension

$c(0)_{TR_{k_{mn}}}$: shipping cost per unit of item k from place m to n at the beginning

$r_{TR_{mn}}$: annual increasing rate of transportation cost per unit at the shipping line from place m to n

3 Mass balance

The following equations are designed for the mass balance, which shows that the demand request is fulfilled by the manufacturing and inventory channel. The ending inventory for the present period is equal to the storage after fulfilling demand with stock from the previous period and present period manufacturing. Mathematically, it is presented as follows:

$$X(t)_{invjk} = X(t-1)_{invjk} + Y(t)_{qTR_{k_{mn}}} - D(t)_{M_k^i} \quad (4\text{–}14)$$

where:

$X(t)_{invjk}$: ending inventory for item k of the distribution centre j at time period t

$X(t-1)_{invjk}$: ending inventory of the distribution centre j for item k at the time period $t-1$, equal to starting inventory of the distribution centre j at time period t

$Y(t)_{qTR_{k_{mn}}}$: shipping quantity of item k from place m to n at time period t after extension

$D(t)_{M_k{}^i}$: demand for item k from the market M^i at time period t

4 Inventory expense

This calculates the stocking cost of goods and is equal to the unit stocking expense multiplied by the quantity to stock. This constraint considers the increasing rate in inventory unit cost. The total inventory cost Equation (4-11) is then updated as follows:

$$C(t)_{inv} = \sum_j \left[c(0)_{invj_k} * \left(1 + r_{invj}\right)^{t-1} * X(t)_{invj_k} \right] \tag{4-11.1}$$

where

$C(t)_{inv}$: inventory cost at time period t

$c(0)_{invj_k}$: inventory cost per unit of item k in distribution centre j at the beginning

r_{invj}: annual increasing rate of inventory cost on per unit at the distribution centre j

$X(t)_{invj_k}$: ending inventory for item k of the distribution centre j at time period t

5 Marketing equation

Sales revenue is calculated by multiplying quantity sold and unit cost. Sales quantities here are based on the demand from marketing, with sales prices and operational costs settled by long-term contracts. Sold quantity $X(t)_{sold_k}$ equals the demand from markets $D(t)_{M_k{}^i}$ in the definition Equation (4-8), and considers the increasing rate on unit sold price. The updated marketing equation is as follows:

$$R(t)_{sale} = \sum_k \left[D(t)_{M_k{}^i} * c(t)_{sold_k} \right]$$
$$= \sum_k \left[D(t)_{M_k{}^i} * c(0)_{sold_k} \times (1 + r_{sold})^{t-1} \right] \tag{4-8.1}$$

where:

$R(t)_{sale}$: revenue at time period t

$X(t)_{sold_k}$: sold quantity of item k at time period t

$D(t)_{M_k^i}$: demand for item k from the market M^i at time period t
$c(t)_{sold_k}$: sold price per unit for item k at time period t
$c(0)_{sold_k}$: sold price per unit of item k at the beginning
r_{sold}: annual increasing rate of sold price

B.2 Financial planning constraints

In this study, financial elements from the company's financial flow are incorporated into the proposed supply chain model. This model focuses on incorporating GCG practices and investigates their impact on supply chain performance. Financial planning is established to support the aim of bringing long-term benefit to the company. This study focuses on the generalised model framework for this incorporation and investigation. The financial information can be obtained from the balance sheet and can be further extended with specifications for subcategories of the financial environment.

1 Financial balance

Financial balance constraint states the cashflow equations, which implicitly indicate the equity changes. Equity is defined as the difference between assets and liabilities (Shapiro 2007). Mathematically, it is presented in Equation (4-2) in Section A.

2 Funds flow equation

The funds flow equation shows the accounting relationship used in the balance sheet for the targeted years for all the financial data collected (Shapiro 2007). This equation also links the financial decision with supply chain decisions through $EBIT(t)$ and corporate financial planning with $\Delta Z(t)_{FA}$, $Z(t)_{Inv/CA}$, finally $Z(t)_E$. Specifically, $EBIT(t)$ presents the net revenue from marketing and supply chain activities with agency cost for the time period t. Investment from a current asset $Z(t)_{Inv/CA}$ into fixed assets aims to enhance the long-term profitability of the firm. For example, the investment in factory equipment is to increase the annual manufacturing capacity. The increasing stability of final equity refers to the long-term profit and value of shareholders' interests in the firm (Shapiro 2007). Managers might impose policy constraints on after-tax profits $Z(t)_{PR}$ and dividend $Z(t)_D$ over several years of a strategic planning horizon to reassure stockholders of the company's market value. Mathematically, they appear as equations (4-3–4-6).

Change in equity is given by the difference between after-tax profit and dividend paid to shareholders in Equation (4-4). After-tax profit $Z(t)_{PR}$ is calculated from the EBIT and long-term debt. Equation (4-5) describes the after-tax profits in terms of $EBIT(t)$. Equation (4-6) is the funds flow for the company.

3 Investment balance

GCG practices ensure that the company has a positive return on its investment decisions through the constraint of investment from current assets. This constraint shows that the allocations of the investment cashflow into fixed assets are mainly from two sources: current assets and long-term debts. It is designed to ensure that the amount of current assets is allocated to the investment for fixed assets development. Similarly, it restricts the amount from long-term debt. Symbolically, it is represented as follows:

$$\Delta Z(t)_{FA} = \Delta Z(t)_L + Z(t)_{Inv/CA} \tag{4-15}$$

where:

$\Delta Z(t)_{FA}$: change in the amount on the fixed asset at time period t
$\Delta Z(t)_L$: change in the amount on long-term debt at time period t
$Z(t)_{Inv/CA}$: investment from current assets at time period t.

4 Expansion expense

In addition to the investment cashflow policy above, the company can also put an operational policy in place for allocations arrangement of the investment into manufacturing expansion. This incorporation of the policy into the model can protect expansion in fixed assets at a certain level that avoids the risk from faulty conditions while maintaining sustainable development. It ensures that the company does not over-expand or under-invest. As a point of this case, the expansion policy in the production line capacity can be promoted. Mathematically, it is presented as follows:

$$\begin{aligned} C(t)_{MA^{\exp and}} &= \sum_k C(t)_{MA^{\exp and}_k} \\ &= \sum_k \left[Y(Ex-t)_{qMA_k} * c(t)_{MA^{\exp and}_k} \right] \end{aligned} \tag{4-16}$$

where:

$C(t)_{MA^{\exp and}}$: expenses on the expansion of the new production line at time period t
$C(t)_{MA^{\exp and}_k}$: expenses on the expansion of the new production line for item k at time period t
$Y(Ex-t)_{qMA_k}$: expansion quantity decision for the production line to produce item k at time period t
$c(t)_{MA^{\exp and}_k}$: unit cost on the new production line expansion for item k at time period t

C. Corporate governance policies: Risk management for SCM and accounting policy

As discussed in Chapter 2, ‘Measures for supply chain performance’, supply chain performance has been measured by revenue growth, flexibility, lead time and cost. These require a company to maximise revenue while keeping a stable system for growth, flexibility for unexpected demand and capable transportation systems to be competitive and minimise operational cost. GCG practices suggest that risk management needs to be incorporated into the system. Specifically, there are two crucial components: optimal supply chain risk management strategies and corporate governance performance considerations. The details are presented below.

C.1 GCG practices for optimal supply chain operational management from a risk management strategies perspective

This study improves supply chain performance by introducing GCG practices. In the supply chain context, corporate governance has been broadened to be a unified social platform. This study considers the whole supply chain network of the company as a systematic frame, with all the participants involved in the supply chain decision-making model.

1 Supply chain specialised agent governance

A global company with a large supply chain network will face significant risk if it keeps its production commitment to one manufacturing supplier. If this unique supplier fails to meet orders, it can lead to bankruptcy. Wherever manufacturing capacity exceeds demand, it also creates the risk of destroying the company's reputation, as orders are not fulfilled.

Specialised agencies are designed to promote efficiencies in the supply chain operations of this system, considering multi-partners (suppliers) in the conduct of supply chain operational procedures. It can improve supply chain flexibility and capability. However, it may lead to the principal–agent problem, which has the following features: have one core supplier's agent, and have a professional company that works as an agent and helps different production factories or shipping agents manage logistics expenses economically. In this study, to maintain stable production progress, multiple manufacturer networks are brought into this model planning. Splitting the production task across different manufacturing factories can protect the company from unexpected rises in market demand and reduce the likelihood of incomplete manufacturing orders. Consequently, the manufacturing task is divided into multiple lines to split the risk of failure. Decision variable $X(t)_{qMA_k}$ in Equation (4-9) is for calculating C_{MA}. In updating the consideration of diverse options for manufacturing factories, which individually is represented as *i*, Equation (4-17) has been developed to express this multiple-partner selection:

$$X(t)_{qMA_k} = \sum_{i}\sum_{k} \alpha_{i_k} X(t)_{qMA_k{}^i} \tag{4-17}$$

Similarly, the multiple-partner selections equation constraint is developed for distribution:

$$Y(t)_{qTR_{mn}} = \sum_{i}\sum_{k} \beta_{i_k} Y(t)_{qTR^{i}{}_{k_{mn}}} \tag{4-18}$$

where:

$X(t)_{qMA_k}$:	production quantity of item k at time period t
α_{i_k}:	the coefficient for item k produced by factory i
$X(t)_{qMA_k{}^i}$:	quantity of item k produced in factory i at time period t
$Y(t)_{qTR_{mn}}$:	total shipping quantity amount from place m to n at time period t
β_{i_k}:	the coefficient for item k shipped through shipping agent i
$Y(t)_{qTR^{i}{}_{k_{mn}}}$:	shipping quantity of item k from place m to n by shipping agent i at time period t

In addition, significant risk arises if the company keeps only a single raw material supplier. Therefore, multiple supplier networks can be also brought into decision-making planning. Consequently, the raw materials supply task is divided into several lines to split the risk of failure.

$$X(t)_{qMA_k} = \sum_{k} X(t)_{rm_k} \tag{4-17.1*}$$

where:

$X(t)_{qMA_k}$:	production quantity of item k at time period t
$X(t)_{rm_k}$:	raw material requirements from manufacturing factories for each item k at time period t.

2 Risk management strategies for supply chain operational system

The supply chain optimisation model framework is extended for company strategic decision-making by combining corporate governance principles or policies and risk management strategies. Accordingly, the proposed model is further investigated under uncertainty and still generates optimality in a fluctuating environment. To achieve this purpose, risk and corporate governance factors need to be considered and clarified.

a Manufacturing risk management strategies

For risk management, two key issues in the governance of manufacturing are considered in this model: capability of manufacturing factories and assembly labour capacity. GCG practices lead to the policy of stable manufacturing under capacity restriction. This study considers dividing the manufacturing task into several factories (or production lines, in other cases), thus mitigating the risk of total production failure. In addition, no single factory or production line is permitted to exceed its manufacturing capacity. Depending on the investment amount from current assets into improving or expanding fixed assets, the manufacturing capacity of each factory increases every year under the corresponding rate r_{capfac_k}. Mathematically, the constraint is formulated as follows:

$$X(t)_{qMA_k} \leq CAP(t)_{fac_k} = CAP(0)_{fac_k} * (1 + r_{capfac_k})^{t-1} \tag{4-19}$$

where:

$X(t)_{qMA_k}$: production quantity of item k at time period t

$CAP(t)_{fac_k}$: manufacturing capacity of a factory to produce item k at time period t

$CAP(0)_{fac_k}$: manufacturing capacity of a factory to produce item k at the beginning

r_{capfac_k}: annual increasing rate of manufacturing capacity for item k

The factory's manufacturing capacity is assumed to be fixed in the absence of further investment. In addition, with the limited available raw material resources for manufacturing at a certain time period, it may also have restrictions:

$$X(t)_{qMA_k} = \sum_i X(t)_{rmk_i} \leq R_{rm_k} \tag{4-19.1*}$$

where:

$X(t)_{qMA_k}$: production quantity of item k at time period t

$X(t)_{rmk_i}$: raw material i required for item k at time period t

R_{rm_k}: the availability limitation on the raw material provided for item k

The situation of manufacturing over-capacity can result in unmet request and break the contract, thereby bringing the risk of bankruptcy. This study accommodates the penalty factor in this situation:

$$X(t)_{qMA_k} + Z_1 = CAP(t)_{fac_k} \tag{4-19.2*}$$

$X(t)_{qMA_k}$: production quantity of item k at time period t

Z_1: penalty factor for the over-capacity manufacturing

$CAP(t)_{fac_k}$: manufacturing capacity of a factory to produce item k at time period t

Here, Z_1 indicates that the situation of exceeding manufacturing capacity will be penalised (see 'The proposed robust optimisation model for supply chain management and corporate governance' later in this chapter for more discussion), whereas minimising this factor can help prevent this over-capacity risk.

b Packaging equations

For the shipping process, semi-finished products need to be assembled and then distributed to different markets. The assembly labour requests for final products are set in Equation (4-20) below. The assembly labour is restricted because of the available labour force constraints in the factory. Investment may be directed into expanding the factories' assembly capacity to match any increase in the manufacturing capacity rate $r_{pac_k} \geq r_{capfac_k}$. Constraint (4-20.1) below gives information on the labour required to complete the work while meeting the maximum capability in the factory for assembling work:

$$LA(t)_{qMA_k} = \sum_i \sum_k \alpha_{i_k} X(t)_{qMA_k{}^i} \qquad (4\text{-}20)$$

$$LA(t)_{qMA_k} \leq P(t)_{qMA_k} \qquad (4\text{-}20.1)$$

$$P(t)_{qMA_k} = P(0)_{qMA_k} * (1 + r_{pac_k})^{t-1} \qquad (4\text{-}20.2*)$$

where:

$LA(t)_{qMA_k}$: labour required to finish packaging item k at time period t

α_{i_k}: the assembly coefficient of material i for item k

$X(t)_{qMA_k{}^i}$: quantity of material i for item k at time period t

$P(t)_{qMA_k}$: packaging capacity for production k at time period t

$P(0)_{qMA_k}$: packaging capacity for production k at the beginning

r_{pac_k}: the annual increasing rate of packaging capacity

Constraint (4-20) indicates the packaging assembly constraints where production packaging has different suppliers' allocations. Equation (4-20.1) shows different packaging capability limits for product k, which may increase with a certain rate at every time period, as presented in Equation (4-20.2*).

c Distribution risk management strategies

The distribution policy is designed to fulfil the shipping mission on time and safely. Shipping capacities are considered in the distribution process with individual shipping line limitations while meeting market demands and stock requirements. As shipping over-capacity results in wastage, this risk management strategy is incorporated into the constraint. The distribution risk management strategies constraint in this model is for maintaining healthy shipping within a company's capability and optimal expenses, even under the circumstance of increasing rate in unit shipping cost, as stated in the earlier section of shipping balance. Each shipping line has set the limitation up to its capacity $CAP_{QTR_{k_{mn}}}$ to avoid overloading. In addition, the total shipping amount of all lines (if more than one) cannot exceed that of the production amount.

$$Y(t)_{qTR_{k_{mn}}} \leq CAP(t)_{QTR_{k_{mn}}} \tag{4-21}$$

$$Y(t)_{qTR_{k_{mn}}} \leq Y(t)_{qMA_k} \tag{4-21.1}$$

where:

$Y(t)_{qTR_{k_{mn}}}$: shipping quantity amount of item k from place m to n at time period t

$CAP_{QTR_{k_{mn}}}$: capacity restriction for item k at shipping line from m to n at time period t

$Y(t)_{qMA_k}$: final manufactured quantity of item k after production line expansion at time period t; it equals $X(t)_{qMA_k}$ if there is no expansion of production line plan

This constraint provides for the shipping arrangement. Each shipping line's options from m to n that planned for different products are based on the optimal balance of expenses and optimal routine.

d Inventory risk management strategies

A well-performing supply chain network requires less lead time and is more able to satisfy increasing market demand (Jie, Parton & Cox 2007). If increasing market demand is met with limited production capacity, it may lead to unmet orders and stock-outs. Stock-outs put reputation at risk and lead to higher agency costs. The company can be equipped with safety inventory for its long-term benefit. Funds are allocated to maintaining inventory up to its capacity CAP_{INVj_k}. The ending volume of inventory is maintained by the safety level ratio, as follows:

$$X(t)_{invj_k} \geq B(t)_{safej_k} \tag{4-22}$$

$$B(t)_{safej_k} = k(t)_{safe} * D(t)_{{M_k}^i} \tag{4-23}$$

where:

$X(t)_{invj_k}$: ending inventory for item k of the distribution centre j at time period t

$B(t)_{safejk}$: safety inventory level for distribution centre j for item k at time period t
$k(t)_{safe}$: safety inventory level ratio at time period t
$D(t)_{M_k^i}$: demand for item k from the market M^i at time period t

Further, this study has a capacity restriction on the inventory:

$$X(t)_{invjk} \leq CAP_{INVjk} \tag{4-24*}$$

where:

$X(t)_{invjk}$: ending inventory for item k of the distribution centre j at time period t
CAP_{INVjk}: inventory capacity of the distribution centre j for item k

Inventory turnover is an indicator that was investigated as one of the three key supply chain performance indicators in the Gartner report (Hofman & Aronow 2012) (see Chapter 2, 'Supply chain management and models'). According to Hofman and Aronow (2012, p. 18), 'The balance sheet treatment of inventory as a valuable asset rings false for many of the short-cycle businesses today that see inventory as more of a liability'. This ratio gives an impression regarding the extent of efficiency performance in company inventory management. The higher the inventory turnover, the more efficiently the inventory system works. It also indicates how fast company products can be sold. This inventory policy constraint of this study constrains the inventory turnover greater than the industry average range to achieve better inventory management in the company. Alternatively, the target can be set at a certain level that the company aims to achieve. In mathematical terms, it is presented as Equation (4-25*):

$$IT(t) = CoS(t) \,/\, \overline{Inv}(t) \geq \delta(t)_{ITR} \tag{4-25*}$$

where:
$IT(t)$: inventory turns at time period t
$CoS(t)$: cost of sales at time period t
$\overline{Inv}(t)$: quarterly average inventory at time period t
$\delta(t)_{ITR}$: average industry ratio for inventory turnover at time period t, or the targeted inventory turns ratio that the company sets for time period t

e Unsatisfied demand risk

Satisfying customer demand builds a good reputation among company customers and stakeholders/shareholders. For this reason, this study has designed a protection scheme and penalty policy to mitigate the chances of an unsatisfied demand situation. That is, the shortage of demand situation is punished with a penalty factor Z_2. Therefore, this risk is managed under the penalty constraint below:

$$X(t)_{invjk} + Z_2 = X(t-1)_{invjk} + Y(t)_{qTR_{kmn}} - D(t)_{M_k{}^i} \quad \text{(4-26*)}$$

where:

$X(t)_{invjk}$:	ending inventory for item k of the distribution centre j at time period t
Z_2:	penalty factor on the unsatisfied demand
$X(t-1)_{invjk}$:	ending inventory of the distribution centre j for item k at the time period $t-1$, equal to starting inventory of the distribution centre j at time period t
$Y(t)_{qTR_{kmn}}$:	shipping quantity of item k from place m to n at time period t after extension
$D(t)_{M_k{}^i}$:	demand for item k from the market M^i at time period t

Z_2 indicates that penalty (see 'The proposed robust optimisation model for supply chain management and corporate governance' later in this chapter for more discussion) will be posted if the unsatisfied demand situation occurs, whereas minimising this factor can help prevent unfilled demand.

f Marketing risk

Considering the inflation rate, the model incorporates an increasing rate of supply chain operational cost and consequently results in increased prices on final sales. This brings financial risk into account. The detailed constraints have already been considered in each of the previous procedures—for example, manufacturing increasing rate r_{MA_k} in Equation (4-9.1), $c(t)_{MA_k} = c(0)_{MA_k} * (1 + r_{MA_k})^{t-1}$; shipping unit cost increasing rate $r_{TR_{mn}}$ in Equation (4-10.1), $c(t)_{TR_{kmn}} = c(0)_{TR_{kmn}} * (1 + r_{TR_{mn}})^{t-1}$; inventory unit cost increasing rate r_{invj} in Equation (4-11.1), $c(t)_{invjk} = c(0)_{invjk} * (1 + r_{invj})^{t-1}$; and sold prices increasing rate r_{sold} in Equation (4-8.1), $c(t)_{sold_k} = c(0)_{sold_k} * (1 + r_{sold})^{t-1}$.

3 Other SCM performance measures

Taking the key proxies for supply chain performance from industry as models, revenue growth as a measure can be incorporated into company policies for supply chain operations to improve the development environment:

$$R(t)_{RG} = \frac{\left[R(t)_{sale} - R(t-1)_{sale}\right]}{R(t-1)_{sale}} \geq \delta(t)_{IRG} \tag{4-27*}$$

$R(t)_{RG}$: revenue growth rate at time period t
$R(t-1)_{sale}$: revenue at time period $t-1$
$R(t)_{sale}$: revenue at time period t
$\delta(t)_{IRG}$: the average industry revenue growth ratio at time period t

C.2 Corporate financial and accounting practices for corporate governance performance

1 Internal control

Section B.2 presents the details of financial planning constraints. This section provides constraints that are designed to achieve a healthy financial environment for the company using GCG practices and accounting policies in the decision-making process, drawing on ideas of financial management in SCM. The constraints applied comprise five factors: debt-to-equity constraint, investment restriction constraint, debt service constraint, minimum working capital constraint and leverage constraint.

a Debt-to-equity constraint

An optimal capital structure that presents the balance between debt and equity is structured, which can lead to healthier company performance. One of the most widely used metrics in leverage measurement is the debt-to-equity ratio (Hill & Jones 2007). The constraint below shows the company's GCG policy for this ratio. The company and the banks from which it raises debt may impose a constraint of the form below to protect the company from bankruptcy or insolvency:

$$Z(t)_L \leq K(t)_{D/E} * Z(t)_E \tag{4-28}$$

where:
$Z(t)_L$: long-term debt; refers to long-term bank loans or bonds at time period t
$Z(t)_E$: equity refers to the value of shareholders' interests in the firm at time period t
$K(t)_{D/E}$: maximum allowed debt-to-equity ratio at time period t

That is, at the end of each year, the company may incur long-term debt up to $K(t)_{D/E}$ times the equity at that point in time. Here, only the long-term debt is considered for a long-term strategic plan. Short-term debt can be added in the future.

b Investment restriction constraint

Investment restriction constraint reflects the company's policy and preference for investing, long-term debt and fixed assets. This study considers the investments in production expansion and fixed assets from two sources: current assets and long-term debt. Mathematically:

$$C(t)_{MA^{\exp and}} + FC(t)_{new} - \left[Z(t)_{Inv/CA} + \Delta Z(t)_L\right] \leq 0 \qquad (4\text{-}29)$$

where:

$C(t)_{MA^{\exp and}}$: expenses on the expansion of the new production line at time period t

$FC(t)_{new}$: investment into fixed assets at time period t

$Z(t)_{Inv/CA}$: investment from current assets at time period t

$\Delta Z(t)_L$: change in the amount of long-term debt at time period t

For future investment, company policy regarding the use of current assets considers the control in rate κ_{inv} to protect the company from developing too fast. Investment in new fixed assets should be no more than a certain proportion—for example, $\kappa(t)_{inv}$ out of the current assets during that accounting time period t. Mathematically, it is presented as follows:

$$Z(t)_{Inv/CA} \leq \kappa(t)_{inv} * Z(t)_{CA} \qquad (4\text{-}30)$$

where:

$Z(t)_{Inv/CA}$: investment from current assets at time period t

$\kappa(t)_{inv}$: the maximum rate of investment from the current asset at time period t

$Z(t)_{CA}$: current assets refer to liquid assets such as cash, inventories or accounts receivable at time period t

The total investment is achieved through the use of current assets and debt. The total investment amount is generally more than the current asset. Considering the diversity of investment areas, the company will not retain much in current assets because of the agency problem, resulting in $Z(t)_{Inv/CA}$ exceeding $Z(t)_{CA}$. This study focuses on supply chain networks and relevant investments, so the constraint on investment here only refers to the contribution to supply chain expansion. The other investments are not included in this study.

The above two investment constraints discipline managers by requiring them to follow certain investment policies in two ways. Constraint (4-29) provides a guide for maintaining healthy financial relationships. Constraint (4-30) ensures that the investment amount from the current assets constraint matches with GCG practices suggesting that a company should plan for sustainability and future value creation using good investments. The investment in this study is put into company facilities expansion for enhancing the operational capabilities, thereby increasing the company's long-term profit and competitiveness.

c Debt service constraint

Managers need to make decisions about the size of long-term debt. Excessive borrowing may lead to bankruptcy and insolvency. *EBIT* clearly shows the capability to repay the debt. The debt service constraint set in this study is to ensure *EBIT* is at least $\lambda(t)_{EB/L}$ times as large as the interest payments on long-term debt at the time period t. This constraint maintains, to an extent, the company's long-term profit capability:

$$EBIT(t) \geq \lambda(t)_{EB/L} * i(t)_{IrD} * Z(t)_L \quad (4\text{-}31)$$

where:

$EBIT(t)$: EBIT at time period t

$\lambda(t)_{EB/L}$: the times in which $EBIT(t)$ is as large as $i(t)_{IrD} * Z(t)_L$ at the time period t

$i(t)_{IrD}$: the interest rate that the corporation must pay on long-term debt at the time period t

$Z(t)_L$: long-term debt; refers to long-term bank loans or bonds at time period t

d Minimum working capital constraint

Working capacity may have a limitation in availability. Constraint (4-32) presents this restriction on labour capacity:

$$Z(t)_{CA} \geq \lambda(t)_{WC} * Z(t)_{CL} \quad (4\text{-}32)$$

where:

$Z(t)_{CA}$: current assets; refers to liquid assets such as cash, inventories or accounts receivable at time period t

$\lambda(t)_{WC}$: minimum working capital available to the company as a function of current liabilities during time period t

$Z(t)_{CL}$: current liabilities; refers to short-term liabilities such as accounts payable or payroll at time period t

e Leverage constraint

Another leverage ratio, the debt-to-assets ratio,[1] can be added into the model framework. This is regarded as the most direct measure of the extent to which the company has borrowed funds to finance the investment (Hill & Jones 2007). Similar to other leverage ratios, which depend on the debt-to-equity ratio, the company can prevent distress and minimise the risk of bankruptcy. This study considers long-term debt instead of total debt under a safety level. Therefore:

$$Lev(t) = \frac{Z(t)_L}{TA(t)} \leq \delta(t)_{Lev} \qquad (4\text{-}33)$$

where:

$Lev(t)$: leverage at time period *t*
$Z(t)_L$: long-term debt refers to long-term bank loans or bonds at time period *t*
$TA(t)$: total assets at time period *t*
$\delta(t)_{Lev}$: the upper line of leverage from company management during time period *t*

2 Principal–agent problem

Agency cost is reduced because of the incorporation of GCG practices. This study considers agency cost in the model constraints.

a Agency cost constraint

The agent is a special company hired to achieve a certain target. In the internal structure of a company, the board or the shareholders are the principal and the managers are the agents. As discussed in Chapter 2 ('Corporate governance for supply chain management'), agency cost contains monitoring cost, bonding cost and residual cost (Jensen & Meckling 1976), represented in an equation as follows:

$$C(t)_{AC} = C(t)_{Mc} + C(t)_{Bc} + C(t)_{Rc} \qquad (4\text{-}34*)$$

where:

$C(t)_{AC}$: agency cost at time period *t*
$C(t)_{Mc}$: monitoring cost at time period *t*
$C(t)_{Bc}$: bonding cost at time period *t*
$C(t)_{Rc}$: residual cost at time period *t*

Agency cost is reduced by conducting GCG practices (McKnight & Weir 2009) (see Chapter 2, 'Corporate governance for supply chain management'). This study incorporates GCG practices into the agency cost calculation. Symbolically:

$$C^{CG}(t)_{AC} = C(t)_{AC} * [1 - \gamma(t)] \qquad (4\text{-}35)$$

where:

$C^{CG}(t)_{AC}$: reduced agency cost because of GCG at time period t
$C(t)_{AC}$: agency cost at time period t
$\gamma(t)$: reducing rate of agency cost at time period t

b Agency cost measures constraint

This study also contains another agency problem management policy: that the rate of agency cost to total cost should be controlled within a certain rate of debt-to-equity ratio while the rate is determined based on the firm's capital structure strategy. Total cost here refers to the sum of supply chain operational cost and agency cost: $C(t)_{MA}$, $C(t)_{inv}$, $C(t)_{TR}$ and $C(t)_{AC}$. Mathematically, it is presented as follows:

$$\frac{C(t)_{AC}}{C(t)_{ALL}} \leq \delta(t)_{D/E} * R(t)_{DE} \qquad (4\text{-}36^*)$$

where:

$C(t)_{AC}$: agency cost at time period t
$C(t)_{ALL}$: total cost includes supply chain operational expenses and agency cost in this study at time period t
$R(t)_{DE}$: debt-to-equity ratio at time period t
$\delta(t)_{D/E}$: the rate of agency cost to total cost from debt-to-equity ratio at time period t

Moreover, as discussed in Chapter 2, the ROA ratio shows the relationship between ROA and firm performance and is the proxy for the overall efficiency and productivity of supply chain operations. This study incorporates a policy of agency cost to total cost that is less than a certain rate of ROA ratio for achieving the efficiency of supply chain operations. The rate value depends on the company's individual strategy.

$$\frac{C(t)_{AC}}{C(t)_{ALL}} \leq \delta(t)_{ROA} * R(t)_{ROA} \qquad (4\text{-}37^*)$$

where:

$C(t)_{AC}$: agency cost at time period t
$C(t)_{ALL}$: total cost at time period t
$\delta(t)_{ROA}$: the rate of agency cost to total cost from ROA ratio at time period t
$R(t)_{ROA}$: return on asset ratio at time period t

3 Other GCG performance measures (accounting measures)

a Operating margin constraint

As explained in Chapters 2 ('Proxies and ratios as a corporate governance performance measurement for firm value') and 3 ('Corporate governance strategies in constraints'), ISRATIO indicates the company's operating efficiency. This study applies this ratio theory and updates with EBIT instead of operating income and revenue instead of net sales to measure the operating efficiency of the supply chain system for the company. Keeping ISRATIO at a stable and healthy rate can help the company maintain an efficient operation and management system. This study accommodates a policy that the company ISRATIO rate should be over the average industry rate. In addition, under this study's circumstance, $EBIT(t)$ replaces the operating income and the net sales value is represented by $R(t)_{sale}$. Therefore, mathematically, it is presented as follows:

$$\xi(t)_{ISRATIO_k} = \frac{EBIT(t)}{R(t)_{sale}} \geq \xi'(t)_{ISRATIO} \tag{4-38}$$

where:

$\xi(t)_{ISRATIO_k}$: ISRATIO (operating margin) of the company associated with item k
$EBIT(t)$: EBIT at time period t
$R(t)_{sale}$: revenue at time period t
$\xi'(t)_{ISRATIO}$: ISRATIO (operating margin) of the average industry level

D. Non-negativity constraints

All variables are non-negative. Applying the RSCMCG model into a strategic supply chain plan for a company, the outputs are expected as follows: the SCM plan (amount of production necessary from each appointed factory when they have several options, shipping schedule and arrangement, the optimal safety level for stock, stock arrangement, sales depending on demand, cost of individual supply chain procedure), financial planning (such as investment from current asset and long-term debt) and risk management strategies.

Summarised mathematical model

Objective equation:

$$Max\ f(equity) = Z(t)_E = Z(1)_E + \sum_t \left[\Delta Z(t)_E\right] \tag{4-1}$$

$$= Z(1)_E + \sum_t \{(1 - r_{PR}) \times [EBIT(t) - i(t)_{IrD} * Z(t)_L] - Z(t)_D\} \tag{4-1'}$$

A Definitional supply chain operational and financial equations

$$Z(t)_{CA} + Z(t)_{FA} - Z(t)_{CL} - Z(t)_L - Z(t)_E = 0 \quad (4\text{-}2)$$

$$\Delta Z(t)_{CA} + \Delta Z(t)_{FA} - \Delta Z(t)_{CL} - \Delta Z(t)_L - \Delta Z(t)_E = 0 \quad (4\text{-}3)$$

$$\begin{aligned}\Delta Z(t)_E &= Z(t)_{PR} - Z(t)_D \\ &= (1 - r_{PR})[EBIT(t) - i(t)_{IrD} * Z(t)_L] - Z(t)_D\end{aligned} \quad (4\text{-}4)$$

$$Z(t)_{PR} = (1 - r_{PR})[EBIT(t) - i(t)_{IrD} * Z(t)_L] \quad (4\text{-}5)$$

$$\begin{aligned}&\Delta Z(t)_{CA} + \Delta Z(t)_{FA} - \Delta Z(t)_{CL} - \Delta Z(t)_L \\ &\quad - (1 - r_{PR})[EBIT(t) - i(t)_{IrD} * Z(t)_L] + Z(t)_D = 0\end{aligned} \quad (4\text{-}6)$$

$$EBIT(t) = R(t)_{sale} - \left[C(t)_{MA} + C(t)_{Inv} + C(t)_{TR}\right] - C(t)_{AC} \quad (4\text{-}7)$$

$$R(t)_{sale} = \sum_k \left[X(t)_{sold_k} * c(t)_{sold_k}\right] \quad (4\text{-}8)$$

$$C(t)_{MA} = \sum_k C(t)_{MA_k} = \sum_k \left[c(t)_{MA_k} * X(t)_{qMA_k}\right] \quad (4\text{-}9)$$

$$C(t)_{TR} = \sum_k \sum_{m,n}^{M,N} \left[Y(t)_{qTR_{k_{mn}}} * c(t)_{TR_{k_{mn}}}\right] \quad (4\text{-}10)$$

$$C(t)_{inv} = \sum_k \sum_j \left[c(t)_{invj_k} * X(t)_{invj_k}\right] \quad (4\text{-}11)$$

B. SCM and financial management equations
B.1 Supply chain operational equation constraints

1 Manufacturing functions

$$\begin{aligned}C(t)_{MA} &= \sum_k \left[X(t)_{qMA_k} * c(t)_{MA_k}\right] \\ &= \sum_k \left[X(t)_{qMA_k} * c(0)_{MA_k} * (1 + r_{MA_k})^{t-1}\right]\end{aligned} \quad (4\text{-}9.1)$$

$$Y(t)_{qMA_k} = X(t)_{qMA_k} + Y(Ex - t)_{qMA_k} \quad (4\text{-}12*)$$

$$C(t)_{MA} = \sum_k C(t)_{MA_k} = \sum_k \left[c(0)_{MA_k} * (1 + r_{MA_k})^{t-1} * Y(t)_{qMA_k} \right] \tag{4-9.1'*}$$

2 Shipping balance

$$\sum_k \sum_{m,n}^{M,N} \theta_{k_{mn}} Y(t)_{qTR_{k_{mn}}} = Y(t)_{qTR_{mn}} \tag{4-13}$$

$$C(t)_{TR} = \sum_k \sum_{m,n}^{M,N} \left[Y(t)_{qTR_{k_{mn}}} * c(0)_{TR_{k_{mn}}} * (1 + r_{TR_{mn}})^{t-1} \right] \tag{4-10.1}$$

3 Mass balance

$$X(t)_{invj_k} = X(t-1)_{invj_k} + Y(t)_{qTR_{k_{mn}}} - D(t)_{M_k{}^i} \tag{4-14}$$

4 Inventory expense

$$C(t)_{inv} = \sum_j \left[c(0)_{invj_k} * (1 + r_{invj})^{t-1} * X(t)_{invj_k} \right] \tag{4-11.1}$$

5 Marketing equation

$$\begin{aligned} R(t)_{sale} &= \sum_k \left[D(t)_{M_k{}^i} * c(t)_{sold_k} \right] \\ &= \sum_k \left[D(t)_{M_k{}^i} * c(0)_{sold_k} * (1 + r_{sold})^{t-1} \right] \end{aligned} \tag{4-8.1}$$

B.2 Financial planning constraints

1 Financial balance

$$Z(t)_{CA} + Z(t)_{FA} - Z(t)_{CL} - Z(t)_L - Z(t)_E = 0 \tag{4-2}$$

2 Funds flow equations

$$\Delta Z(t)_{CA} + \Delta Z(t)_{FA} - \Delta Z(t)_{CL} - \Delta Z(t)_L - \Delta Z(t)_E = 0 \tag{4-3}$$

$$\begin{aligned} \Delta Z(t)_E &= Z(t)_{PR} - Z(t)_D \\ &= (1 - r_{PR})[EBIT(t) - i(t)_{IrD} * Z(t)_L] - Z(t)_D \end{aligned} \tag{4-4}$$

$$Z(t)_{PR} = (1 - r_{PR})[EBIT(t) - i(t)_{IrD} * Z(t)_L] \quad (4\text{-}5)$$

$$\Delta Z(t)_{CA} + \Delta Z(t)_{FA} - \Delta Z(t)_{CL} - \Delta Z(t)_L - (1 - r_{PR})[EBIT(t) - i(t)_{IrD} * Z(t)_L] + Z(t)_D = 0 \quad (4\text{-}6)$$

3 Investment balance

$$\Delta Z(t)_{FA} = \Delta Z(t)_L + Z(t)_{Inv/CA} \quad (4\text{-}15)$$

4 Expansion expense

$$C(t)_{MA^{\exp and}} = \sum_k C(t)_{MA^{\exp and}_k} = \sum_k \left[Y(Ex - t)_{qMA_k} * c(t)_{MA^{\exp and}_k} \right] \quad (4\text{-}16)$$

C. Corporate governance policies: Risk management for SCM and accounting policy
C.1 GCG practices for optimal supply chain operational management from a risk management strategies perspective

1 Supply chain specialised agent governance

$$X(t)_{qMA_k} = \sum_i \sum_k \alpha_{i_k} X(t)_{qMA_k{}^i} \quad (4\text{-}17)$$

$$Y(t)_{qTR_{mn}} = \sum_i \sum_k \beta_{i_k} Y(t)_{qTR^i{}_{k_{mn}}} \quad (4\text{-}18)$$

$$X(t)_{qMA_k} = \sum_k X(t)_{rm_k} \quad (4\text{-}17.1*)$$

2 Risk management strategies for supply chain operational system

a Manufacturing risk management strategies

$$X(t)_{qMA_k} \le CAP(t)_{fac_k} = CAP(0)_{fac_k} * (1 + r_{capfac_k})^{t-1} \quad (4\text{-}19)$$

$$X(t)_{qMA_k} = \sum_i X(t)_{rm_{ki}} \le R_{rm_k} \quad (4\text{-}19.1*)$$

$$X(t)_{qMA_k} + Z = CAP(t)_{fac_k} \quad (4\text{-}19.2*)$$

b Packaging equations

$$LA(t)_{qMA_k} = \sum_i \sum_k \alpha_{i_k} X(t)_{qMA_k{}^i} \tag{4-20}$$

$$LA(t)_{qMA_k} \le P(t)_{qMA_k} \tag{4-20.1}$$

$$P(t)_{qMA_k} = P(0)_{qMA_k} * (1 + r_{pac_k})^{t-1} \tag{4-20.2*}$$

c Distribution risk management strategies

$$Y(t)_{qTR_{k_{mn}}} \le CAP(t)_{QTR_{k_{mn}}} \tag{4-21}$$

$$Y(t)_{qTR_{k_{mn}}} \le Y(t)_{qMA_k} \tag{4-21.1}$$

d Inventory risk management strategies

$$X(t)_{invj_k} \ge B(t)_{safej_k} \tag{4-22}$$

$$B(t)_{safej_k} = k(t)_{safe} * D(t)_{M_k{}^i} \tag{4-23}$$

$$X(t)_{invj_k} \le CAP_{INVj_k} \tag{4-24*}$$

$$IT(t) = CoS(t) / \overline{Inv}(t) \ge \delta(t)_{ITR} \tag{4-25*}$$

e Unsatisfied demand risk

$$X(t)_{invj_k} + Z_2 = X(t-1)_{invj_k} + Y(t)_{qTR_{k_{mn}}} - D(t)_{M_k{}^i} \tag{4-26*}$$

f Marketing risk

$$c(t)_{sold} = c(0)_{sold_k} * (1 + r_{sold})^{t-1} \tag{4-8.1}$$

$$c(t)_{MA_k} = c(0)_{MA_k} * (1 + r_{MA_k})^{t-1} \tag{4-9.1}$$

$$c(t)_{TR_{mn}} = c(0)_{TR_{mn}} * (1 + r_{TR_{mn}})^{t-1} \tag{4-10.1}$$

$$c(t)_{invj} = c(0)_{invj} * (1 + r_{invj})^{t-1} \tag{4-11.1}$$

3 Other SCM performance measures

$$R(t)_{RG} = \frac{\left[R(t)_{sale} - R(t-1)_{sale}\right]}{R(t-1)_{sale}} \ge \delta_{IRG} \tag{4-27*}$$

C.2 Corporate financial and accounting practices for corporate governance performance

1 Internal control

a Debt-to-equity constraint

$$Z(t)_L \leq K_{D/E} * Z(t)_E \tag{4-28}$$

b Investment restriction constraint

$$C(t)_{MA^{\exp and}} + FC(t)_{new} - \left[Z(t)_{Inv/CA} + \Delta Z(t)_L\right] \leq 0 \tag{4-29}$$

$$Z(t)_{Inv/CA} \leq \kappa_{inv} * Z(t)_{CA} \tag{4-30}$$

c Debt service constraint

$$EBIT(t) \geq \lambda(t)_{EB/L} * i(t)_{IrD} * Z(t)_L \tag{4-31}$$

d Minimum working capital constraint

$$Z(t)_{CA} \geq \lambda(t)_{WC} * Z(t)_{CL} \tag{4-32}$$

e Leverage constraint

$$Lev(t) = \frac{Z(t)_L}{TA(t)} \leq \delta(t)_{Lev} \tag{4-33}$$

2 Principal–agent problem

a Agency cost constraint

$$C(t)_{AC} = C(t)_{Mc} + C(t)_{Bc} + C(t)_{Rc} \tag{4-34*}$$

$$C^{CG}(t)_{AC} = C(t)_{AC} * \left[1 - \gamma(t)\right] \tag{4-35}$$

b Agency cost measures constraint

$$\frac{C(t)_{AC}}{C(t)_{ALL}} \leq \delta(t)_{D/E} * R(t)_{DE} \tag{4-36*}$$

$$\frac{C(t)_{AC}}{C(t)_{ALL}} \leq \delta(t)_{ROA} * R(t)_{ROA} \tag{4-37*}$$

3 GCG performance measures (accounting measures)

a Operating margin constraint

$$\xi(t)_{ISRATIO_k} = \frac{EBIT(t)}{R(t)_{sale}} \geq \xi'(t)_{ISRATIO} \tag{4-38}$$

D. Non-negativity constraints
All variables are non-negative.

F. Definitions of the variables and parameters

$Z(t)_{CA}$: current assets; refers to liquid assets such as cash, inventories or accounts receivable at time period t

$Z(t)_{FA}$: fixed assets; refers to illiquid assets such as plants or equipment at time period t. Intangible assets, such as customer goodwill or a cadre of superior design engineers among the fixed or current assets, are not included here

$Z(t)_{CL}$: current liabilities; refer to short-term liabilities such as accounts payable or payroll at time period t

$Z(t)_{L}$: long-term debt; refers to long-term bank loans or bonds at time period t

$Z(t)_{E}$: equity refers to the value of shareholders' interests in the firm at time period t

$Z(t)_{PR}$: after-tax profits at time period t

$Z(t)_{D}$: dividends paid to shareholders at time period t

$EBIT(t)$: EBIT at time period t

r_{PR}: corporate tax rate during time period t

$i(t)_{IrD}$: interest rate of company's long-term debt at time period t

Δ: denotes the change of the variable during the time period

$R(t)_{sale}$: revenue at time period t

$C(t)_{MA}$: manufacturing cost at time period t

$C(t)_{inv}$: inventory cost at time period t

$C(t)_{TR}$: transportation cost at time period t

$C(t)_{AC}$: agency cost at time period t

$c(t)_{sold_k}$: sold price per unit for the item k at time period t

$C(t)_{MA_k}$: total manufacturing cost for item k at time period t

$c(t)_{MA_k}$: manufacturing cost per unit for item k at time period t

$c(t)_{TR_{k_{mn}}}$: shipping cost per unit of item k from place m to n at time period t

$c(t)_{invj_k}$: inventory cost per unit of item k in distribution centre j at time period t

$c(0)_{MA_k}$: manufacturing cost per unit for item k at the beginning

r_{MA_k}: annual increasing rate of manufacturing cost per unit for item k

$\theta_{k_{mn}}$: the proportion of total shipped amount for each shipping line from place m to n of item k

$c(0)_{TR_{k_{mn}}}$: shipping cost per unit of item k from place m to n at the beginning

$r_{TR_{mn}}$: annual increasing rate of transportation cost per unit at the shipping line from place m to n

$D(t)_{M_k{}^i}$: demand of item k from the market M^i at time period t

$c(0)_{invj_k}$:	inventory cost per unit of item k in distribution centre j at the beginning
r_{invj}:	annual increasing rate of inventory cost per unit at the distribution centre j
$R(t)_{sale}$:	revenue at time period t
$c(0)_{sold_k}$:	sold price per unit of item k at the beginning
r_{sold}:	annual increasing rate of sold price
$\Delta Z(t)_{FA}$:	change amount on the fixed asset at time period t
$\Delta Z(t)_{L}$:	change amount on long-term debt at time period t
$Z(t)_{Inv/CA}$:	investment from current assets at time period t
$C(t)_{MA^{\exp and}}$:	expenses on the expansion of the new production line at time period t
$C(t)_{MA^{\exp and}_k}$:	expenses on the new production line expansion for item k at time period t
$c(t)_{MA^{\exp and}_k}$:	unit cost on the new production line expansion for item k at time period t
α_{i_k}:	the coefficient for item k produced by factory i
β_{i_k}:	the coefficient for item k has been shipped through shipping agent i
$CAP(t)_{fac_k}$:	manufacturing capacity of factory to produce item k at time period t
$CAP(0)_{fac_k}$:	manufacturing capacity of factory to produce item k at the beginning
r_{capfac_k}:	annual increasing rate of manufacturing capacity for item k
Z_1:	penalty factor on the over-capacity manufacturing
$CAP(t)_{fac_k}$:	manufacturing capacity of factory to produce item k at time period t
$LA(t)_{qMA_k}$:	labour required to finish packaging item k at time period t
$P(t)_{qMA_k}$:	packaging capacity for production k at time period t
$P(0)_{qMA_k}$:	packaging capacity for production k at the beginning
r_{pac_k}:	the annual increasing rate of packaging capacity
$CAP_{QTR_{k_{mn}}}$:	capacity restriction for item k at shipping line from m to n at time period t
$B(t)_{safej_k}$:	safety inventory level for distribution centre j for item k at time period t
$k(t)_{safe}$:	safety inventory level ratio at time period t
CAP_{INVj_k}:	inventory capacity of the distribution centre j for item k
$IT(t)$:	inventory turns at time period t
$CoS(t)$:	cost of sales at time period t
$\overline{Inv}(t)$:	quarterly average inventory at time period t
$\delta(t)_{ITR}$:	average industry ratio for inventory turnover at time period t or the targeted inventory turns ratio that the company sets for time period t
Z_2:	penalty factor on unsatisfied demand

$R(t)_{RG}$: revenue growth rate at time period t
$R(t-1)_{sale}$: revenue at time period $t-1$
$R(t)_{sale}$: revenue at time period t
$\delta(t)_{IRG}$: the average industry revenue growth ratio at time period t
$K(t)_{D/E}$: maximum allowed debt-to-equity ratio at time period t
$FC(t)_{new}$: investment into fixed assets at time period t
$\kappa(t)_{inv}$: the maximum rate of investment from the current asset at time period t
$\lambda(t)_{EB/L}$: the times which $EBIT(t)$ is as large as $i(t)_{IrD} * Z(t)_L$ at the time period t
$\lambda(t)_{WC}$: minimum working capital available to the company as a function of current liabilities during time period t
$Lev(t)$: leverage at time period t
$TA(t)$: total assets at time period t
$\delta(t)_{Lev}$: the upper line of leverage from company management during time period t
$C(t)_{Mc}$: monitoring cost at time period t
$C(t)_{Bc}$: bonding cost at time period t
$C(t)_{Rc}$: residual cost at time period t
$C^{CG}(t)_{AC}$: reduced agency cost because of GCG at time period t
$\gamma(t)$: reducing rate of agency cost at time period t
$R(t)_{DE}$: debt-to-equity ratio at time period t
$\delta(t)_{D/E}$: the rate of agency cost to total cost from debt-to-equity ratio at time period t
$\delta(t)_{ROA}$: the rate of agency cost to total cost from ROA ratio at time period t
$R(t)_{ROA}$: ROA ratio at time period t
$\xi(t)_{ISRATIO_k}$: ISRATIO (operating margin) of the company associated with item k
$\xi'(t)_{ISRATIO}$: ISRATIO (operating margin) of the average industry level

Decision variables include the following:

$X(t)_{sold_k}$: sold quantity for item k
$X(t)_{qMA_k}$: production quantity of item k at time period t
$Y(t)_{qTR_{k_{mn}}}$: shipping quantity of item k from place m to n at time period t after extension
$X(t)_{invj_k}$: ending inventory for item k of the distribution centre j at time period t
$Y(t)_{qMA_k}$: final manufactured quantity of item k after production line expansion at time period t; it equals $X(t)_{qMA_k}$ if there are no expansions in production line plan
$Y(Ex-t)_{qMA_k}$: expansion quantity decision for the production line to produce item k at time period t

$Y(t)_{qTR_{mn}}$:	total shipping quantity amount from place m to n at time period t
$X(t-1)_{invj_k}$:	ending inventory of the distribution centre j for item k at time period $t-1$, equal to starting inventory of the distribution centre j at time period t
$X(t)_{qMA_k{}^i}$:	quantity of item k produced in factory i at time period t
$Y(t)_{qTR^i{}_{k_{mn}}}$:	shipping quantity of item k from place m to n by shipping agent i at time period t
$X(t)_{rm_k}$:	raw material requirements from manufacturing factories for each item k at time period t
$X(t)_{rm_{ki}}$:	raw material i required for item k at time period t

Constructed robust optimisation model framework for integrated supply chain management and corporate governance under uncertainty

Nowadays, there are many uncertainties in supply chain implementation because of complex supply chain network requirements and the surrounding environment. By taking risk management and GCG practices into account during the strategic planning stage of a supply chain, this research develops a novel framework, RSCMCG, for using GCG policies to promote greater effectiveness and efficiency in SCM for optimal risk management. This section discusses the approaches and solutions for the proposed integrated SCM and corporate governance model framework through robust optimisation and presents them in mathematical form followed by the simulation settings. In practice, the model framework can be further developed into a quantitative model for implementation and analysis.

The proposed robust optimisation model for supply chain management and corporate governance

Uncertainties exist anywhere at any time and should be considered in planning to achieve stable solutions. To incorporate uncertainties into the combined supply chain and corporate governance model, the robust optimisation method is applied. As discussed in Chapter 3 ('The main approaches to robust optimisation'), Mulvey's (Mulvey, Vanderbei & Zenios 1995) and Bertsimas' (Bertsimas & Sim 2003, 2004) robust optimisation methods are applied and adjusted in this study.

A. Robustness of the model: mean-variance method with penalty function and Uset

The mean-variance method (Mulvey, Vanderbei & Zenios 1995) discussed in Chapter 3 ('The main approaches to robust optimisation') is applied to this model and the corresponding updates in the objective function of the proposed model framework are presented as follows:

$$Max\ Equity = Min\ f(-equity)$$

$$\text{with } \xi_s = -Z(t)_E = -\left\{ Z(1)_E + \sum_t \left[\Delta Z(t)_E \right] \right\}$$

$$= Min \sum_s p_s \xi_s + \lambda \sum_s p_s (\xi_s - \sum_{S'} p_{s'} \xi_{s'})^2$$

$$+ \omega \sum_s p_s \sqrt{\left[\sum_I \left(z_1^{(s)} \right)^2 + \sum_J \left(z_2^{(s)} \right)^2 \right]}$$

$\sum_s p_s (\xi_s - \sum_{S'} p_{s'} \xi_{s'})^2$ stands for the term of variance. $\sum_{S'} p_{s'} \xi_{s'}$ is the expected value, which is then calculated using the variance: $Var(X) = \sum_{i=1}^{n} p_i \cdot (x_i - \mu)^2 = \sum_{i=1}^{n} (p_i \cdot x_i^2) - \mu^2$. λ, ω are risk indicators. λ denotes the weighting scale to measure the trade-off between feasibility and cost and ω represents the weighting penalty for the stock over or below the safety level (Yu & Li 2000). $\sum_I \left(z_1^{(s)} \right)^2 + \sum_J \left(z_2^{(s)} \right)^2$ is a feasibility penalty function, which is used to penalise the violations of the control constraints.

This adjustment in the RSCMCG model adds decision-maker risk preference into the planning procedure by incorporating risk indicators and risk penalty functions into the model. The penalty factors Z_1 and Z_2 are incorporated into constraints (4-19.2*) and (4-26*) see 'Constraints of the robust supply chain management and corporate governance model') to control the risks in supply chain processes.

The penalty factor Z_1 measures the difference between actual manufacturing quantity and the factory's maximum capacity. For each scenario *s*:

$$X(t)_{qMA_k}^{(s)} + Z_1^{(s)} = CAP(t)_{fac_k}^{(s)}$$

where:

$X(t)_{qMA_k}^{(s)}$: production quantity of item *k* at time period *t* for scenario *s*

$Z_1^{(s)}$: penalty factor on the over-capacity manufacturing for scenario *s*

$CAP(t)_{fac_k}^{(s)}$: manufacturing capacity of factory to produce item *k* at time period *t* for scenario *s*.

The second penalty factor, Z_2, measures the gap between actual inventories and the remains after filling demand to ensure warehouse safety levels. This constraint in the RSCMCG framework can improve inventory management by ensuring that final stock quantity is closer to the safety inventory while keeping stock expenses low. Constraint (4-26*) demonstrates this situation. For each scenario s:

$$X(t)_{invj}^{(s)} + Z_2{}^{(s)} = X(t-1)_{invj}^{(s)} + Y(t)_{qTR_{k_{mn}}}^{(s)} - D(t)_{M_k{}^i}^{(s)}$$

where:

$X(t)_{invj}^{(s)}$:	ending inventory of the distribution centre j at time period t for scenario s
$Z_2{}^{(s)}$:	penalty on the scenario, s which has unsatisfied demand
$X(t-1)_{invj}^{(s)}$:	starting inventory of the distribution centre j at time period t equals the ending inventory at time period $t-1$ for scenario s
$Y(t)_{qTR_{k_{mn}}}^{(s)}$:	shipping quantity of item k from place m to n at time period t after extension for scenario s
$D(t)_{M_k{}^i}^{(s)}$:	demand of item k from the market M^i at time period t for scenario s
s:	indicates scenario s.

Here, this study considers the uncertainty existing in the assembly/packaging process of manufacturing as an example for incorporating an uncertain environment—represented by the uncertainty coefficients α_{i_k} for the labour hours required for each product to complete the assembly process—through the ellipsoid uncertainty set. Constraint (4-17) can be updated as below if there are three factories,

$$X(t)_{qMA_k} = \sum_{i=1,2,3} \sum_k \alpha_{i_k} X(t)_{qMA_k{}^i} = \alpha_{1_k} * x(t)_{qMA^1{}_k} + \alpha_{2_k} * x(t)_{qMA^2{}_k} +$$

$\alpha_{3_k} * x(t)_{qMA^3{}_k}$, and coefficients α_{i_k} are formulated in the set $\mathrm{A} = \left\{ \tilde{\alpha}_{i_k} \middle| \tilde{\alpha}_{i_k} \in \bar{\alpha}_{i_k} + \hat{\alpha}_{i_k} \mu_{i_k}, \forall i,k, \mu \in H \right\}$, where: $H = \left\{ \mu \middle| \left|\mu_{i_k}\right| \le 1,\ \forall i,k, \sum_k \left|\mu_{i_k}\right| \le \Gamma_i \right\}$

The rest of this section discusses the corresponding adjustments in the model.

For an integrative robust SCM model, GCG practices for uncertainties in constraints and considerations are included in the model constraints and mean variance and penalty functions in the robustness objective function. The theoretical frame of the robust optimisation model for this study is presented as the above concept, and the corresponding adjustment in the RSCMCG model can be achieved in the Risk Solver Platform through the Uset (uncertainty set) setting in the 'Chance Constraint' section.

B. Uset with robust counterpart form in the Risk Solver Platform
The robust optimisation approach can be simulated through Uset in the Risk Solver Platform. By applying the Uset and robust counterpart together with the Psi function, the RSCMCG model of this study can be applied in practice to solve problems with uncertainties. This application is discussed and explained through a hypothetical case study in Chapter 5. In the Risk Solver Platform, $\mathbf{Uset}_{\Omega}$, in which $\boldsymbol{\Omega}$ is the bound of the uncertainties in the formulation, is measured by a norm. The general robust counterpart form is formed with a norm (Bertsimas & Thiele 2004). Here, the uncertain sets are performed in D Norm and L2 Norm. For example, solving problems with D Norm, the robust counterpart is a linear problem, while the robust counterpart of problems with L2 Norm will be a SOCP problem.

Settings in the Risk Solver Platform

The setting configurations are presented in Chapter 3 ('Introduction of Risk Solver Platform applied for optimisation model with uncertainty'). This section specifies the updates for the proposed RSCMCG model framework in the Risk Solver Platform.

A. Robust optimisation method in the Risk Solver Platform
According to the Frontline Solvers (2013, p. 248):

The idea behind robust optimisation in the Risk Solver Platform is to transform an optimisation problem with known structure such as a stochastic linear programming problem into a larger, conventional robust counterpart problem that accounts for the impact of bounded uncertainty on the constraints and objective. Solving the robust counterpart—a single linear programming or SOCP problem—gives us an approximate solution to the original stochastic problem. The robust counterpart is a LP problem because the platform tab chance constraints use option is set to D Norm. If it had been set to L2 Norm, the robust counterpart model would have been a SOCP. When D Norm is used, the robust counterpart of a stochastic linear programming problem is a LP problem. When L2 Norm is used, the robust counterpart is a SOCP problem.

In the Risk Solver Platform, there are differences between the original model and the robust optimisation model. For the original model, for example, a stochastic LP model, set the 'Solve Uncertain Models' option to 'Simulation Optimisation' and then click the analyse button to analyse the structure of the model. The model diagnosis section of the task pane model tab 'pops up' to show the results, which display the uncertain 'variables, functions and dependencies'. When transforming into the robust optimisation model, the 'Solve Uncertain Models' option needs to be changed to 'Automatic' and then the 'analyse' button clicked. This analyses the transformed structure of the robust counterpart model for the original robust optimisation, which becomes a linear deterministic problem with possible scenarios.

The constraints criterion applied in Uset, which is located under the 'Chance Constraint' in the Risk Solver Platform, has its advantage. The robust counterpart model more accurately reflects the degree to which the chance constraint is satisfied, which can lead to less conservative solutions with better objective values (Chen, Sim & Sun 2007). The 'Ω ' under uncertainty set is set as the budget for uncertainty.

The Risk Solver Platform performs one simulation at the outset to assess the impact of uncertainty and construct the robust counterpart problem. The strength of robust optimisation is its scalability to very large problems, since only one simulation and one optimisation of a linear problem or SOCP problem is required. However, robust optimisation cannot solve more general nonlinear, non-convex problems.

As discussed above, the uncertainties assumed in the proposed RSCMCG model framework are the manufacturing assembly coefficients, which can be the quantity of each material or amount of labour engaged. This can differ on a case-by-case basis. In addition, this study applies Psi Uniform (min or max) to simulate values for uncertain parameters.

B. Settings in the Risk Solver Platform for the proposed RSCMCG model framework

In the 'Optimisation Model' section in the 'Platform' component, choose 'Psi Interpreter' from the 'Interpreter' tab and 'Solve Complete Problem' (or analysis without solving first to examine the feasibility of the proposed model) from 'Solve Mode'. Then select 'Stochastic Transformation' from 'Solve Uncertain Models' for the reason that problems with uncertainty are assumed in linear mode and are without recourse in this study. This study applies the robust optimisation method; therefore, after this setting, move to the 'Transformation' section and select 'Robust Counterpart' in the 'Stochastic Transformation' option to conduct the robust optimisation method with 'Chance Constrains Use' choosing 'D Norm'.

Using the 'Robust Optimisation' approach, the Risk Solver Platform will attempt to transform the original robust optimisation problem with uncertainties into a conventional optimisation 'Robust Counterpart' model without uncertainty. For the specific 'Chance Constraints' setting, while the Psi Percentile and Psi statistics function are accepted for simulation optimisation, the transformation for robust optimisation requires that it is directly expressed as chance property in the constraint itself and not in the formula.

As discussed in Chapter 3 ('Introduction of Risk Solver Platform applied for optimisation model with uncertainty'), different solver engines can be chosen. For the proposed RSCMCG model framework, the Standard LP/Quadratic Engine, Standard LSGRG Nonlinear Solver Engine or Standard SOCP Barrier Engine can be chosen based on the specific problem. The LP/Quadratic Solver can solve problems with quadratic objective functions. The Standard SOCP barrier engine can help find an optimal solution with a linear objective function and second-order cone constraints as SOCP problems. One has to be careful of any convex quadratic constraints that can also be converted into second-order cone constraints with several steps of linear algebra. The SOCP Barrier Solver or the MOSEK Solver Engine can both make these transformations automatically, and SOCP problems can be solved using the GRG Nonlinear Solver or the Large-Scale GRG, Large-Scale SQP or KNITRO Solver engines. While the Risk Solver Platform includes the enhanced LSGRG Solver, it uses the Generalised Reduced Gradient method, as implemented in Lasdon and Waren's GRG2 code (Frontline Solvers 2013). The GRG method can be viewed as a nonlinear extension of the Simplex method, which selects a basis, determines a search direction and performs a line search on each major iteration while solving systems of nonlinear equations at each step to maintain feasibility. The above engines all can be applied to solve the RSCMCG model framework. The results returned from these different engine options may differ. Reports for the solutions and analyses of the problem are also available in the Risk Solver Platform. The Linearity Report and Structure Report can help when encountering the message 'the linearity conditions required by this Solver engine are not satisfied'. The feasibility report and feasibility-bound report can help when one encounters the message 'solver could not find a feasibility solution'. The scaling report can help when one encounters either of these messages or other unexpected messages or solution values.

Summary

By using the basic rules of supply chain modelling systems from previous work, such as Shapiro's (2007) model, Ragsdale (2012) and Williams (2013), together with the corporate risk management frameworks from Léautier (2007), this study has extended optimal supply chain models and developed a robust integrated supply chain and corporate governance model (RSCMCG).

This study sets the objective of maximising company equity to achieve long-term profit and shareholders' interests. The supply chain operational decisions and costs are the main variables. The integrated supply chain network, including manufacturing, distribution, inventory and marketing procedures, are considered in this RSCMCG model. Each part yields equations and constraints in the proposed model. Through the model, the different operations of comprehensive supply chain networking and financial management have been connected to achieve optimal resources planning, and GCG practices are investigated and quantified into the constraints for risk management.

Unlike the previous deterministic optimisation models, which have not considered uncertainty when generating their optimal solutions, this robust optimisation method applied in the RSCMCG model framework can find robust and optimal solutions to a series of problems in uncertain environments. The preference for risk aversion is presented in the objective function by introducing risk coefficients or a transformed Uset structure in constraints of the Risk Solver Platform. These balance the interplay between profit and risk. This also assists in dealing with risks and thus supports long-term benefits for the company.

The decisions and risk management strategies for each stage made from running the RSCMCG model can support the company in achieving robustness and optimality in the entire supply chain network.

Note

1 $Lev(t) = \frac{TD(t)}{TA(t)}$ (Hill & Jones 2007), with $TD(t)$ for total debt at time period t, which includes long-term debt and short-term debt.

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5 Analysis and discussion

Introduction

This chapter illustrates the implementation of the proposed framework and mathematical model using a hypothetical case study. It first describes the background of the hypothetical case study, input data and data collection process. Next, it presents the numerical implementation of the case study based on the RSCMCG model proposed in Chapter 4. It then demonstrates the corresponding spreadsheet modelling and Risk Solver Platform settings. It ensures the plausibility of the model by following the validation with construct, model structure and results. Following this, it presents the validated model output and analysis through four models of the RSCMCG framework. It states the simulations conducted for the hypothetical case through two other approaches: the deterministic optimisation supply chain model and simulation optimisation supply chain model. It further explores the findings for the proposed RSCMCG model by comparing the results with models using the other two methods. The chapter concludes by discussing the results and achievements of the proposed models.

Background of the hypothetical case study

Scenario description

A hypothetical case is used to present and explain the application of the RSCMCG model proposed in the previous chapter.

The purpose of applying the model to a case study in this research is to present the framework and model results in a practical way that illustrates the influence and impact of good corporate governance (GCG) practices on the design of supply chain networks and strategic decision-making. The scenario contains one core company that targets to establish its strategic planning for supply chain operations over the next three years to achieve maximum shareholder interests while maintaining sustainable supply chain operations in an uncertain environment. To achieve this

DOI: 10.4324/9781003266457-5

goal, the scenario designed must meet three criteria: with respect to supply chain management (SCM), the company in the scenario has a complete supply chain operations system, comprising production, transportation, inventory and market sales; with respect to financial planning and management, the company includes a financial sector featuring the main elements of the company balance sheet; to check the impact of the corporate governance practices and risk management strategies on the model, this study designs different combinations of multiple partnerships in each division, including suppliers, distributions, warehouse and markets. In the production division, it has different manufacturing suppliers with their manufacturing capacities. Assembling the packaging needs enough labour to produce different articles, with availability limitations at certain periods. The transportation division may have alternative shipping options for articles going to different markets. Different shipping lines work under different prices based on time, distance and tolls. Each line also has set load limitations. In the inventory division, there are warehouses for each article to choose depending on market and storage costs. In the market sales division, demands come from different markets, and the core company is responsible for capital budgeting.

In the hypothetical case study, the system is undertaken within a supply chain network that has a core company and related upstream and downstream supply chain partners comprising production, transportation, inventory and market sales (see the company's supply chain networking in Figure 5.1). This core company has two main products: *A* and *B*. It has

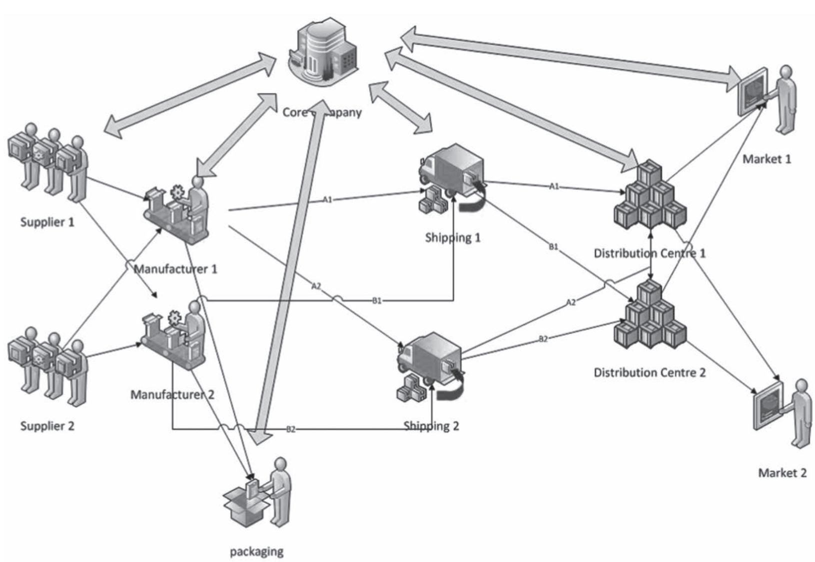

Figure 5.1 Supply chain networking of the company.

two manufacturing suppliers (MA_1, MA_2), two logistics groups for transportation demands (TR_1, TR_2), two distribution centres for inventory (Inv_1, Inv_2) and two markets with different demands for marketing and sales (M^1, M^2).

Unit costs of manufacturing, shipping and inventories increase annually according to the current economic environment. Corresponding unit prices on sales also increase annually. Further, the product demand increases annually as the market is assumed to expand.

Data collection and specification of input data for the hypothetical case

The model proposed in this book requires the details of supply chain systems and financial planning in accordance with the company's corporate governance practices. The data used in this hypothetical case study are drawn from two sources: secondary data and simulated data.

Secondary data for the supply chain operational system are adapted from Shapiro's (2007) cases, including the case example of an integrated supply chain and marketing model for 'Gold Beer with Five ad campaigns'. Data for financial planning are adapted from the case discussion of an integrated financial planning and supply chain production model for 'Ajax Computer Company'. Data from this resource include the first year's unit costs of manufacturing, transportation and inventory and three years' demand from separate markets. These data form the basis for datasets developed later in this chapter. In the context of expansion and inflation, this hypothetical case study applies the annual percentage rate of the increasing unit costs of operational chains over two years based on the industry ratios. For example, an annual increase of 5% for unit manufacturing costs over two years is applied. Here, the average rate of 5% is obtained from the manufacturing industry ratios website,[1] and it fits comfortably between the increasing rate of manufacturing cost of 2.5% in Australia and 13.6% in China (Ai et al. 2009; Mojonnier 2012). The same method is applied to other data using an indexation of 0.07 for transport and 0.03 for inventory.

The experimental data for the above cases have been simulated for the next two years based on practical experience. For example, the original fixed construction of the manufacturing division from Shapiro (2007) has been adjusted for the fluctuating coefficients on assembly elements for practical uncertain environmental considerations.

Data below are presented briefly from three areas: supply chain operations, financial management and corporate governance practices. More details are presented with the numerical model later in this chapter (see 'Numerical implementation of the hypothetical case study with the proposed robust supply chain management and corporate governance mode framework').

1 Supply chain operations division

This area has four operational procedures: manufacturing, transportation, inventory and market sales. The manufacturing division contains the unit manufacturing cost and the product capacity of each factory in a calculated time period (e.g. yearly in this study) for two different products. The transportation division contains the unit shipping cost and shipping limits. The inventory division contains the starting inventory of the first year, unit stock cost and the safety inventory for each production at each distribution centre. The market sales contain the revenue on sales in each market. All the expenses and prices are expressed in thousands of dollars ($'000).

a Manufacturing division

Year 1

Production	*Production capacity at factory (Units)*	*Unit cost on manufacturing ($'000)*
A	4,000	2.75
B	4,800	2.28

The total packaging labour available is limited to 70,000 time units. In a supply chain assembly process, certain hours are required for Product A and Product B as the packaging coefficients to complete production—for example, six hours for A and 13 hours for B. These packaging coefficients for the assembly process are uncertainty elements in the robust optimisation model framework, which is explained in detail later in this chapter (see 'Constraints'). If overtime work is required, the cost will be 0.12 (in $'000) extra per unit.

b Transportation and inventory division

Year 1

Items	*Unit cost on shipping lines ($'000)*	*Unit cost on inventory (units)*	*Starting inventory (units)*
A_1	0.15	0.64	1,200
A_2	0.62	0.64	800
B_1	0.15	0.57	1,100
B_2	0.62	0.57	600

In years 2 and 3, the study assumes indexation of 0.07 for transport and 0.03 for inventory.

c. Market sales division

The demands from markets and associated sale prices for the next three years are listed below.

Items	*Year 1 (units)*	*Year 2 (units)*	*Year 3 (units)*	*Sale prices ($'000)*
A_1	1,458	1,612	1,751	7
A_2	2,475	2,728	2,955	7
B_1	1,188	1,293	1,390	6.25
B_2	1,944	2,108	2,260	6.25

2 Financial division

The financial division contains the variables of current assets, fixed assets, current liabilities, long-term debt, equity, EBIT, after-tax profits, dividends and investment from current assets. All are measured in thousands of dollars ($'000).

Year	*Current assets ($'000)*	*Fixed assets ($'000)*	*Current liabilities ($'000)*	*Long-term debt ($'000)*	*Dividends ($'000)*	*Agency cost ($'000)*
1	3,000	13,000	2,000	6,000	2,500	3,000
2						4,000
3						4,000

3 Corporate governance division

The corporate governance division contains corporate governance principles and relevant policies for the purposes of improving company performance. Incorporating GCG practices leads to reduced agency costs. Details are listed in the next section.

Numerical implementation of the hypothetical case study with the proposed robust supply chain management and corporate governance model framework

This section presents the numerical details of dealing with this hypothetical problem using the proposed RSCMCG model framework in Chapter 4. These include objective function and constraints (in definitional supply chain and financial equations, SCM and financial management equations and corporate governance policies that risk management for SCM and accounting). The numerical model with explanations is presented below.

Objective function

Following the proposed RSCMCG framework in Chapter 3 and the model discussion in Chapter 4, maximising equity as a final target value is recognised as an efficient measure of firm value. This value links operational flow with the financial flow in the SCM framework through EBIT for maximum firm value. With the data obtained, the numerical objective function for this case based on Equation (4-1') is as follows:

$$Max\ f(equity) = Z(t)_E = Z(1)_E + \sum_t \left[\Delta Z(t)_E\right]$$
$$= Z(0)_E + \sum_{t=1,2,3} \left[\Delta Z(t)_E\right] = 8000 + \sum_{t=1..,3} \Delta Z(t)_E$$

$$\Delta Z(t)_E = Z(t)_{PR} - Z(t)_D = (1 - r_{PR})[EBIT(t) - i_{IrD} * Z(t)_L] - Z(t)_D$$
$$= (1 - 0.65) * [EBIT(t) - 0.1 * (6000 + Z(t)_L)]$$

Constraints

Numerical representations of constraints having elements associated with the supply chain, corporate governance and risk management strategies are presented below.

A Definitional supply chain operational and financial equations

Following the definitional equations, (4-2–4-11), in Chapter 4 ('Constraints of the robust supply chain management and corporate governance model'), the supply chain operations and financial elements of this hypothetical case are built up for three years respectively, and the details are depicted here in Sections B.1 and B.2: supply chain operational equation constraints and financial planning constraints.

B SCM and financial management equations

B.1 Supply chain operational equation constraints

The operational chain under consideration comprises manufacturing, transportation, inventory and marketing.

1 Manufacturing function

Based on the data presented in 'Data collection and specify input data for the hypothetical case', the manufacturing constraint is provided, with unit cost 2.75[2] and 2.28 (in \$'000) for products A and B, respectively, and overtime 0.12 (in \$'000) if it is applicable. Further, the indexation for this category is 0.05. Therefore, the manufacturing function for this case adopted from Equation (4-9.1) with three periods is as follows:

$$C(1)_{MA} = \sum_{k=1}^{K} C(1)_{MA_k} = \sum_{k}^{A,B,O} \left\{x(1)_{qMA_k} * c(1)_{MA_k}\right\}$$

$$= x(1)_{qMA_A} * 2.75 + x(1)_{qMA_B} * 2.28 + x(t)_{qMA_O} * 0.12$$

$$C(2)_{MA} = \sum_{k}^{A,B,O} \left\{ x(2)_{qMA_k} * c(2)_{MA_k} \right\}$$
$$= x(2)_{qMA_A} * 2.75 * (1+0.05)^1 + x(2)_{qMA_B} * 2.28 * (1+0.05)^1 + x(2)_{qMA_O} * 0.12 * (1+0.05)^1$$

$$C(3)_{MA} = \sum_{k}^{A,B,O} \left\{ x(3)_{qMA_k} * c(3)_{MA_k} \right\}$$
$$= x(3)_{qMA_A} * 2.75 * (1+0.05)^2 + x(3)_{qMA_B} * 2.28 * (1+0.05)^2 + x(3)_{qMA_O} * 0.12 * (1+0.05)^2$$

2 Shipping balance

Shipping balance Constraint (4-13) is formulating the distribution process. As mentioned previously, two products (A and B) are being shipped to two different markets (M^1, M^2) through two distribution centres (Inv_1, Inv_2) that are designed to be in close proximity in this hypothetical case. Therefore, each product has two shipping line options from their manufacturer (MA_1, MA_2) to two distribution centres (Inv_1, Inv_2). This study assumes that the unit cost differs according to the end point of the shipping lines—for example, from either manufacturer MA_i to Inv_1, they cost the same. Therefore, there are four shipping scenarios: $Y(t)_{qTRA_{MA_i-Inv1}}$, $Y(t)_{qTRA_{MA_i-Inv2}}$, $Y(t)_{qTRB_{MA_i-Inv1}}$ and $Y(t)_{qTRB_{MA_i-Inv2}}$. Equation (4-13) becomes $\sum_{m,n}^{M,N} \theta_{k_{mn}} Y(t)_{qTR_{k_{mn}}} = Y(t)_{qTRk_{MA_i-Inv_i}}$.

For simplicity and clarity, this study uses the following notation: $Y(t)_{qTR_{A_1}}$ (for $Y(t)_{qTRA_{MA_i-Inv1}}$), $Y(t)_{qTR_{A_2}}$ (for $Y(t)_{qTRA_{MA_i-Inv2}}$), $Y(t)_{qTR_{B_1}}$ (for $Y(t)_{qTRB_{MA_i-Inv1}}$) and $Y(t)_{qTR_{B_2}}$ (for $Y(t)_{qTRB_{MA_i-Inv2}}$). $Y(t)_{qTR_A}$ stands for total shipping quantity of Product A while $Y(t)_{qTR_B}$ stands for total shipping quantity of Product B. Therefore, the formulae of shipping balance for three years in this case are as follows:

$$Y(1)_{qTR_{A_1}} + Y(1)_{qTR_{A_2}} = Y(1)_{qTR_A}, Y(1)_{qTR_{B_1}} + Y(1)_{qTR_{B_2}} = Y(1)_{qTR_B}$$

$$Y(2)_{qTR_{A_1}} + Y(2)_{qTR_{A_2}} = Y(2)_{qTR_A}, Y(2)_{qTR_{B_1}} + Y(2)_{qTR_{B_2}} = Y(2)_{qTR_B}$$

$$Y(3)_{qTR_{A_1}} + Y(3)_{qTR_{A_2}} = Y(3)_{qTR_A}, Y(3)_{qTR_{B_1}} + Y(3)_{qTR_{B_2}} = Y(3)_{qTR_B}$$

According to the transportation expenses Equation (4-10), the shipping cost is calculated as $C(1)_{TR} = \left[Y(1)_{qTR_{A_1}} + Y(1)_{qTR_{B_1}}\right] * 0.15 + \left[Y(1)_{qTR_{A_2}} + Y(1)_{qTR_{B_2}}\right] * 0.62$. Transportation costs for the following two years are indicated in 'Data collection and specify input data for the hypothetical case'. Unit cost on shipping is increasing at an annual rate of 7%; therefore, applying Equation (4-10.1), the formulae for the next two years are as follows:

$$C(2)_{TR} = \left[Y(2)_{qTR_{A_1}} + Y(2)_{qTR_{B_1}}\right] * 0.15 * (1 + 0.07) + \left[Y(2)_{qTR_{A_2}} + Y(2)_{qTR_{B_2}}\right] * 0.62 * (1 + 0.07)$$

$$C(3)_{TR} = \left[Y(3)_{qTR_{A_1}} + Y(3)_{qTR_{B_1}}\right] * 0.15 * (1 + 0.07)^2 + \left[Y(3)_{qTR_{A_2}} + Y(3)_{qTR_{B_2}}\right] * 0.62 * (1 + 0.07)^2$$

3 Mass balance

Mass balance is the equation constraint presenting the relationship among inventory, transportation and market demand. The ending inventory of the previous time period becomes the beginning inventory for the current period, to which is added the shipping amount from the manufacturer less the demand from the market M^i in Equation (4-14).

Therefore, for Year 1:

$$X(1)_{inv1_{A_1}} = X(0)_{inv1_{A_1}} + Y(1)_{qTR_{A_1}} - D(1)_{M_{A_1}{}^1} = 1200 + Y(1)_{qTR_{A_1}} - 1458$$

$$X(1)_{inv1_{A_2}} = X(0)_{inv1_{A_2}} + Y(1)_{qTR_{A_2}} - D(1)_{M_{A_2}{}^2} = 800 + Y(1)_{qTR_{A_2}} - 2475$$

$$X(1)_{inv2_{B_1}} = X(0)_{inv2_{B_1}} + Y(1)_{qTR_{B_1}} - D(1)_{M_{B_1}{}^1} = 1100 + Y(1)_{qTR_{B_1}} - 1188$$

$$X(1)_{inv2_{B_2}} = X(0)_{inv2_{B_2}} + Y(1)_{qTR_{B_2}} - D(1)_{M_{B_2}{}^2} = 600 + Y(1)_{qTR_{B_2}} - 1944$$

For Year 2:

$$X(2)_{inv1A_1} = X(1)_{inv1A_1} + Y(2)_{qTRA_1} - D(2)_{MA_1}{}^{1}$$
$$= X(1)_{inv1A_1} + Y(2)_{qTRA_1} - 1612$$

$$X(2)_{inv1A_2} = X(1)_{inv1A_2} + Y(2)_{qTR\,A_2} - D(2)_{MA_2}{}^{2}$$
$$= X(1)_{inv1A_2} + Y(2)_{qTR\,A_2} - 2728$$

$$X(2)_{inv2B_1} = X(1)_{inv2B_1} + Y(2)_{qTR_{B_1}} - D(2)_{MB_1}{}^{1}$$
$$= X(1)_{inv2B_1} + Y(2)_{qTR_{B_1}} - 1293$$

$$X(2)_{inv2B_2} = X(1)_{inv2B_2} + Y(2)_{qTR_{B_2}} - D(2)_{MB_2}{}^{2}$$
$$= X(1)_{inv2B_2} + Y(2)_{qTR_{B_2}} - 2108$$

For Year 3:

$$X(3)_{inv1A_1} = X(2)_{inv1A_1} + Y(3)_{qTRA_1} - D(3)_{MA_1}{}^{1}$$
$$= X(2)_{inv1A_1} + Y(3)_{qTRA_1} - 1751$$

$$X(3)_{inv1A_2} = X(2)_{inv1A_2} + Y(3)_{qTR\,A_2} - D(3)_{MA_2}{}^{2}$$
$$= X(2)_{inv1A_2} + Y(3)_{qTR\,A_2} - 2955$$

$$X(3)_{inv2B_1} = X(2)_{inv2B_1} + Y(3)_{qTR_{B_1}} - D(3)_{MB_1}{}^{1}$$
$$= X(2)_{inv2B_1} + Y(3)_{qTR_{B_1}} - 1390$$

$$X(3)_{inv2B_2} = X(2)_{inv2B_2} + Y(3)_{qTR_{B_2}} - D(3)_{MB_2}{}^{2}$$
$$= X(2)_{inv2B_2} + Y(3)_{qTR_{B_2}} - 2260$$

4 Inventory expense

Basic inventory expense is calculated using Equation (4-11). Therefore, for the first year in this case, $C(1)_{inv} = \left[X(1)_{invA_1} + X(1)_{invA_2} \right] * 0.64 + \left[X(1)_{invB_1} + X(1)_{invB_2} \right] * 0.57$ with unit shipping cost 0.64 and 0.57 (in $'000) for products A and B, respectively.

For the next two years, this study considers indexation of 3% in the hypothetical case study. Therefore, the equation constraints for years 2 and 3 are updated in the original equation by Equation (4-11.1):

$$C(2)_{inv} = \left[X(2)_{inv\,A_1} + X(2)_{inv\,A_2}\right] * 0.64 * (1 + 0.03) + \left[X(2)_{inv\,B_1} + X(2)_{inv\,B_2}\right] * 0.57 * (1 + 0.03)$$

$$C(3)_{inv} = \left[X(3)_{inv\,A_1} + X(3)_{inv\,A_2}\right] * 0.64 * (1 + 0.03)^2 + \left[X(3)_{inv\,B_1} + X(3)_{inv\,B_2}\right] * 0.57 * (1 + 0.03)^2$$

5 Marketing equation

For sales revenue Equation (4-8), with sold quantity for item k equal to demand $D(t)_{M_k{}^i}$ from markets in this study, and with unit cost of 7 and 6.25 (in $'000) for final products A and B, respectively, in M^1, M^2, the numerical equation for Year 1 is as follows:

$$R(1)_{sale} = D(1)_{M_{A_1}{}^1} * 7 + D(1)_{M_{A_2}{}^2} * 7 + D(1)_{M_{B_1}{}^1} * 6.25 + D(1)_{M_{B_2}{}^2} * 6.25$$

For the following two years, this study considers the marketing risk with increasing selling price. For years 2 and 3, the indexation for the sold price of 10% annually is applied in this case. Therefore, for each time period of Equation (4-8.1):

$$R(2)_{sale} = D(2)_{M_{A_1}{}^1} * 7 * (1 + 0.1) + D(2)_{M_{A_2}{}^2} * 7 * (1 + 0.1) + D(2)_{M_{B_1}{}^1} * 6.25 * (1 + 0.1) + D(2)_{M_{B_2}{}^2} * 6.25 * (1 + 0.1)$$

$$R(3)_{sale} = D(3)_{M_{A_1}{}^1} * 7 * (1 + 0.1)^2 + D(3)_{M_{A_2}{}^2} * 7 * (1 + 0.1)^2 + D(3)_{M_{B_1}{}^1} * 6.25 * (1 + 0.1)^2 + D(3)_{M_{B_2}{}^2} * 6.25 * (1 + 0.1)^2$$

B.2 Financial planning constraints

Under the guidelines presented in Chapter 4, the financial planning constraints are incorporated as follows:

1 Financial balance

The start of Year 1's financial status is given. The values of financial elements indicate the starting amount for the years. For example, $Z(1)_E$ presents the equity amount at the beginning of Year 1. As stated earlier in this chapter, the data for the financial division in Year 1 comprises current assets 3,000, fixed assets 13,000, current liabilities 2,000, long-term debt 6,000 and equity 8,000 (in $'000) (Shapiro 2007).

Based on the financial balance Constraint (4-2), the initial equity is as follows:

$$Z(0)_E = Z(0)_{CA} + Z(0)_{FA} - Z(0)_{CL} - Z(0)_L$$
$$= 3000 + 13000 - 2000 - 6000 = 8000$$

Then, for the following years, equity amounts are calculated as follows:

$$Z(1)_E = Z(0)_E + \Delta Z(1)_E$$

$$Z(1)_E = Z(1)_{CA} + Z(1)_{FA} - Z(1)_{CL} - Z(1)_L$$

$$Z(2)_E = Z(2)_{CA} + Z(2)_{FA} - Z(2)_{CL} - Z(2)_L$$

$$Z(3)_E = Z(3)_{CA} + Z(3)_{FA} - Z(3)_{CL} - Z(3)_L$$

2 Fundsbflow equations

The fundsbflow equations of (4-3–4-6) reflect the relationship between SCM and financial planning in company policies, with $r_{PR} = 0.65$, $i_{IrD} = 0.1$ applied in the case. Therefore, $\Delta Z(1)_{CA} + \Delta Z(1)_{FA} - \Delta Z(1)_{CL} - \Delta Z(1)_L - (1 - 0.65)[EBIT(1) - 0.1 * Z(1)_L] + Z(1)_D = 0$

For each year:

$$3000 + \Delta Z(1)_{FA} - \Delta Z(1)_{CL} - \Delta Z(1)_L - (0.35)[EBIT(1) - 0.1 * 2000] + 2500 = 0$$

$$\Delta Z(2)_{CA} + \Delta Z(2)_{FA} - \Delta Z(2)_{CL} - \Delta Z(2)_L - (1 - 0.65)[EBIT(2) - 0.1 * Z(2)_L] + Z(2)_D = 0$$

$$\Delta Z(3)_{CA} + \Delta Z(3)_{FA} - \Delta Z(3)_{CL} - \Delta Z(3)_L - (1 - 0.65)[EBIT(3) - 0.1 * Z(3)_L] + Z(3)_D = 0$$

3 Investment balance

The investment balance constraint allows the company to have a safe and heathy development mode considering the structure of debt and current assets. The change in fixed assets is determined by the change in long-term debt and investment from current assets. In Equation (4-15), $\Delta Z(t)_L$ depends on the company's debt situation. The fixed assets result for the three years is as follows:

$$\Delta Z(1)_{FA} = 1131 + Z(1)_{Inv/CA}$$

$$\Delta Z(2)_{FA} = 0 + Z(2)_{Inv/CA}$$

$$\Delta Z(3)_{FA} = 0 + Z(3)_{Inv/CA}$$

4 Expansion expense

In this study, the investment on expansion decisions appears as the expansion rates of manufacturing capacity and shipping lines (see Section C of this section). Further investment decisions that can be made in the expansion of the company are considered future areas for this research (see Chapter 6).

C. Corporate governance policies: Risk management for SCM and accounting policy

C.1 GCG practices for optimal supply chain operational management from a risk management strategies perspective

1 Supply chain specialised agent governance

For specialised agent governance, Equations (4-17) and (4-18) for this case are presented as below:

$$X(t)_{qMA_k} = \sum_i \sum_k \alpha_{i_k} X(t)_{qMA_k{}^i} = \alpha_{1_A} X(t)_{qMA_A{}^1} + \alpha_{2_A} X(t)_{qMA_A{}^2} + \alpha_{1_B} X(t)_{qMA_B{}^1} + \alpha_{2_B} X(t)_{qMA_B{}^2}$$

$$Y(t)_{qTR_{mn}} = \sum_i \sum_k \beta_{i_k} Y(t)_{qTR^i{}_{k_{mn}}} = \beta_{1_A} Y(t)_{qTR^1{}_{A_{mn}}} + \beta_{2_A} Y(t)_{qTR^2{}_{A_{mn}}} + \beta_{1_B} Y(t)_{qTR^1{}_{B_{mn}}} + \beta_{2_B} Y(t)_{qTR^2{}_{B_{mn}}}$$

2 Risk management strategies for supply chain operational system

a Manufacturing risk management strategies

Based on Equation (4-19), each factory has a manufacturing capacity restriction. The increasing manufacturing capacity r_{capfac_k} here is 20%, therefore:

$$X(1)_{qMA_A} \le CAP(1)_{fac_A} = CAP(0)_{fac_A} * (1 + r_{capfac_A})^0 = 4000$$

$$X(1)_{qMA_B} \le CAP(1)_{fac_B} = CAP(0)_{fac_B} * (1 + r_{capfac_B})^0 = 4800$$

$$X(2)_{qMA_A} \le CAP(2)_{fac_A} = CAP(0)_{fac_A} * (1 + r_{capfac_A})^1 = 4000 * (1 + 0.2)$$

$$X(2)_{qMA_B} \le CAP(2)_{fac_B} = CAP(0)_{fac_B} * (1 + r_{capfac_B})^1 = 4800 * (1 + 0.2)$$

$$X(3)_{qMA_A} \le CAP(3)_{fac_A} = CAP(0)_{fac_A} * (1 + r_{capfac_A})^2 = 4000 * (1 + 0.2)^2$$

$$X(3)_{qMA_B} \le CAP(3)_{fac_B} = CAP(0)_{fac_B} * (1 + r_{capfac_B})^2 = 4800 * (1 + 0.2)^2$$

b Packaging equations

In this hypothetical case, the uncertain parameters are considered to exist in the packaging assembly process in Equation (4-20). They appear as uncertain parameters α_1, α_2 for assembly coefficients of completing the packaging for products A and B, respectively.

$$LA(t)_{qMA_k} = \sum_i \sum_k \alpha_{i_k} X(t)_{qMA_k{}^i}$$
$$= \alpha_1 * x(t)_{qMA^1{}_A} + \alpha_2 * x(t)_{qMA^2{}_B} + (-1) * x(t)_{qMA^3{}_O}$$

For three years:

$$LA(1)_{qMA_k} = \sum_i \sum_k \alpha_{i_k} X(1)_{qMA_k{}^i}$$
$$= \alpha_1 * x(1)_{qMA^1{}_A} + \alpha_2 * x(1)_{qMA^2{}_B} + (-1) * x(1)_{qMA^3{}_O}$$

$$LA(2)_{qMA_k} = \sum_i \sum_k \alpha_{i_k} X(2)_{qMA_k{}^i}$$
$$= \alpha_1 * x(2)_{qMA^1{}_A} + \alpha_2 * x(2)_{qMA^2{}_B} + (-1) * x(2)_{qMA^3{}_O}$$

$$LA(3)_{qMA_k} = \sum_i \sum_k \alpha_{i_k} X(3)_{qMA_k{}^i}$$
$$= \alpha_1 * x(3)_{qMA^1{}_A} + \alpha_2 * x(3)_{qMA^2{}_B} + (-1) * x(3)_{qMA^3{}_O}$$

where α_i is the uncertainty coefficient, as presented in Chapter 4 ('The proposed robust optimisation model for supply chain management and corporate governance'). α_1 is randomly generated between value 5 and 7, while α_2 is randomly generated between value 12 and 14 with the 'PsiUniform' function in D Norm in the Risk Solver Platform. The details of generating process and settings are presented in 'Specify the Risk Solver Platform settings for solution: Task pane tool icons setting for the characteristics of the simulation software'.

Based on Equations (4-20) to (4-20.1) and $r_{pac_k} = r_{capfac_k}$ in this case, the formulae for the three years are as follows:

$$LA(1)_{qMA_k} = \sum_i \sum_k \alpha_{i_k} X(1)_{qMA_k{}^i} \le P(1)_{qMA_k} = 70,000$$

$$LA(2)_{qMA_k} = \sum_i \sum_k \alpha_{i_k} X(2)_{qMA_k{}^i} \le P(2)_{qMA_k} = 70,000$$

$$LA(3)_{qMA_k} = \sum_i \sum_k \alpha_{i_k} X(3)_{qMA_k{}^i} \le P(3)_{qMA_k} = 70,000$$

c Distribution risk management strategies

Based on the distribution policy, a capacity limitation on the shipping line that equals the manufacturing quantity is set in this particular case—from Constraints (4-21) and (4-21.1), this hypothetical case assumes, $CAP_{QTR_{k_{mn}}} = Y(t)_{\ qMA_k}$, and therefore:

$$Y(t)_{qTR_{k_{mn}}} \leq CAP_{QTR_{k_{mn}}} = Y(t)_{\ qMA_k}$$

For each time period:

$$Y(1)_{qTR_A} \leq Y(1)_{qMA_A},\ \ Y(1)_{qTR_B} \leq Y(1)_{qMA_B}$$

$$Y(2)_{qTR_A} \leq Y(2)_{qMA_A},\ Y(2)_{qTR_B} \leq Y(2)_{qMA_B}$$

$$Y(3)_{qTR_A} \leq Y(3)_{qMA_A},\ \ Y(3)_{qTR_B} \leq Y(3)_{qMA_B}$$

d Inventory risk management strategies

The inventory risk management strategy applied in this study is 'safety level', as presented in constraints (4-22) and (4-23). In the hypothetical case, $k(t)_{safe}$ is equal to 0.1, which caters to unexpected or sudden expansion in the market demand. $D(t)_{M_{A_1}{}^1}$ indicates the demand of Product A from market M_k at the time period t. In addition, there are two warehouses here, Inv_1, Inv_2 for stocking two products, A and B, and inventory quantities for each are noted as $X(t)_{inv1_{A_1}}$, $X(t)_{inv1_{A_2}}$, $X(t)_{inv2_{B_1}}$ and $X(t)_{inv2_{B_2}}$. Therefore, the safety level inventory is calculated for three years using the following equations:

$$X(1)_{inv1_{A_1}} \geq B(1)_{safe1_{A_1}} = k_{safe} * D(1)_{M_{A_1}{}^1} = 0.1 * 1458$$

$$X(1)_{inv1_{A_2}} \geq B(1)_{safe1_{A_2}} = k_{safe} * D(1)_{M_{A_2}{}^2} = 0.1 * 2475$$

$$X(1)_{inv2_{B_1}} \geq B(1)_{safe2_{B_1}} = k_{safe} * D(1)_{M_{B_1}{}^1} = 0.1 * 1188$$

$$X(1)_{inv2_{B_2}} \geq B(1)_{safe2_{B_2}} = k_{safe} * D(1)_{M_{B_2}{}^2} = 0.1 * 1944$$

$$X(2)_{inv1_{A_1}} \geq B(2)_{safe1_{A_1}} = k_{safe} * D(2)_{M_{A_1}{}^1} = 0.1 * 1612$$

$$X(2)_{inv1_{A_2}} \geq B(2)_{safe1_{A_2}} = k_{safe} * D(2)_{M_{A_2}{}^2} = 0.1 * 2728$$

$$X(2)_{inv2_{B_1}} \geq B(2)_{safe2_{B_1}} = k_{safe} * D(2)_{M_{B_1}{}^1} = 0.1 * 1293$$

$$X(2)_{inv2B_2} \geq B(2)_{safe2B_2} = k_{safe} * D(2)_{M_{B_2}2} = 0.1 * 2108$$

$$X(3)_{inv1A_1} \geq B(3)_{safe1A_1} = k_{safe} * D(3)_{M_{A_1}1} = 0.1 * 1751$$

$$X(3)_{inv1A_2} \geq B(3)_{safe1A_2} = k_{safe} * D(3)_{M_{A_2}2} = 0.1 * 2955$$

$$X(3)_{inv2B_1} \geq B(3)_{safe2B_1} = k_{safe} * D(3)_{M_{B_1}1} = 0.1 * 1390$$

$$X(3)_{inv2B_2} \geq B(3)_{safe2B_2} = k_{safe} * D(3)_{M_{B_2}2} = 0.1 * 2260$$

e Unsatisfied demand risk

Equation (4-26*) addresses the risk of unfilled demand with penalty factor for a mean-variance robust approach (as discussed in Chapter 4, 'Constructed robust optimisation model framework for integrated supply chain management and corporate governance under uncertainty'), and the formulae are as follows:

$$X(1)_{invjk} + Z_2 = X(0)_{invjk} + Y(1)_{qTR_{k_{mn}}} - D(1)_{M_k i}$$

$$X(2)_{invjk} + Z_2 = X(1)_{invjk} + Y(2)_{qTR_{k_{mn}}} - D(2)_{M_k i}$$

$$X(3)_{invjk} + Z_2 = X(2)_{invjk} + Y(3)_{qTR_{k_{mn}}} - D(3)_{M_k i}$$

It is not applied in the simulation process in this case. Instead, this hypothetical case applies Uset, as discussed in Chapter 4 ('Constructed robust optimisation model framework for integrated supply chain management and corporate governance under uncertainty').

f Marketing risk

Marketing risks are represented by indexation in unit costs of supply chain operations, including manufacturing cost, shipping cost, inventory cost and the increasing market price for the goods. They are sequentially calculated for years 2 and 3 using Equations (4-9.1), (4-10.1), (4-11.1) and (4-8.1) for this hypothetical case study (see Section B.1).

C.2 Corporate governance performance

1 Internal control

Internal control protects a company through a corporation's internal governance. The company in this hypothetical case aims for steady growth and maximising shareholders' long-term interests. Therefore, this study applies superior safety corporate policies in corporate finance management through equations (4-28) to (4-33).

a Debt-to-equity constraint

Debt-to-equity constraint shows the capital structure of the company. To achieve a stable performance with balanced debt and equity, the ratio $K_{D/E}$ is equal to 0.5 in Constraint (4-28) to keep long-term debt in control—that is, 50% of equity. Mathematically, it is presented as follows:

$$Z(1)_L \leq 0.5 * Z(1)_E$$

$$Z(2)_L \leq 0.5 * Z(2)_E$$

$$Z(3)_L \leq 0.5 * Z(3)_E$$

b Investment restriction constraint

For applying Equation (4-29), which reflects the company's investment policy and preference in this case, the formulae are as follows:

$$C(1)_{MA\exp and_k} + FC(1)_{new} - \left[Z(1)_{Inv/CA} + \Delta Z(1)_L\right] \leq 0$$

$$C(2)_{MA\exp and_k} + FC(2)_{new} - \left[Z(2)_{Inv/CA} + \Delta Z(2)_L\right] \leq 0$$

$$C(3)_{MA\exp and_k} + FC(3)_{new} - \left[Z(3)_{Inv/CA} + \Delta Z(3)_L\right] \leq 0$$

This strategic plan is designed for long-term benefits target and steadily development, and in this case, $\kappa = 50\%$ is applied in this investment policy Constraint (4-30). Therefore, for each of the three periods, the formulae are as follows:

$$Z(1)_{Inv/CA} = 50\% * Z(1)_{CA} = 50\% * 3000$$

$$Z(2)_{Inv/CA} = 50\% * Z(2)_{CA}$$

$$Z(3)_{Inv/CA} = 50\% * Z(3)_{CA}$$

c Debt service constraint

For satisfactory debt servicing from EBIT, this case applies Constraint (4-31) and set $\lambda_{EB/L}$ with a typical value of 5 (Shapiro 2007). The interest rate the corporation pays on long-term debt is represented by i_{IrD} with 0.1. Therefore, debt service constraints for each of the three periods, in this case, are as follows:

$$EBIT(1) \geq 5 * 0.1 * Z(1)_L$$

$$EBIT(2) \geq 5 \times 0.1 * Z(2)_L$$

$$EBIT(3) \geq 5 * 0.1 * Z(3)_L$$

d Minimum working capital constraint

Equation (4-32) is applied in this study for imposing a minimum working capital constraint from management. The λ_{WC} is applied with a typical value of 2 (Shapiro 2007). For each of the three periods, the formulae are as follows:

$$Z(1)_{CA} \geq 2 * Z(1)_{CL}$$

$$Z(2)_{CA} \geq 2 * Z(2)_{CL}$$

$$Z(3)_{CA} \geq 2 * Z(3)_{CL}$$

e Leverage constraint

In this case, applying leverage Constraint (4-33) with δ_{Lev} equal to 0.375, it is set for boosting the company's profit while enhancing the safety of the company's financial flexibility. The equations for each of the three periods are as follows:

$$Lev(1) = \frac{TD(1)}{TA(1)} = \frac{Z(1)_L}{TA(1)} \leq \delta(1)_{Lev} = 0.375$$

$$Lev(2) = \frac{TD(2)}{TA(2)} = \frac{Z(2)_L}{TA(2)} \leq \delta(2)_{Lev} = 0.375$$

$$Lev(3) = \frac{TD(3)}{TA(3)} = \frac{Z(3)_L}{TA(3)} \leq \delta(3)_{Lev} = 0.375$$

2 Principal–agent problem

Agency cost increases over time because of demands from marketing and advertising, while it decreases with the implementation of GCG practices. It is accommodated through Equation (4-35) in this case study. With the data obtained, the formulae are as follows:

$$C^{CG}(1)_{AC} = C(0)_{AC} * \left[1 - \gamma(1)\right] = 3000 * (1 - 66.7\%) = 1000$$

$$C^{CG}(2)_{AC} = C(1)_{AC} * \left[1 - \gamma(2)\right] = 4000 * (1 - 50\%) = 2000$$

$$C^{CG}(3)_{AC} = C(2)_{AC} * \left[1 - \gamma(3)\right] = 4000 * (1 - 50\%) = 2000$$

3 Other GCG performance measures (accounting measures)

a Operation margin constraint

Incorporating Constraint (4-38) maintains the company's operations efficiency, and this case study uses average industry ISRATIO $\xi'_{ISRATIO}$ with 0.3. Therefore, the formulae for each of the three periods are as follows:

$$\xi(1)_{ISRATIO_k} = \frac{EBIT(1)}{R(1)_{sale}} \geq \xi'(1)_{ISRATIO} = 0.3$$

$$\xi(2)_{ISRATIO_k} = \frac{EBIT(2)}{R(2)_{sale}} \geq \xi'(2)_{ISRATIO} = 0.3$$

$$\xi(3)_{ISRATIO_k} = \frac{EBIT(3)}{R(3)_{sale}} \geq \xi'(3)_{ISRATIO} = 0.3$$

The ratio measures do not reflect real-world cases when simulating the hypothetical case. However, it can be achieved in a real case study in the future.

Characteristics of the simulation software

Spreadsheet modelling

Some key formulations applied in the simulation of this case study are presented here. For example, 'PsiMean' and 'PsiOutput' are used to simulate uncertainty parameters and the output figures separately. Year 1 details of the case study are presented in table format.

The general process of robust optimisation together with corresponding system settings in detail are presented in Chapters 3 and 4, respectively; the important aspects referring to detailed steps in this particular hypothetical case study are presented in Appendix 5. Please note that the signs '<=, >=' in the spreadsheet are only a memory aid and do not serve as computational functions in this simulation. Instead, the actual calculation and constraints are added in the Risk Solver Platform model tool.

The definition of the objective function, variables and all the constraints are presented in the task pane tool. This can only be achieved in the Risk Solver Platform.

Specify the risk solver platform settings for solution: task pane tool icons setting for the characteristics of the simulation software

All simulations are implemented in the Risk Solver Platform (Version 11.5). General settings for the robust optimisation model are presented in Chapter 4. After adjustments have been made specifically to this particular case, the RSCMCG model for this hypothetical case study is formulated in Excel format, as presented below.

'Model' component under the task pane

Following the setting in the modelling of the spreadsheet, some settings need to be updated in the 'Model' component. The 'Model' component setting can be found under the task pane tool.

After adding the new constraints and making some changes to variables and parameters, the corresponding changes in the Task Pane Model Tap setting need to be made. The specifications in the 'Model' component need to match the spreadsheet modelling in the previous section and the numerical model in the 'Objective function' and 'Constraints' sections.

1 Objective function
The objective function is formulated in the spreadsheet and afterwards set as maximum in the platform 'Optimisation' section in the 'Model' component.
2 Variables
The variables are identified in the Risk Solver Platform to find an optimal solution by running the model.
3 Constraints
Constraints sets are divided into several groups, one of which is normal constraints. Normal constraints demonstrate the simple unequal or equal relationship between the two objectives.
4 Bound
Bound constraints put the statements of zero comparison relationships on the cells.
5 Settings for 'Optimisation' section
Cells for objective, variables and constraints need to be identified and modelled. They may be part of a formula, such as Cell $F$5, to transform the mathematical framework into a simulation system.

To specify the uncertainties in the supply chain case, the uncertainty parameters need to be identified and constrained. In this particular hypothetical case, 'PsiUniform' is applied in the Risk Solver Platform to formulate the random values that uncertainties may occur in the assembly process of two packaging coefficients for products A and B. To be specific, PsiUniform (5, 7) represents a randomly generated number from a value of 5 to 7 and is formulated on cells $B$5, $B$30 and $B$52, while PsiUniform (12, 14) is for cells $C$5, $C$30 and $C$52. Following this, in the Risk Solver Platform, the constraints for the robust optimisation approach are presented as 'Uset' under the 'Chance' option. There are three sets of constraints for the uncertain parameters. For example, Cell $F$5 is the constraint cell for the uncertain coefficient of $B$5 and $C$5 in Year 1, representing the assembly packaging process. The platform formula for this constraint is $USet_{\Omega}(\alpha) \leq \beta$ under 'Chance Constraints' in the 'Model' Tab. The α is the cell with uncertainty, while β shows the uncertainty upper limit. Ω is the conventional size applied to control for robustness. After choosing the option 'add constraint' in the 'Model' component, choose 'Uset'. Then select Cell $F$5 in the RHS column and choose '<=' in the inequities option, followed by filling the left-hand side (LHS) with Cell $J$5. The next step is setting 'size Ω'. 'Size' set is controlling the robustness level of the constraint. The larger this number, the more conventional the solution for the decision provided through the simulation. In this hypothetical case study, uncertainty size is set as 2. Similarly, apply the above procedures to the cells $F$30 and $F$52.

Setting for 'Platform' component

In the 'Platform' component, 'Psi Interpreter' is selected under 'Interpreter' to use the Platform's 'Polymorphic Spreadsheet Interpreter'. Under 'Solve Uncertain Models', choose 'Stochastic Transformation'; then 'Transformation' can be effected to choose 'Robust Counterpart' for robust optimisation. This will result in solving the model in its conventional LP model, but with considerably more decision variables and constraints than the original model (Frontline Solvers 2013a). The use of 'Chance Constraints' is therefore effective only when the above two options are chosen. It is designed to determine the norm (distance measure) used to constrain the size of uncertain sets in the robust counterpart model. The alternatives for this option are L1 Norm, L2 Norm, L-Inf Norm or D Norm (default). It depends on the individual case. D Norm is equivalent to the intersection of the L1 Norm and L-Inf Norm. In our hypothetical case study, uncertain environments are expressed in the form of D Norm in the Risk Solver Platform. If L2 Norm is chosen, the robust counterpart model will be a SOCP model, which requires a SOCP or smooth nonlinear solver such as SOCP Barrier Solver or GRG Nonlinear Solver. When L1, L-Inf or D Norm are chosen, the robust counterpart model will be an LP model that can be solved by LP, QP or SOCP solvers. Regarding the 'Chance Constraints' setting, as mentioned in Chapter 4, the transformation for robust optimisation requires expressing the chance property directly in the constraint itself, not in the formula, and this study uses the Uset under the 'Chance Constraints' option in the 'Model' tab.

Selections for 'Engine' component

In this case study simulation, the engine is chosen automatically by the platform, which is the Standard LP/Quadratic Engine. There are no nonlinear constraints in the case study model.

As mentioned previously, this study applies version 11.5 of the Risk Solver Platform, which does not include the 'stochastic decomposition method' option. Further, since 2014, this engine has been upgraded, with options for 'stochastic decomposition method' bundled within the 'Analytic Solver Platform'. This can be used to solve linear models with recourse variables and uncertainty in the constraints only. The Risk Solver Platform has a new version 12.0, which has updated Excel 2013 support with new Evolutionary Solver power, Stochastic Decomposition, Visualisation and a client for Solver Web Service. Additionally, the LSGRG Nonlinear Engine can be chosen to solve the problem (see Appendix 6 for more details).

Plausibility of the robust optimisation approach and results: generalisation

The validation process follows the steps discussed in Chapter 3 ('Validation of the framework and superiority of the model'). The parameter outcome sets and validation experiments are conducted using the steps of McCarl and Spreen (1997). The details are discussed in this section.

Validation by construct

Following the procedures of McCarl and Spreen (1997), as discussed in Chapter 3 ('Validation and verification'), the validation by construct for the proposed RSCMCG model in this study is checked as follows.

a The models are built using the correct procedures. This is consistent with the previous studies and theories. The RSCMCG model extends the previous supply chain models discussed in Shapiro's (2007) *Modeling the supply chain*, Ragsdale's (2012) *Spreadsheet modeling and decision analysis* and Taha's *Operations research* (2007). Based on the methods proposed in previous studies (Bertsimas & Sim 2003, 2004; Bertsimas & Thiele 2004), this study has constructed the cases and experiments from practical considerations such as spreadsheet modelling cases in previous studies (Balakrishnan, Render & Stair 2007; Monahan 2000; Powell & Baker 2007; Ragsdale 2012).

b Ensuring the trial results indicate that the models are working. Many experiments have been conducted in this study under different scenarios, taking into consideration concerns expressed in previous studies. Adjustments have been made and tested repeatedly until satisfactory results have been achieved.

In the hypothetical case of previous sections, the model had been tested for different conditions and adjusted for a solvable version. For example, in terms of inventory, there is one inventory balance equation that is modelled as $X(t)_{invjk} = X(t-1)_{invjk} + Y(t)_{qTR_{k_{mn}}} - D(t)_{{M_k}^i}$.

The corresponding spreadsheet is (Cell I 22 = S18 + E14–M22; and then copy to J22:L22) and set the binary on I22:L22. However, if one runs the model under this formulation, the results turn out to be an Error. Cell I22 is not a variable but is marked as integer or binary. It needs to be modified as follows:

Q18 = −E14 + I22 + M22 copy to Q19:21

Add one more constraint: $Q18:$Q21=$S18:$S21. Then put the constraints on Q18. Similar processes have been applied for the whole model.

c Ensure that the constraints imposed restrict the model to realistic solutions. The models proposed in this study have been developed from a supply chain operational perspective and combined with risk concerns in financial management. Further, concerns have been incorporated into the objective and constraints to integrate corporate governance and risk management strategies to improve supply chain performance. The procedures and financial elements have been taken from the balance sheets of company's financial reports.

d Ensure that the data are set up in a manner that can be replicated for practical outcomes. The data generated in this study are informed by the practical instructions from Shapiro (2007) and companies' financial reports. Moreover, the models have been tested and analysed under a range of scenarios and repeated many times (more than 100). Therefore, it is expected that the results from the model support decision-makers.

Following the above steps, this study has been conducted under proper guidance, since the early stages of model construction and internal consistency have been ensured.

Model structure

The initial supply chain model framework consists of the essential supply chain procedures, including manufacturing, shipping and inventory, while considering the participants in each division. The initial model has been developed by incorporating financial planning elements in *Modeling the supply chain* (Shapiro 2007) and extended for risk management strategies and corporate governance concerns (discussed in Chapter 4).

This model has implemented the proposed novel framework of integrated robust SCM with corporate governance (RSCMCG model) for risk management. It then presents the influence of its outputs on the improved performance of the company's supply chain and associated financial areas. The focus of the model in this study is to incorporate GCG practices for risk management strategies into the constraints or objectives of a supply chain model to achieve sustainable long-term profit for the company.

Validation by results

After the internal consistency is ensured in the above two sections, the external or representational correctness of the results is investigated.

The models have been designed from output parameters and reflect the behaviour of the company's objective. The measurement of outcomes such as ISRATIO reflecting supply chain performance and firm value have been discussed with the practical cases. The final equity of the firm reflects shareholders' interests and long-term firm valuation. Further on, this study completes the process of 'Validation of Model and Result' at two levels: descriptive and analytical (Islam & Mak 2006) (as presented in Chapter 3, 'Validation and verification'). The objective of the RSCMCG model is to incorporate corporate governance practices and risk management into a supply chain model to maximise long-term benefit for the company and shareholders, subject to the supply chain operations and financial management constraints of that time period. Therefore, the model is validated at a descriptive level. The results of the RSCMCG model support the decisions using parameters such as debt-to-equity ratio, safety stock level and risk control. Revenue growth for the supply chain performance measure also shows the steady increase in the output of the proposed RSCMCG model, which is volatile in the models based on other approaches, such as deterministic optimisation tests (see the results in 'Supply chain model through deterministic optimisation method'). Therefore, at the analytical level, this RSCMCG model is also validated.

The RSCMCG model is a robust optimisation model, and the Risk Solver Platform is used for simulation. The objective of the proposed model is to support strategic decision-making under uncertainty for SCM by addressing the risk management concerns of corporate governance and financial management. The plausibility of the results and the validity of the model criteria for application to SCM are also ensured in the next section using sensitivity and flexibility analysis.

Model results and analysis: robust optimal supply chain management solution under the proposed robust supply chain management and corporate governance model

This section presents the results for the hypothetical case study that are derived from the initial RSCMCG model. After completing the spreadsheet modelling and task pane settings, the model is ready to run for the solution and final result by clicking the green button on the right side of the column task pane list. The RSCMCG model framework has been run in four different models (RSCMCG-1 to 4) that differ in their constraints for certain GCG practices (safety inventory policy, indexation, agency cost problem and manufacturing expansion) for a deep investigation, comparing the outputs and examining the impact of the different strategies. The RSCMCG-1 model considers the safety inventory policy. The RSCMCG-2 model considers the indexation of costs and the agency cost. These first two models are also simulated to compare their results with the initial deterministic optimisation supply chain model and the SCMFP model (see 'Solve the hypothetical case study with other supply chain models through two methods: Deterministic optimisation and simulation optimisation' and 'Findings and decision analysis from the robust supply chain management and corporate governance model'). The RSCMCG-3 model applies the strategies of safety inventory, indexation and the agency cost problem, while the RSCMCG-4 model includes all the above four strategies (and has the same condition presented in 'Numerical implementation of the hypothetical case study with the proposed robust supply chain management and corporate governance model framework'). A summary table for the four RSCMCG models with different sets of strategies is presented in Appendix 5 (Part 2). The details of the first two models are explained in the following three sections. More results and findings from the updated RSCMCG model framework (e.g., RSCMCG-4 model) are illustrated in 'Findings and decision analysis from the robust supply chain management and corporate governance model'.

Results of the validated robust supply chain management and corporate governance model

The first two scenarios of the RSCMCG model framework have been simulated under the following conditions. The first model (RSCMCG-1) is simulated under the scenario of limited risk management strategies, as explained earlier. The output of the RSCMCG-1 model in the spreadsheet format is presented in Appendix 7. Results show an equity of \$29.9M[3] in the final year with a profit of \$33.0M. This model scenario is used for comparison, with results obtained from applying two other methods: deterministic optimisation and simulation optimisation in 'Solve the hypothetical case study with other supply chain management models through two methods: Deterministic optimisation and simulation optimisation', under the same circumstances. To some extent, the results show that the RSCMCG model is more robust and steady than the other two methods (see the findings discussed in 'Findings and decision analysis from the robust supply chain management and corporate governance model').

As mentioned at the beginning of this section, in addition to the RSCMCG-1 model, this study runs a second model RSCMCG-2 for the problem, with consideration of the following: indexation in expenses, comprising manufacturing cost, shipping cost, inventory cost and sales prices; agency cost reduction, from an initial \$3M, \$4M and \$4M to \$1M, \$2M and \$2M during years 1, 2 and 3, respectively. It removes the safety inventory level to investigate the influences of the indexation and agency cost. The results in the spreadsheet format are presented in detail in Figure 5.2a–c. The final validated RSCMCG-2 module for the hypothetical case includes 75 variables, 73 functions and 306 dependants, and it has 58 bounds and 26 integers in the problem. Relevant reports consist of a Structure Report and Answer Report. The 'Output' component of the task tool generates the model analysis and the results in the framework.

The screen message reads as follows: 'Solver found a conservative solution to the robust chance-constrained problem. All constraints are satisfied.' This message appears when solving a model with uncertainty and chance constraints using robust optimisation. The system has transformed the original model with uncertainty into a robust counterpart model that is a conventional optimisation model without uncertainty (Frontline Solvers 2013b).

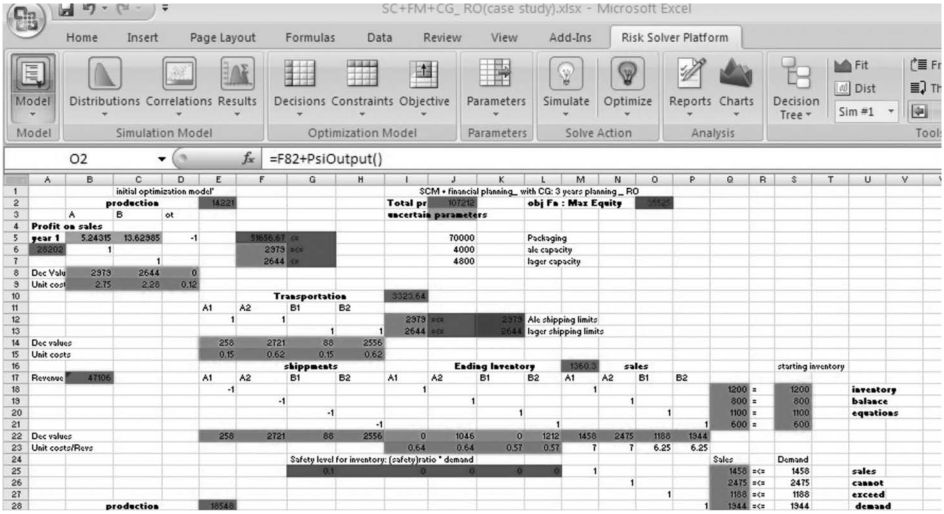

Figure 5.2a Simulation results for the RSCMCG-2 model (Part A).

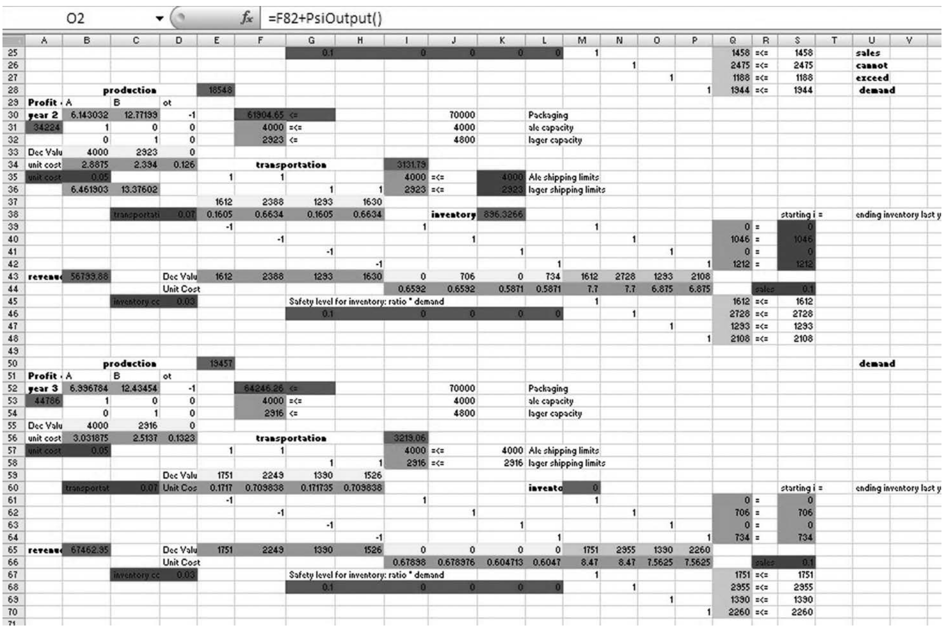

Figure 5.2b Simulation results for the RSCMCG-2 model (Part B).

71																
72														CG		
73		Current Assets	Fixed assets	current liabilities	long-term debt	equity	earnings before Int&taxes	After Tax Profits	Dividends	Investment from Current Assets	Equity minus Debt			agency cost: Marketing and overhe	corporate tax rate	long-term debt interest rate
74										ratio on the investment amount from initial CA	anuual investment increase rate			agency cost reduced with bringing GCG	r	i
75		CA	FA	CL	L	E	EBIT	PR	D	0.5						
76	Start year 1	3000	13000	2000	6000	8000				1500					0.65	0.1
77	Delta	5770.9435	2631	500	1131	6770.9435	27201.51		2500					1000		
78	Start year 2	8770.9435	15631	2500	7131	14770.9435		9270.9435		4385.47175	7639.9435	>=	0			
79	Delta	4143.3757	4385.47175	0	0	8528.847445	32224.0927		2500					2000		
80	Start year 3	12914.3192	20016.4718	2500	7131	23299.79095		11028.8474		6457.1596	16168.7909	>=	0			
81	Delta	5768.5086	6457.1596	0	0	12225.6682	42786.4377		2500					2000		
82	Start year 4	18682.8278	26473.6313	2500	7131	35525.45915		14725.6682			28394.4591	>=	0			
83																
84																

Figure 5.2c Simulation results for the RSCMCG-2 model (Part C).

From the screenshot of the simulation results of the RSCMCG-2 model shown in the Excel sheet (Figure 5.2a–c), the optimal solution for supply chain operations (in yellow) and financial plan (in green) and the objective of maximum final equity (highlighted in red) with risk management strategies (in orange and purple) for supporting the company to make supply chain decisions are presented under the hypothetical case study scenario.

The outcome comprises four elements, as listed below:

1 the final equity and associated profit expected through this plan
2 a detailed three-year supply chain operational plan for the company, including quantities to be produced at each factory, shipping amount on each transportation line and inventory quantities of each product
3 a corresponding three-year financial plan to the above SCM physical chain plan, including debt amount, expenses for company expansion and investment from current assets
4 strategically, this simulation output also presents recommendations for the company about corporate governance practices and risk management strategies, which can bring a sustainable and optimal SCM system.

Making decisions through analyses of the reports and results

Taking the RSCMCG-2 model's results as an example, this section shows its Structure Report and Answer Report to explain the decision-making through the RSCMCG framework.

The Structure Report, as presented in Appendix 8 (Part 1), shows the variables and functions for the problem that has been studied. In this case, the results of the RSCMCG-2 model framework show 75 variables and 73 functions, with 306 dependents.

To achieve the optimum expected objective value at the final equity of $35.5M, the Answer Report in Appendix 8 (Part 2) presents the allocations of resources and operation solutions for the SCM of the hypothetical case. Decisions for Year 1 supply chain operations include manufacturing 2979 units of Product A ($B$8) and 2648 units of Product B ($C$8), without overtime production ($D$8); shipping decisions include transporting 258 units through A1 ($E$14) and 2,721 units through A2 ($F$14), 88 units through B1 ($G$14) and 2,560 units through B2 ($H$14); after satisfying market demands, Year 1 has ending inventory including zero units of A1 ($I$22), 1,046 units of A2 ($J$22), zero units of B1 ($K$22) and 1,216 units of B2 ($L$22). Similarly, the optimal solutions for supply chain operational decisions for years 2 and 3 are presented.

The solutions and strategies under the constraints are also presented in the Answer Report. The constraints section contains formulae for constraint cells, the status of the results for the formulae cells (constraints) and corresponding slack. The majority of the results show two statuses for the constraints: binding and non-binding. The binding status of the constraints illustrates that the associated supply chain resources are all used up based on available amounts without any slack if SCM managers follow the supply chain operational planning and strategies proposed through the RSCMCG-2 model. Accordingly, the same report also has the output for 'slack', showing information about the surplus. Clearly, for binding constraints, the slack value is zero. Binding constraints in this hypothetical case study include sets of manufacturing capacity constraints for Product A, shipping capacity constraints for products A and B, mass balance constraints, financial balance constraints, financial flow equations and investment balance.

The rest of the 33 constraints out of 73 are non-binding constraints, which in this hypothetical study include manufacturing capacity constraints for Product B, inventory safety level constraints, debt and equity constraints and non-negative constraints for decision variables (except overtime working). Associated positive slack value reflects the information of the amount of the residual resource.

There is a special third group in this study in particular that presents the results for $USet_{\Omega}$. Differing from binding and non-binding, the solution for $USet_{\Omega}$ shows '100% satisfied'. The three $USet_{\Omega}$ constraints in this hypothetical case study are set for the packaging hours for assembly process coefficients. The Answer Report in Appendix 8 shows the solution for the 100% satisfied $USet_{\Omega}$ constraint and have 13,233, 12,707 and 7,601 slack units sequentially for years 1, 2 and 3, respectively, in the RSCMCG-2 model. This gives the optimal solution for the assembly packaging quantity and leaves space for risk management in unstable situations.

Sensitivity and feasibility analysis

Shadow costs indicate how far each variable (activity) is from its optimal solution (Pannell 1996). The shadow price of a constraint indicates the amount by which the objective function value changes given a unit increase in the RHS value of the constraint, assuming all other coefficients remain constant.

Risk control is the parameter designed for balancing the risk attitude and profit earning. The range for this factor depends on the decision-maker's preference. Risk-averse investors prefer to put money into safe investments with guaranteed profit and are reluctant to take risk. Risk-averse managers would be likely to set the value for this element higher, while risk seekers would do the opposite. In the Risk Solver Platform, risk preference is incorporated through Usets. The size of Usets represents managers' preferred risk level. The larger the size, more conservative the decision.

The opportunity cost of the activity is the returns from other potential activities that must be taken up in advance to undertaking this activity. The robust optimisation method aims to keep the solution close to optimal while it is still feasible for all the scenarios. To achieve this main target, it forgoes the opportunity of better profits, which is regarded as an opportunity cost.

Solve the hypothetical case study with other supply chain management models through two methods: deterministic optimisation and simulation optimisation

The study further conducts simulations for the hypothetical case with two other approaches (deterministic optimisation method and simulation optimisation method) to present the superiority of the results from the proposed RSCMCG model. The comparisons are made by adjusting a single factor (or a few constraint policies, such as safety inventory policy, indexation, agency cost problem and manufacturing expansion) to examine the impact of GCG practices on SCM performance.

Supply chain model through deterministic optimisation method

The linear deterministic optimisation model for an integrated supply chain network initially investigated the SCM structure from Shapiro's (2007) integrated supply chain model combined with financial planning. A deterministic optimisation model for the integrated supply chain is designed to maximise profit by covering the main processes of supply chain physical flow—manufacturing, inventory, transportation and marketing—while keeping the main financial planning constraints constant (see the mathematical deterministic optimisation supply chain model in Appendix 10).

This section tests the initial SCM model under the deterministic optimisation scheme. All the factors are assumed to be certain and without risks, and the supply chain results are conducted in a certain mode. The results are presented from deterministic optimisation with two versions: the initial deterministic optimisation supply chain model and the deterministic optimisation SCMFP model.

The initial deterministic optimisation supply chain model

The initial deterministic optimisation supply chain model is designed to incorporate physical flow and financial flow, without considering the risk management strategies proposed in the RSCMCG model framework, such as safety inventory level, indexation, agency problem and manufacturing expansion issues. In this section, deterministic LP is used to construct the integrated supply chain and financial management model. The goal of this model is to maximise the value of a firm (indicated by its profitability) and is represented as final equity. The detailed mathematical model of this approach for this hypothetical case is elaborated in Appendix 10.

The decision variables in this model are long-term debt, product quantity, shipping quantity and inventory quantity. This initial deterministic optimisation supply chain model differs from the proposed RSCMCG model in that it does not include uncertainty environment variables, safety inventory level and risk management strategies. The notations are applied as presented in Chapter 4; a full list can be found in the 'List of Abbreviations and Definitions'.

The background of the scenario and the company stays the same as described in 'Background of the hypothetical case study' except for the uncertainties in the packaging process. In this deterministic optimisation, the case applies with certain values 6 and 13 for the assembly coefficients of A and B, respectively. Under these conditions, the results in the spreadsheet are presented as Section 2 of Appendix 10, and this initial supply chain model, in fact, could not find a feasible solution. A further in-depth examination of the infeasibility of the initial deterministic optimisation supply chain model shows that the unexpected increasing demand has exceeded the limited manufacturing capacity of the factory, with a zero inventory policy and absence of other risk management strategies for emergency supply.

The extended deterministic supply chain management with a financial planning model

To find a feasible solution, the initial deterministic optimisation supply chain model is updated here by incorporating the risk management strategy of safety inventory level to be an extended deterministic SCMFP model. The results are investigated using two scenarios—one valued as 6 and 13 and the other valued as 7 and 14 for packaging assembly coefficients[4] of A and B, respectively, to examine the different results due to the changes in circumstances. The relevant peripheral details of the spreadsheet modelling, settings and simulation results for this hypothetical case study can be found in Section 2–4 of Appendix 10. The settings for the 'Platform' and 'Engine' components in the Risk Solver Platform for this SCMFP model are presented in Section 3 of Appendix 10. The spreadsheet modelling results for two scenarios of this SCMFP model in the Risk Solver Platform are presented in Section 4 of Appendix 10 with the following packaging assembly coefficients: (1) 6 and 13 for A and B, respectively, at Scenario 1; (2) 7 and 14 for A and B, respectively, at Scenario 2. The simulation report on running the SCMFP model with coefficient values (7, 14) can be found in Section 5 of Appendix 10.

However, this SCMFP model still does not consider the uncertain environment—instead, it assumes that all the factors are confirmed and then works out the best optimal solution in this context. The solution derived from this model is optimal, which maximises the profit but is not stable. A minor change in the environment or conditions will lead to different results for the problem. This costs more money compared with the case solution under robust optimisation in an uncertain environment.

Supply chain model under uncertainty through simulation optimisation method

Simulation optimisation is applied to uncertainty problems to find an optimal solution based on a series of simulations of the situation (more discussions are presented in Chapter 2, 'Simulation optimisation'). The uncertainty parameter values are generated based on random generators.

To solve the problem under a simulation optimisation approach, corresponding changes should be made in the Risk Solver Platform settings. In the 'Optimisation Model' group, choose 'Automatic' for 'Interpreter'; 'Solve Complete Problem' (or analysis without solve first to examine the feasibility of the proposed model) for 'Solve Mode'; 'Simulation Optimisation' for 'Solve Uncertain Model'. Then move to 'Transformation', selecting 'Automatic' (from the 'Automatic', 'Deterministic Equivalent' and 'Robust Counterpart') for 'Stochastic Transformation'. Select the 'Standard Evolutionary Engine' solver from the dropdown list. The diagrams of the screen for the platform settings are attached in Appendix 11, with separate task pane settings for the 'Platform' and 'Engine' components.

In the above hypothetical case with uncertain packaging assembly coefficients, the uncertainty parameter for the assembly function is assumed to be normally distributed in a simulation optimisation context with corresponding settings in the 'Model' component in the Risk Solver Platform. The objective function is set as maximised expected value of equity from a series of simulations.

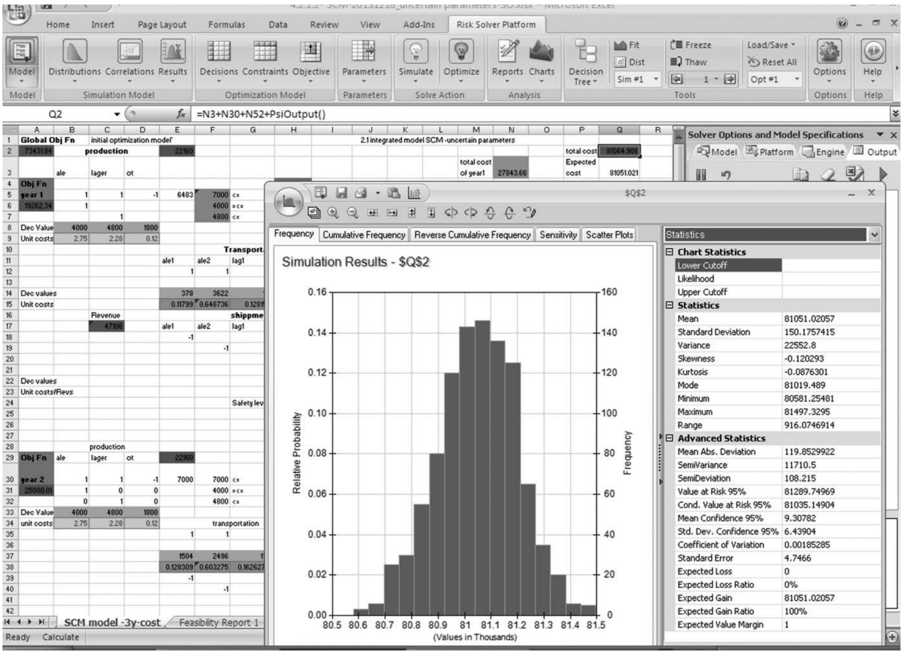

Figure 5.3 Results shown for the SCM model through simulation optimisation.

After application of this model, the output is presented in Section 3 and the Answer Report in Section 4 of Appendix 11. A diagram of the probability distribution for the expected objective value from this solution with this approach is presented in Figure 5.3.

The simulation optimisation method has strength in its generality for generating all the possible simulations randomly. However, it also has weaknesses because it requires a new simulation at each step of the optimisation, and since it assumes no pre-structure in the model, the number of steps can grow exponentially with the number of variables and constraints (Frontline Solvers 2013b). Moreover, it has no concept of recourse decisions. The robust optimisation is capable of solving larger problems faster than the simulation optimisation method (Frontline Solvers 2013b). The RSCMCG models are superior to this model in terms of stability, optimality and feasibility.

Findings and decision analysis from the robust supply chain management and corporate governance model

The previous section conducted simulations with another two methods for solving the hypothetical case: (1) deterministic optimisation: the initial deterministic optimisation supply chain model (referred to as the 'DP [deterministic programming] model' in this section during comparisons) and the SCMFP model; and (2) supply chain model under uncertainty through the simulation optimisation method. This section compares the proposed RSCMCG model's results with those of the above models, focusing on the comparisons between the RSCMCG models and supply chain deterministic optimisation models.

Compare the supply chain management with the financial planning model and the robust supply chain management and corporate governance model

Comparing the results from the SCMFP model framework with packaging coefficient values (7, 14) and the RSCMCG model (in 'Model results and analysis: Robust optimal supply chain management solution under the proposed robust supply chain management and corporate governance model'), the following conclusions can be drawn.

First, the SCMFP model framework is still under a deterministic optimisation scheme that does not consider the uncertainties occurring in the packaging process. In contrast to the initial DP SCM model, which cannot find a feasible solution (see the discussion in 'The initial deterministic optimisation supply chain model'), the SCMFP model framework found the optimal solution for the problem with the addition of a safety inventory strategy. In the (7, 14) scenario, if the company follows the solution from the SCMFP model, it is expected to achieve \$33.5M final equity and \$93.1M profit (see Appendix 10). With similar conditions in the RSCMCG-1 model of safety inventory strategies only, the problem is considered with uncertainty in the packaging process with values for the two assembly coefficients generated randomly in the ranges of [5, 7] and [12, 14] through the Psi function in D Norm in the Risk Solver Platform, respectively. Through the solutions provided by this RSCMCG-1 model, equity of \$29.7M and profit of \$93.0M are expected, with a detailed operations plan and strategies working for all the possibilities. However, if solving this hypothetical case with uncertainties through the SCMFP model framework, it cannot achieve a solution that works for all the possible scenarios occurring in the uncertain environment. It is found that the proposed RSCMCG-1 model is more stable if there are uncertainties and that it can provide a solution that works optimally for the company compared with the SCMFP scheme. The final profit achieved by the RSCMCG-1 model framework has not improved yet, with an 11% decrease in equity and a 0.18% decrease in profit because of its conservative robustness to solve the uncertainty problem.

Second, the RSCMCG-2 model has further improved the framework for better SCM performance with more GCG practices, such as risk management strategies for the indexation of prices and agency problems without the safety inventory policies (which is the same condition with the DP model). From the results shown in Figure 5.14 and Appendix 9, unlike the unfeasibility from the initial DP supply chain model, this RSCMCG-2 model is able to provide a robust optimal solution for the company in the uncertain environment. The results of the RSCMCG-2 model show that the company can finally expect $35.6M of equity and $107.2M of profit by the end of Year 3, which is an improvement of 6.1% and 15.1%, respectively, compared with the deterministic SCMFP model.

It is concluded that the RSCMCG model framework, including models 1 and 2, is superior to the initial DP supply chain model and the SCMFP model in robustness and profitability. More discussion on RSCMCG models 3 and 4 can be found in the following two sections.

Findings for achieving objectives through the corporate governance mechanisms in the robust supply chain management and corporate governance model

Comparing these models, this study finds that if the company follows the corporate governance mechanisms provided by the solutions of the RSCMCG model, it is expected to achieve robust optimal equity and profits for a three-year term. In the example case study, the final equity is $35.53M each year, even in an uncertain environment when the proposed RSCMCG model (RSCMCG-2) is used. This value is higher than the final equity of $34.05M derived from the initial DP supply chain model. The total profit is $94.72M from the DP model compared with $107.21M from the RSCMCG model (RSCMCG-2). Though a profit of $28.20M for Year 1 from the RSCMCG model (RSCMCG-2) is less than $32.90M from the DP model, the profits in the next two years are increasingly stable and yield $34.22M and $44.79M from the RSCMCG model (RSCMCG-2); $28.71M and $33.11M are achieved in the DP model for years 2 and 3, respectively.

In addition, the results from the RSCMCG model framework show a steady increase in EBIT, which indicates a strong ability to service the company's debt obligation, leading to better performance. For example, by running RSCMCG-4, the expected EBIT values for three years are $26.73M, $31.22M and $40.67M. By contrast, the initial DP supply chain model, as discussed in 'Supply chain model through deterministic optimisation method', shows its instability with potential weakness in this capability, with $29.90M, $24.71M and $29.11M of EBIT for three years, respectively. A similar situation occurs in the SCMFP model, with $26.20M, $25.62M and $30.32M of EBIT for three years, respectively.

In the tested hypothetical case study, the actual output from the proposed model turns out to be less than the normal model initially. This is in fact expected as it is based on the robust optimisation theory. Robust optimisation does not aim to obtain the 'best' solution for the present, but it aims for stable and robust results in a volatile environment in the long run. This differentiation identifies the proposed robust model framework for competitive strategy-making. The different experiments using uncertain parameters in the models and the reports of the proposed model show the robustness of the solution and its closeness to the optimal value.

Findings for making decisions through the robust supply chain management and corporate governance model: robustness and optimality

Decisions regarding supply chain operations and financial arrangements for optimal robust equity purposes are made through the RSCMCG model framework in 'Making decisions through analysis of the reports and results'. Risk management strategies are proposed considering the constraints in the RSCMCG model framework.

There are better supply chain operational performances through strategies from the RSCMCG model compared with other methods. Although Year 1's transportation expense is more in RSCMCG-2 at $3.32M compared with $2.33M in the SCMFP model, costs are saved in the next two years even with increased unit costs in RSCMCG-2, with $3.13M and $3.22M from RSCMCG-2 compared with $3.27M and $3.43M from the SCMFP model ($2.08M, $3.40M and $3.58M from the initial DP supply chain model). The results also show expense on operating transportation lines of $2.35M, $3.25M and $3.48M from RSCMCG-1 (see details in Appendix 7), while these figures are $3.37M, $3.24M, $3.47M from RSCMCG-4, considering all the indexation in expenses (see details in Appendix 9). The RSCMCG model has reached the optimality of shipping processes for the company's objective of optimal performance. Similarly, the company keeps its robustness and optimality in inventory performance, spending $1.47M, $1.15M and $0.54M on stock for the three years by following RSCMCG-4 (see Appendix 9). In addition, in RSCMCG-4, the indexation is included, which accounts for market risk. Incorporating indexation in market prices of the RSCMCG-4 model[5] leads to an adjustment in expenses of $19.19M, $3.24M and $1.15M for manufacturing, transportation and inventory, respectively, in Year 2, while increasing 8%, −0.07%[6] and 267.9% compared with the SCMFP model.

Following the corporate risk management strategies made through the RSCMCG model, the company achieves a healthy and optimal capital structure with continuously increasing profit and stable relationships among different elements for adding firm value. For example, the debt-to-equity ratios as the capital structure measure (discussed in Chapters 2 ['Proxies and ratios as corporate governance performance measurement for firm value'] and 4 ['Integrated robust supply chain management and corporate governance model for risk management']) are shown as 2, 0.83, 0.49 and 0.31 for the beginning of the year to the end of the third year (which is the start of the fourth year), respectively, in the RSCMCG-4.

While a high debt-to-equity ratio generally means a company has aggressive financial growth, with debt leading to volatile earning and high bankruptcy risk, the results of the proposed model suggest that financial policies lead to smooth, stable financial growth in capital structure. The ISRATIO shows 0.57, 0.55 and 0.60 in the RSCMCG-4, which indicates good profitability of the company under the strategies provided by the RSCMCG model framework.

Compared with the other three models, the solution from the RSCMCG-4 model provides superior cashflow for the company: $7.47M, $15.65M and $27.13M for the remaining cashflow of equity to pay off debt for three years compared with $7.29M, $16.00M and $26.37M from the SCMFP model. The reason for this is that the RSCMCG model yields a greater reduction in agency cost and better performance in EBIT, which comes from a better SCM performance.

Moreover, the RSCMCG model framework proposed in this study considers uncertainties in the supply chain environment to achieve a robust and optimal objective. For example, this study considers uncertainty in the assembly process in the hypothetical case study, with assembly coefficients ranging between [5, 7] and [12, 14] for products A and B, respectively. This scenario causes the collapse of the initial DP model, and no feasible solution can be found. Conversely, the RSCMCG model maintains feasibility, providing an optimal solution for the unstable case. The SCM performance is further improved by developing the RSCMCG-3 and RSCMCG-4 models from the RSCMCG-1 and 2 models. The RSCMCG-3 model incorporates safety inventory policies based on the RSCMCG-2 model framework, while the RSCMCG-4 further incorporates the expansion policy in manufacturing. The results are presented in Appendix 9. Following the policies and strategies provided by the RSCMCG-4, one can expect the company to achieve $34.23M and $103.61M, respectively, in equity and profit, an increase of 2.3% and 11.3% compared with the results from the SCMFP model.

In addition, incorporating GCG practices in marketing and capacity expansion of the RSCMCG-4 model framework supports the company in achieving a more robust objective under uncertainties and improving SCM performance. The 20% expansion policy in manufacturing provides greater capability in company manufacturing to satisfy the speedy increase in market demand.

Conclusions

Using a hypothetical case study, this study explores how GCG practices interact with SCM to improve the company's operational planning and economic performance. The results from running the model frameworks for the case study explain the elements of corporate governance in an integrated supply chain optimisation model.

First, the risk management strategies as the key elements for GCG practices are addressed through the model framework and case study. The impacts on supply chain performance from these risk management strategies are presented through the results. Risk aversion as an indicator of shareholders risk preference is another GCG practice incorporated into the constraints (or objective function). Constraints on corporate financial management are also shown through their influences on supply chain performance, resulting in better long-term benefits. To deal with the uncertainties existing in the hypothetical case study, the RSCMCG model helps find a stable optimal solution for the company to follow to achieve optimal equity and profit. This is also reflected in the reliability aspect of the proposed model from the GCG practices.

Further, comparing the proposed RSCMCG model framework with other model frameworks that do not have GCG practices incorporated in SCM establishes its superiority. The RSCMCG model framework is more robust while keeping optimality in an uncertain environment and achieving better supply chain performance. Moreover, through the robust optimisation approach, the results and analysis show that the solutions derived from the proposed model are more robust and feasible compared with the solutions from the initial deterministic optimal programming for the SCM model.

To summarise, incorporating corporate governance mechanisms and risk management strategies improves supply chain performance, yielding a more reliable operational chain and enhanced reputation from better demand satisfaction.

Notes

1 http://www.inc.com/quarterly-financial-report/manufacturing.html
2 As explained earlier in this chapter, the units for all the expenses and prices are thousands of dollars ($'000). This is simplified in the numerical model for presentation. For example, 2.75 represents $2,750.
3 $29.9M stands for $29.9 million; the same notation applies throughout this study. In the appendix of the results presentation, for example, the spreadsheet may show the answer with 29,877 for this value, with $'000 as unit measure, and finally rounds to one decimals for presentation (therefore $29.9M).
4 Packaging assembly coefficients: the uncertain parameters in the RSCMCG model, with randomly generated in (5, 7) and (12, 14) for products A and B, respectively
5 Indexation for RSCMCG-4 model: 0.05 in manufacturing cost, 0.07 in transportation cost and 0.03 in inventory cost.
6 −07%: negative sign represents the reduction in this case.

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6 Discussion, implications and future directions

Introduction

To avoid corporate failures and crises caused by agency problems and other external factors, good corporate governance (GCG) mechanisms and efficient supply chain management (SCM) strategies are essential for risk management and decision-making under uncertainty. The literature review in Chapter 2 investigates the interrelationships and interactions among SCM, corporate governance and risk management, especially in the context of a robust optimisation model framework, which has previously not been studied. Chapter 3 discovers the interrelationships and builds an integrated model framework for robust SCM with corporate governance for risk management (RSCMCG) as a principal–agent game theory model. Chapter 4 uses the integrated model framework to develop a computational optimal RSCMCG model for SCM in the context of GCG practices under uncertainty. The RSCMCG model is viewed as a principal–agent game theory model and as an artificial intelligence/machine-learning algorithm. The model is applied to a hypothetical case study, and the results and analysis are presented in Chapter 5. The discussion in Chapter 5 elaborates on the study's contribution to existing theoretical and experimental knowledge and its implications for future work. This chapter presents further conclusions regarding the RSCMCG model framework's findings for corporate governance mechanisms and SCM strategies and illustrates the implications of this study for risk management and decision-making under uncertainty; it also recommends directions for future work.

The chapter first demonstrates further conclusions for making decisions based on the findings from the modelling results in Chapter 5 and for producing sound SCM strategies and achievements by applying the robust optimisation model to supply chain networking. Next, it discusses the propositions of the RSCMCG framework and further illustrates the study implications from a broader viewpoint of SCM, corporate governance and company performance through risk management and decision-making under uncertainty. It then explains the contributions from the theoretical and methodological aspects of the study and delineates how the proposed model framework can contribute to practices, including the areas of

DOI: 10.4324/9781003266457-6

automation. It also presents the study limitations and directions for future research are presented. Finally, the chapter concludes with the key findings of this study.

Decision-making through the robust supply chain management and corporate governance model

The RSCMCG model proposed by this study has been justified and found to be valid in that it adopts an integrated and comprehensive framework and modelling approach to formulate GCG practices for risk management strategies into supply chain decision-making under uncertainties. The integrated RSCMCG model framework is applied with adjustments of the model specifics for different circumstances. This study has simulated four models in the RSCMCG model framework, which are presented in Chapter 5. Findings have been drawn in 'Findings and decision analysis from the robust supply chain management and corporate governance model' by comparing the different models under the RSCMCG framework with three other models—(1) the initial DP supply chain model, (2) the deterministic SCMFP model and (3) the SCM model—in an uncertain environment through the simulation optimisation approach. The study has investigated how the model framework works by incorporating GCG practices to improve performance and demonstrates the superiority of robust optimisation.

The modelling method used in this study shows that the proposed RSCMCG model provides solutions for SCM based on optimal risk management strategies for achieving better performance while keeping profit stable. This study has chosen equity as the objective because it is recognised as an efficiency measure of firm value, and maximising the final equity aims to achieve long-term benefit for the company (see more discussions in Chapters 2 and 3). The goal of business is to enhance economic value through growth and consistency of earnings, cashflow stability and reduced financial distress costs with minimal risk exposure (Zenios 2007). The objective functions frequently applied to previous supply chain models, such as maximising profit or minimising cost, are for meeting short-term targets and operational planning. The equity maximisation objective in the proposed RSCMCG model combined with definitional supply chain operational and financial constraints support the decision-maker pursuing long-term benefit for the company and shareholders while bringing SCM performance into the company's financial management. The results of the proposed RSCMCG model for the hypothetical case study demonstrate its better performance in achieving sustainable benefit for the company. This study has shown how to make decisions regarding company operations through the RSCMCG model in Chapter 5. The constraints of the model impose supply chain operations policies on performance and quantify the GCG practices and mechanisms in the SCM. The results for decision variables provide managers with the strategic plan for SCM and corporate financial management of the company ('Model results and analysis: Robust optimal supply chain management solution under the proposed robust supply chain management and corporate governance model'). The status and analysis of the constraints for the GCG practices provide risk management strategies for company management and the expected results or performance these strategies yield. Moreover, the policy impacts can also be analysed and presented through the output of the RSCMCG model.

The RSCMCG model thereby contributes to the long-term profit of a company and enhances shareholders' interests while dealing with corporate risks and optimising supply chain operational systems. The solutions are analysed by changing the constraints or variables' values. The new RSCMCG model proposed in this study generates reliable, superior and stable solutions.

Implications of the research

The objective of this book has been to formulate the strategies and operations of the corporate governance and SCM game that can provide optimal outcomes for corporations in SCM and firm performance through managing agency risks and other forms of risk for optimal decision-making under uncertainty by adopting decision-support systems and artificial intelligence. This section discusses the implications of the modelling exercises for formulating a set of above strategies and operations that can be followed by the principal and agent to achieve optimal outcomes for the company and for optimal decision-making.

The goal of financial management is to maximise the value of a firm, which is determined by its profitability and risk level. The aim of this study has been to combine corporate governance in the SCM model to maximise the benefit for the company while controlling for uncertainties. Financial planning policies with risk strategies from GCG practices are incorporated into the model.

Implications for optimal supply chain management: a new robust supply chain management framework incorporating good corporate governance practices for risk management

This study has investigated the interrelationships among SCM, corporate governance and risk management and has established a new collaborative framework to support strategic decision-making under uncertainty. Compared with the previous supply chain model frameworks introduced in Chapter 2, which focus on supply chain operation procedures, this framework has been conceptualised by incorporating GCG practices. The risk management strategies from GCG practices are incorporated into the supply chain framework to improve supply chain performance and help the company gain long-term benefits while controlling risks. It is based on the elements of agency theory, principal–agent game theory, supply chain operational networking management, GCG practices and robust optimisation practices, as discussed in Chapter 3.

Based on the framework, the RSCMCG model is developed that combines risk management strategies for SCM and GCG practices. The supply chain in an uncertain environment is further managed by applying robust optimisation through the Risk Solver Platform to guide the company in making decisions using strategies to achieve superior performance. A hypothetical case study of a company has been employed to illustrate the solutions and outputs achieved by applying the RSCMCG model.

The model objectives and constraints are built to consider shareholders' interests and stabilise company profit while maintaining sustainable operational management. The RSCMCG model is a principal–agent game theory model, as the interests, goals and strategies of both the principal and agent are embedded in the objective function and the constraints of the model. The RSCMCG model is also an artificial intelligence algorithm for decision-making and risk management. The final objective of the study has been to maximise equity with profit while managing risk. As reviewed in Chapter 2, proxies can be used for corporate governance performance measurement. This study has used EBIT as a proxy for measuring firm value and supply chain performance in the model, and it has also linked SCM and corporate finance. As discussed in Chapter 5, the study results show how it can be used to investigate the company's corporate performance and thereby improve supply chain performance. Further, the output of this study also shows that by bringing in GCG practices, revenue has increased with EBIT in all RSCMCG models, resulting in increased tax. It consequently increases corporate social responsibility in terms of supply chain performance.

Risk management strategies are provided by incorporating quantified GCG practices into the model constraints. The output of the RSCMCG model explores the impact of risk management strategies in SCM performance and instructs the framework to conduct them in practical supply chain operations management.

Strategies for risk management in supply chain networking based on good corporate governance practices

As discussed in Chapter 2, risks that exist in manufacturing, shipping and inventory operations can have a negative impact on supply chain performance. Most work in psychology represents risk as a situation in which probabilities and outcomes are well specified. However, accurate probability estimates may not always be available; therefore, strategies need to be developed in light of flexible probabilities and outcomes. Incorporating risk management into the SCM model is essential and urgent.

By incorporating risk management, this study has built a RSCMCG framework and model for supporting decision-makers to improve the company's supply chain performance and long-term benefit. The results of running the RSCMCG model in a hypothetical case study have examined the effectiveness of the proposed framework and its application. The following four sections demonstrate the implications of the strategies provided by this RSCMCG model for management in the supply chain based on corporate governance practices and mechanisms for risk management. The first part discusses the integrated supply chain and financial management operations arrangement, and the second part discusses the risk management strategies related to the company's supply chain activities (operational policies). The third part covers corporate governance performance in the supply chain (financial policies). The final section discusses strategies for dealing with particular uncertainties in the environment.

Integrated supply chain management network with operational management and financial management

An integrated supply chain model has been developed in this doctoral research following the RSCMCG framework. It includes policies for physical flows and financial flows. The operational equation constraints represent the fundamental arrangement of supply chain processes while the financial planning constraints support maximising shareholders' value and long-term benefits for the company. To be specific, the integrated supply chain model scheme contains operational policies in the manufacturing function, shipping balance, mass balance, inventory expense and marketing equation, and financial planning in financial balance, funds flow equation, investment balance and expansion expense.

Each procedure in the supply chain operation systems is discussed in Chapter 4 and applied in Chapter 5 for the hypothetical case study through the RSCMCG model. The results from running the model show the connection among the operational processes, strategic decisions for the physical flow with their associated expenses and the financial chain flow. The manufacturing function works on the optimal production decision by considering the balance between demand request and cost while bringing in indexation in the RSCMCG-4 model. In addition, the expansion in manufacturing decisions can be further extended within this frame. Shipping balance captures the different distribution options and associated costs. The decision variables for shipping amounts in each distribution option are provided through this constraint in the model. The mass balance constraint balances distribution, inventory and demand, which incorporates the company policy of fulfilling demand from inventory and manufacturing. Inventory expense and the marketing equation provide the monetary flow in the inventory process and product sales.

The financial balance equation gives the changes in current assets determined by the differences in sums of current liabilities, long-term debts and equity in fixed assets, which, in turn, influences investment decisions for expansion (see Chapters 4 and 5 for further discussion). This equation maintains the balancing, clearly connects the relationships among the key financial elements of the company and presents the company's capital structure. The funds flow equations show the interaction among accounting elements and are also the key link between financial decisions and supply chain decisions through EBIT. These constraints are retained while monitoring cashflow health for long-term benefit. In addition, the investment and expansion constraints have equipped the company with guidance for long-term development.

By applying these above constraints in the case, the basic integrated structure of supply chain operational and financial flows for the company have been realised and can be applied in practice for similar problems.

Risk management strategies related to company supply chain activities (operational policies)

This section discusses the implications for risk management strategies in the company's supply chain operational activities.

1 Strategies related to specialised agent and manufacturing operation policy

Production and procurement procedures are crucial for a company's operations. In this study, supply chain risk management strategies representing supply chains specialised agent governance have been designed into the model and use multiple suppliers with controlled individual supply amounts. Overlooking these factors may lead to manufacturing risk. This constraint spreads the risk of organising all the orders from one supplier. The results show that the proper arrangement of suppliers in the RSCMCG model can distribute more production amounts without breaking the limitation in shipping. It shows 51,656.67, 2,979 and 2,644 units from the maximum capacity of 70,000, 4,000 and 4,800 units in Year 1 RSCMCG-2 model compared with 36,490, 2,979 and 1,432 units in the initial DP supply chain model. Meanwhile, it may also lead to a rise in costs from \$11.46M (DP model) to \$14.22M (RSCMCG-2 model) and \$14.54M (RSCMCG-4 model) by considering this agent policy and uncertainties in the environment to achieve sustainability in the manufacturing process.

For manufacturing capacity, the results of the RSCMCG-4 model framework suggest strategies for investing in production line capacity expansion for each year. This strategy can enhance the company's production capability so that it can deal with increasing demand or shortage risk from the uncertain supply chain environment. For example, through the strategies provided by the RSCMCG-4 model, the production capacity in Year 2 is planned to expand into 4,800 units and 5,760 units for products A and B, respectively, from 4,000 units and 4,800 units in Year 1. This enables the company to produce 4,380 units of Product A in Year 2 to satisfy demand, which exceeds the company's original manufacturing capacity (4,000 units). Consequently, production performance for the company, in this case, is improved by minimising manufacturing risks. Moreover, this can cover the risk from the shortage of stock, which occurs in the initial DP supply chain model.

2 Strategies related to distribution and inventory operations

The distribution strategy is given by the RSCMCG-4 model, which suggests dividing the product into two lines for each product to smooth the shipping amount of each line meeting the demand at the optimal expense. For example, a distribution strategy is given by 1,628, 2,754, 1,304 and 1,426 units for A1, A2, B1 and B2 shipping amounts, respectively, in Year 2, and similarly by 1,765, 2,977, 1,399 and 1,149 units for Year 3. The heavy distribution demand is spread through the four shipping lines to ensure satisfaction in timing and placement. The distribution risk management strategies extend the principal–agent problem with the external supply chain network and provide an understanding of the broad agency problems in SCM. The distribution risk management constraint in the RSCMCG model maintains healthy shipping status for the company in the case by managing the company's limited capability and optimal routine arrangements, even under the circumstance of increasing costs (for example, a 7% rise over the previous year in unit shipping cost in the RSCMCG-4 model).

The RSCMCG model also provides strategies for inventory management applied to the safety inventory level policy. The results from the models show the importance of the safety stock policy in satisfying increasing market demand. For example, the initial DP supply chain model does not apply the safety inventory policy (namely zero inventory in the model), resulting in failure to find a feasible solution in the hypothetical case study. This is caused by increasing demand over production capacity, resulting in unsatisfied order demand (see Chapter 5). By contrast, after incorporating this risk management strategy, the SCMFP model generates an optimal solution. In the final operation strategy, the model requires 1,045, 80, 1,061 and 60 units for A1, A2, B1 and B2 warehouses, respectively, as the ending stock based on the safety level policy, which can cater to increasing demand in Year 2. The safety stock level is set as 10% of the demand from markets in the RSCMCG-4 model. For the first year, 145.5, 247.5, 118.8, 194.4 units are designed as the safety level based on the markets' demands in the hypothetical case. Eventually, combined with the three-year operations plan, the RSCMCG-4 model suggests 146, 248, 119 and 2,019 units to be stored at warehouses A1, A2, B1 and B2, respectively at the end of Year 1 for safety stock requirements. Similar strategies are made for the following two years. In conclusion, a safety inventory level policy combined with associated expenses helps the company maintain enough stock to meet fluctuations in market demand while minimising inventory costs. Therefore, as discussed in Chapters 3 ('The proposed new robust supply chain management and corporate governance model framework and specifications of model elements') and 4 ('Constraints of the robust supply chain management and corporate governance model'), it enhances the company's reputation and long-term benefit.

Risk management strategies related to corporate governance in supply chain management, financial policy and corporate performance

As discussed in Chapters 2 and 3, implementing GCG practices can improve firm performance. This study identifies the internal control policies and derives strategies from corporate governance instruments for providing an understanding of their incorporation within the SCM system. This study combines corporate financial management in the SCM by employing fundamental financial rules, funds flow policy and investment in expansion policies. The financial risk considerations, financial policies and internal governance instruments incorporated into this study are used to explain how the company can balance financial and investment decisions while minimising risks and maintaining benefits.

Internal control plays an important role in achieving good firm performance, as discussed in Chapter 2. Although long-term debt is usually set as zero or no cashflows from debt financing, the output of the proposed RSCMCG model suggests a certain safety level of debt. While debt financing provides benefits, such as substituting weak internal governance and reducing agency cost, it also contains financial risks. Three constraints on long-term debt in terms of financial policies are incorporated into the model and can protect the company from the risks of bankruptcy and insolvency. The first is the debt-to-equity constraint, which disciplines managers by limiting their allowable amount of long-term debt in a certain ratio value of equity,[1] minimising financial distress and avoiding the risk of bankruptcy. The second is the leverage constraint, which limits the amount of long-term debt by restricting it to a certain percentage of total assets, therefore avoiding any misconduct on the part of managers and minimising financial distress and further bankruptcy risks. The third is the debt service constraint, which controls the relationship between EBIT and long-term debt. It serves to protect the company from the risk of insolvency and allows the reduction of agency costs through debt monitoring. The results of RSCMCG-4 in this study suggest a stable amount of long-term debt in three years, and the RHS of the debt-to-equity constraint shows the balance amount of equity subtracting debt, where a steady increase ensures a safety level of debt. The results also show the company's financial reliability through its payment capability for long-term debt. Having incorporated constraints for leverage and bankruptcy risks, this study minimises the company's bankruptcy risks related to debt financing while ensuring an effective internal mechanism in debt control to minimise agency cost. In addition, the constraint on minimum working capacity ensures sufficient funds for maintaining a steady working capability through investment in labour expenses.

The principal–agent problem is another key issue associated with improving firm performance (see Chapter 2, 'Key corporate governance issues pertaining to supply chain management') by resolving agency problems and reducing agency costs. Agency theory in SCM and corporate governance both address the problem of conflict between principal and agent in management. This study provides further understanding of the principal–agent problem and agency cost management through a principal–agent game theory model. The expanded principal and agent game in the external supply chain network is demonstrated through SCM specialised agent governance in the RSCMCG-4 model and proves its effective function in the previous section. The agency problem is further extended in this framework with risk management strategies in agency cost constraints. Incorporating GCG practices such as debt monitoring in this model leads to the associated reduction of agency costs. In the hypothetical case study, taking the RSCMCG-4 model as an example, the agency cost is reduced to $1M, $2M and $3M for each of the three years, respectively, from $3M, $4M and $4M by incorporating GCG practices.

Finally, the results of running the RSCMCG-4 model show the final financial structure outcome expected for the company. For example, current assets in the RSCMCG-4 model are $8.61M, $14.53M and $22.64M for each of the three years, respectively, compared with $8.42M, $12.92M and $16.83M in the SCMFP model. The chain of our RSCMCG-4 model shows steady current assets. Through running strategies provided by the RSCMCG-4 model, in the final year, $22.64M, $21.26M, $2.50M, $7.13M and $34.27M are expected for current assets, fixed assets, current liabilities, long-term debts and equity, respectively, compared with $16.83M, $26.30M, $2.50M, $7.13M and $33.50M given by the SCMFP model's results. The current assets flow and equity of the company are stronger under the RSCMCG-4 model frame, with other financial factors, such as current liabilities, remaining steady; thereby, it also enhances the company's ability to meet short-term obligations measured by their higher liquidity ratio.[2] The decision-making on investment amount in the expansion is affected by the current assets in this RSCMCG model framework. Following this policy, increasing the RHS of the financial balance equation could increase the investment for future development.

Strategies for making decisions in the supply chain under uncertainty

In this study, risk management strategies and the robust optimisation approach are incorporated into the RSCMCG model framework to support decision-making in an uncertain supply chain environment. For example, the coefficients of the packing process are taken as uncertain in the hypothetical case study in Chapter 5. Following the RSCMCG framework, the corresponding numerical model has been constructed to support the company in the hypothetical case to make decisions for its SCM under uncertainty.

By examining risk management strategies and the robust optimisation approach related to supply chain networks and internal company governance in the RSCMCG model framework, this study extends the previous work of other researchers in SCM decision-making under uncertainty. For example, Shapiro (2007) explored data-driven versions of deterministic optimisation and stochastic programming models for supply chain decision-making under uncertainty while focusing on short-term strategies hedging against these contingencies. Some other studies have focused on the robust optimisation approach (Ben-Tal et al. 2005; Ben-Tal & Nemirovski 2002; Bertsimas, Brown & Caramanis 2011; Bertsimas, Pachamanova & Sim 2004; Hahn & Kuhn 2012b). The results of this study show that supply chain risk management strategies such as specialised agent governance, stable capacity for manufacturing risk management strategies, distribution risk management, safety inventory policies and marketing risk management, combined with the robust optimisation approach for dealing with uncertainties in the packaging procedure, are effective internal and external governance instruments for contingency management in supply chain networks. It provides a stable optimal operational solution and risk management strategies for the company and expects to achieve reliable targets in a fluctuating environment such as uncertain coefficients in the packaging process.[3]

Corporate governance in the supply chain: improved supply chain performance through incorporating good corporate governance practices

Corporate governance is very important for strategic operational planning in the supply chain industry. Decision-making under uncertainty needs support from corporate risk management to improve performance. Incorporating corporate governance and SCM is vital to achieving stable and optimal solutions in an uncertain environment.

This study fills the research gap in the literature by connecting corporate governance principles with SCM, especially from a decision-making perspective. A practical and robust supply chain model framework for formulating risk management strategies that can achieve benefits for GCG practices has been built through this study. Further, it contributes to theories and practices by providing in-depth insights into how to link GCG practices with SCM. It integrates GCG practices into supply chain system strategies. These strategies incorporate the broader concept of GCG practices and normative corporate governance principles into specific quantitative monetary units; therefore, the effectiveness of GCG practices can be assessed. For example, in Chapter 4, the proposed RSCMCG model framework defines GCG principles, which respect the rights of shareholders, and measures the effectiveness through an increased shareholder interest. Equity, chosen as a proxy for shareholders' interests, can also assess the company's long-term benefit and future sustainability. High equity demonstrates a company's sustainable performance, which means the company is able to fulfil the GCG principles related to stakeholders' interests, and thereby achieve high EBIT, meaning the company can contribute more tax to the government that raises its corporate social responsibility profile, settle its trade payment to suppliers and pay salaries and employees' benefits to managers and staff. Further on, better performance in corporate social responsibility can stimulate a better supply chain environment for the company (Ciliberti, Pontrandolfo & Scozzi 2008).

This study offers further insight into risk management strategies that can improve supply chain performance through GCG practices. An overarching objective of incorporating risk management is value creation for the company. This study addresses how GCG practices should be incorporated into the SCM optimisation model to improve supply chain performance and to create value and long-term benefit. The importance of corporate governance factors such as internal control and principal–agent problems are identified in this new RSCMCG framework. Internal control constraints, such as debt-to-equity balance, investment restrictions, debt service constraint and safety leverage level control, are incorporated and illustrate their functions in the hypothetical case study in Chapter 5 of steady financial flow in an uncertain environment.[4] For example, the investment restriction and safety leverage level constraints can reduce the waste of monetary flow and reduce the risk of over-expansion or debt and, in return, increase trust in organisations.

In particular, this study provides an extended understanding of the concepts of the trust role of corporate governance, as discussed in previous studies (Handfield & Bechtel 2002; Ireland & Webb 2007; Jie, Parton & Cox 2007; Kwon & Suh 2004; Welty & Becerra-Fernandez 2001). It also offers further insight into a reliable system and supply chain framework. The RSCMCG model proposed in Chapter 4 is required to support such an alliance of trust. Illustrated through the results of the RSCMCG model for the hypothetical case study in Chapter 5, the company has a stabilised financial structure, showing the well-balanced debt and equity, steadily developed investment, satisfied capability in payment of the debt and safe leverage ratios; it deals with the contingencies of the environment by following the plan and strategies provided by the RSCMCG model. Consequently, this reliable system can enhance the trust-based relationship among manufacturers, suppliers, distribution centres and shipping operators in the supply chain network that embraces all components, from raw materials to the end-customer, resulting in further improvements in supply chain performance and firm value performance in the future.

The RSCMCG mathematical model in Chapter 4 and the numerical model application in Chapter 5 are able to provide the instruments for quantifying broad concepts of GCG practices to the optimal management of operations, risk policies and internal control, and normative risk management strategies in the company. In addition, the numerical models in Chapter 5 illustrate the risks of internal governance, external regulatory surroundings and the supply chain environment. Through integrating supply chain operations management and corporate risk management, this study also shows how good risk management strategies can help management mitigate these risks. By examining risk management policies related to inventory safety level, indexation, principal–agent problem and capacity extension through different numerical models of the RSCMCG model framework, this study shows that they are effective governance instruments that can improve supply chain performance, extending the previous supply chain model studies of Shapiro (2007) and others from the perspective of integrating GCG practices into SCM optimisation.

Theoretical and methodological implications and contributions of the study

Theoretical implications and contributions

The main aim of this study has been to formulate risk management strategies for GCG practices to improve supply chain performance in the context of making decisions for SCM in an uncertain environment. To achieve this aim, this study has explored theories on SCM, corporate governance, risk management and robust optimisation for decision-making under uncertainty.

The expected main contributions of the book are discussed in Chapter 1. The experience of the modelling study has confirmed the following contributions, among others.

The book contributes to SCM literature by developing an integrated framework based on managerial and financial perspectives for achieving the benefit of risk management strategies for GCG practices such as managing risks and improving performance. The framework is depicted in Figure 6.1. In line with GCG principles and SCM theories,[5] this study associates company performance with shareholders' value, robust supply chain operations and resource optimisation. Extending the studies on lean production, real-time and just-in-time of SCM (Bozarth & Handfield 2005;

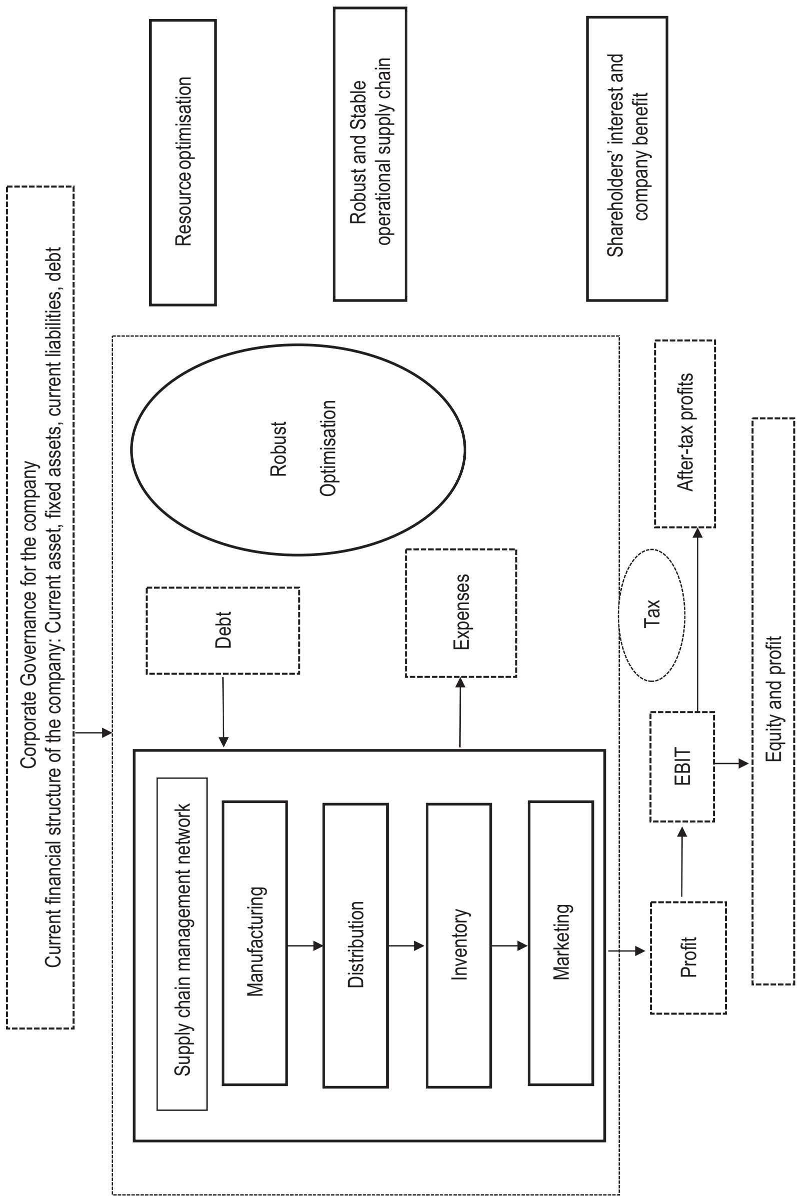

Figure 6.1 An integrated framework for achieving the benefit of risk management strategies for GCG practices.

Handfield & Nichols 1999; Jacobs & Chase 2011; Neef 2004), which focus on strategies to achieve short-term profit, this study provides strategic planning for shareholders' value and long-term benefit for the company in an uncertain supply chain environment. Developing on the fundamentals of the interrelationships among SCM, corporate governance and risk management, the integrated framework provides an understanding of how to formulate risk management strategies for integrated operational and financial chains from a GCG practices perspective and analyses the influences of these strategies on supply chain performance. As a consequence, this study provides supply chain decision-making strategies for operating systems to achieve robust supply chain networks and optimisation of resources, which extends previous work (Agrawal, Smith & Tsay 2002; Graves 1988; Moinzadeh 2002; Shapiro 2007) that focused on integrating specific company objectives.

This study provides an extended understanding of corporate governance in company SCM. It extends the understanding of the governance role of corporate financial management in supply chain networks, as previously discussed by Shapiro (2007), while bringing in ideas of corporate risk management frameworks from Léautier (2007). From a corporate finance and accounting practices aspect, more equations and constraints on managing the relationships between corporate financial management and supply chain operations are included and worked interactively to improve the strategic planning of firms. In addition, from an SCM perspective, corporate risk management strategies from agency theory and managerial practices are incorporated into the RSCMCG framework, such as diverse suppliers, alternative shipping lines and safety inventory. By employing equity as a proxy for shareholders' value and long-term benefit for the company, this study highlights the importance of corporate governance concepts that ultimately maximise equity calculated from financial flow equations with EBIT. Using EBIT as a proxy of shareholders' benefit, one can build the linkage between SCM and corporate governance. The results of this study show that equity is optimal; therefore, optimal shareholders' value and long-term benefit for the company have been achieved by employing risk management strategies from corporate governance.

This study contributes to corporate governance literature by incorporating GCG practices into SCM, as discussed in 'Corporate governance in supply chain: Improved supply chain performance through incorporating good corporate governance practices', and by providing an extended understanding of principal–agent problems in corporate governance and how they relate to SCM performance. This study supports the argument that agency cost can be reduced by the optimal capital structure on the separation of ownership and control with the firm theory of Jensen and Meckling (1976) such as the incentive effects associated with debt. This is presented in the corporate finance and accounting practices for corporate governance performance constraints of the RSCMCG model framework. In addition, the approach in this study to the agency problem is extended by applying the external supply chain network of the company as principal and the participants in the supply chain as agents—this differs fundamentally from most previous literature on corporate governance, which has focused on the governance of the company and the relationship between agent (i.e., manager of the firm) and principals (i.e., outside equity and debt-holders), agency cost and firm performance (Berger & Di Patti 2006; Cyert, Kang & Kumar 2002; Jensen & Meckling 1976; Larcker, Richardson & Tuna 2007; Wang & Sami 2011).[6] The collaborative RSCMCG system is intelligently connected through the supply chain specialist agent–governance constraint. The results from the RSCMCG model in Chapter 5 shows that employing the extended agency problem from agency theory in SCM with the external supply chain network effectively stimulates the supply chain performance in both monetary and operations flow.

The study provides a framework for integrating risk management strategies from GCG practices in SCM for decision-making under uncertainty, extending the understanding of the risk management framework in previous studies, such as supply chain risk management (Waters 2011) and ERM[7] (Committee of Sponsoring Organizations 2013), through robust optimisation theory (Bertsimas & Sim 2003; Bertsimas & Thiele 2004; Tang 1990). The results of this study show that risk management smooths the instabilities of outcomes that may occur in the initial linear deterministic supply chain optimisation model, such as the over-expanding manufacturing order, the over-capacity of shipping or shortage in stock. The strategies from the RSCMCG model framework provide the approach to managing these risks and uncertainties and can be specified with further targeted company information. Moreover, risk management strategies balance the supply chain agencies' conflicts and improve operations performance. The RSCMCG model framework in this study achieves stable internal development for the company and external network collaborations among the supply chain partnerships for long-term benefit while considering decision-makers' risk appetite and tolerance factors through optimisation modelling based on robust optimisation and machine learning.

Methodological implications and contributions

Despite a considerable number of studies on supply chain models, this study provides a new insight into applying the robust optimisation approach. An integrated model for optimal SCM, including material and cashflow processing that also considers the effect of corporate governance under risk management, is a new idea that has been subject to limited discussion. The RSMCG model is a principal–agent game theory model and provides an artificial intelligence algorithm for machine learning for decision-making, risk management and strategy formulation for improved company performance.

This study further provides an understanding of integrating GCG practices in the linear optimisation supply chain model, extending the supply chain model of Shapiro (2007) and Ragsdale (2007, 2012) with more corporate governance risk management strategies (Léautier 2007). It incorporates risk management strategies and GCG concepts into the model objective and constraints. The objective function of the model uses equity, which is applied as proxy of shareholders' value and links the operational supply chain with corporate governance through the EBIT equation. The equations of the model include the balance sheet of the financial division and operational conditions of the supply chain division to achieve an improved approach to strategic planning, reflecting the relationship between SCM and corporate governance. The fundamental supply chain operational and financial constraints are extended with risk management strategies and GCG practices. Risk management strategies quantify normative GCG principles into specific quantitative monetary variables and supply chain operations in the model so that the effectiveness of GCG practices is addressed in the management of the supply chain to achieve long-term benefits. As discussed in Chapters 3 and 4, with application in Chapter 5, the RSCMCG model proposed in this study also incorporates decision-makers' risk preference when facing uncertainties in the supply chain environment, considers the uncertainty factors in the supply chain environment and then achieved the stable, optimal risk management strategies of the SCM for the company.

The robust optimisation approach, a suitable mathematical program, is explored to implement the framework, providing new insights and a way to study corporate governance in combination with SCM. It also provides an understanding of integrating corporate governance concepts in the optimisation model. The Risk Solver Platform was chosen to simulate and present the model in a practical sense and can be applied in many commercial operations.

This book presents an innovative approach to SCM through the development of the RSCMCG framework and derivation of the RSCMCG model that handles risk management through robust optimisation. It successfully incorporates GCG practices into SCM to achieve superior supply chain performance.

Practical application of the proposed framework

This study uses a hypothetical case study to illustrate the RSCMCG model's improved supply chain performance by incorporating risk management strategies from GCG practices. It extends the previous studies (Calder

2008; Collier & Agyei-Ampomah 2008; Daelen & Elst 2010; Scott 1998; Zulkafli & Samad 2007) that focus on heuristic and qualitative analysis of GCG practices to improve firm performance.

This RSMCG model can be incorporated in automated ERP, supply chain, risk management and corporate governance artificial systems (Libert, Beck & Bonchek 2017) as an intelligent decision-support system.

Various studies have shown that GCG practices can improve firm performance (presented in Chapter 2). This study demonstrates the impact of GCG practices on supply chain performance by applying the RSCMCG framework to a hypothetical case study. The results show that risk management strategies are an effective way to include GCG practice in SCM and operational performance (discussed in 'Strategies for risk management in supply chain networking based on good corporate governance practice'). For example, maintaining supplier diversity and specifying restrictions for each supplier is a strategy for avoiding unsatisfactory manufacturing capacity. In particular, this will turn out to be very important when there is an unexpected demand expansion or when a natural disaster occurs.

This study proposes a robust optimisation modelling framework for integrating SCM with GCG practices for risk management, in the presentation of the conceptualisation and computationally feasible formulations. The proposed approach has flexibility in different model assumptions and the extension of supply chain industries' configurations.

The RSMCG model framework presents instructions for modelling the corporate governance principles into the supply chain network governance and internal company management. Further, it elaborates the risk management strategies for running the numerical RSCMCG model with specified company data and information for individual cases.

Limitations and recommendations for future research

By developing the RSCMCG model, this study contributes to SCM and risk management frameworks and optimisation modelling. Despite achieving good SCM performance and proposing effective risk management strategies for the company, there are some limitations to the model, and it requires further extensions; these are discussed in this section.

Future extension to robust supply chain management and corporate governance framework

In future research, the RSMCG model should be integrated into automated ERP, supply chain, risk management and corporate governance artificial decision-support systems (Libert, Beck & Bonchek 2017).

As stated above, the proposed RSCMCG model framework is an extension of existing supply chain modelling proposed by Shapiro (2007) and Ragsdale (2007, 2012) and of corporate governance risk management strategies (Léautier 2007). The RSCMCG model has demonstrated its superiority in dealing with decision-making under uncertainty in SCM. However, the integrated framework proposed in this study can be more useful if future work can extend it in the areas of financial management and operational management. This study has considered financial elements to bridge connections between SCM and corporate governance—for example, equity as the objective of shareholders' interests and EBIT as the linkage of financial flow and physical flow in the RSCMCG framework. Further research can apply other financial elements relevant to individual cases, such as free cashflow to equity to measure shareholders' rights. In future, capital budgeting and income statements, which show specific details about a company's financial and operational performance, can be further used to improve decision-making. Other operational management strategies with financial policies can be applied—for example, extending investment in expanding production capacity with more details of the supply chain operation system expansion, such as facilities or factories replacement. As a result, the model can provide specific operational expansion plans for the company, which can be combined with other investment decisions for financial projects in future research.

The model can be extended with other governance instruments, such as managers' compensation reward systems and alliance strategies. Board governance is related to the structure and size of the board, the quality of the board of directors and the audit committee. Linking managers' compensation to the company's supply chain performance and governance through the model can enhance the power of the framework.

In addition, the current SCM sector can be extended with more competitive practical supply chain strategies, such as alliances. This may be more expensive in terms of direct procurement costs. However, these strategies allow the company to significantly reduce overheads for maintaining a large supplier list and for negotiating and monitoring contracts with multiple suppliers of specific items. Such relationships also permit the company to focus on product quality and to more easily achieve integrated SCM with its suppliers, thereby reducing inventory costs (Shapiro 2007).

Further research can also be extended by studying the company's corporate governance principles and policies to improve the model framework and its ability to combat the financial crisis and enhance performance. The results from this study can act as a pilot for those who want to explore this area and discover the impact of GCG practices on a company's performance.

Future extension of the simulation and applications

The RSCMCG framework has been applied to a hypothetical case study using simulated data from a random number generator. Bootstrapping from historical data can be another optional way to randomly generate scenarios for forecasting purposes when the company has a historical database (Pachamanova & Fabozzi 2010), while scenario generation methods can be another option for stochastic programming (Cornuejols & Tutuncu 2007). To develop the model further, the RSCMCG framework can be applied to listed companies with supply chain networks involving manufacturing, distribution, inventory and marketing procedures such as Walmart or Li & Fung Limited.

Finally, using e-commerce technologies such as business-to-business can enhance efficiency and competitiveness in SCM (Simchi-Levi, Thorne & Hilton 2009). For integrating SCM and corporate governance, considering the incorporation of hardware and interfaces into the system is essential for a systematic framework in the future. This will strengthen the coordination among related channel partners in the supply chain and enhance company governance in information gathering, transmission and sharing as well as cross-company communication. Therefore, the proposed RSCMCG model can be extended by incorporating the 'Service System', which is depicted in Figure 6.2. In this extended framework, the new sector 'Service System' comprises six service divisions: knowledge management, data management, task management, communication management, information management and risk management (Lou & Dai 2015). Knowledge management services include directing and coordinating the information flow and task allocation and problem-solving processes. Data management services include coping with the framework's internal and external data retrieval and storage requests. Task management services include describing task profiles and requirement details (such as purchase order issued by a retailer). Communication management services are responsible for all the external communication needs of the framework, such as the facilities for internet communications. Information management services maintain a transparent process during problem-solving and assist users' engagement with the system as well as delivering information in relation to users' queries. In addition, risk management services are designed to deal with unknown or uncertain factors to keep the services system in a steady and optimal status with the help of the RSCMCG model proposed in Chapter 4. However, they are not presented in the book. In future, this integration can be further developed. The architecture of the information system will support transparency among the members of the supply chain, and this can further improve the mutual adoption of GCG policies and practices in the RSCMCG framework.

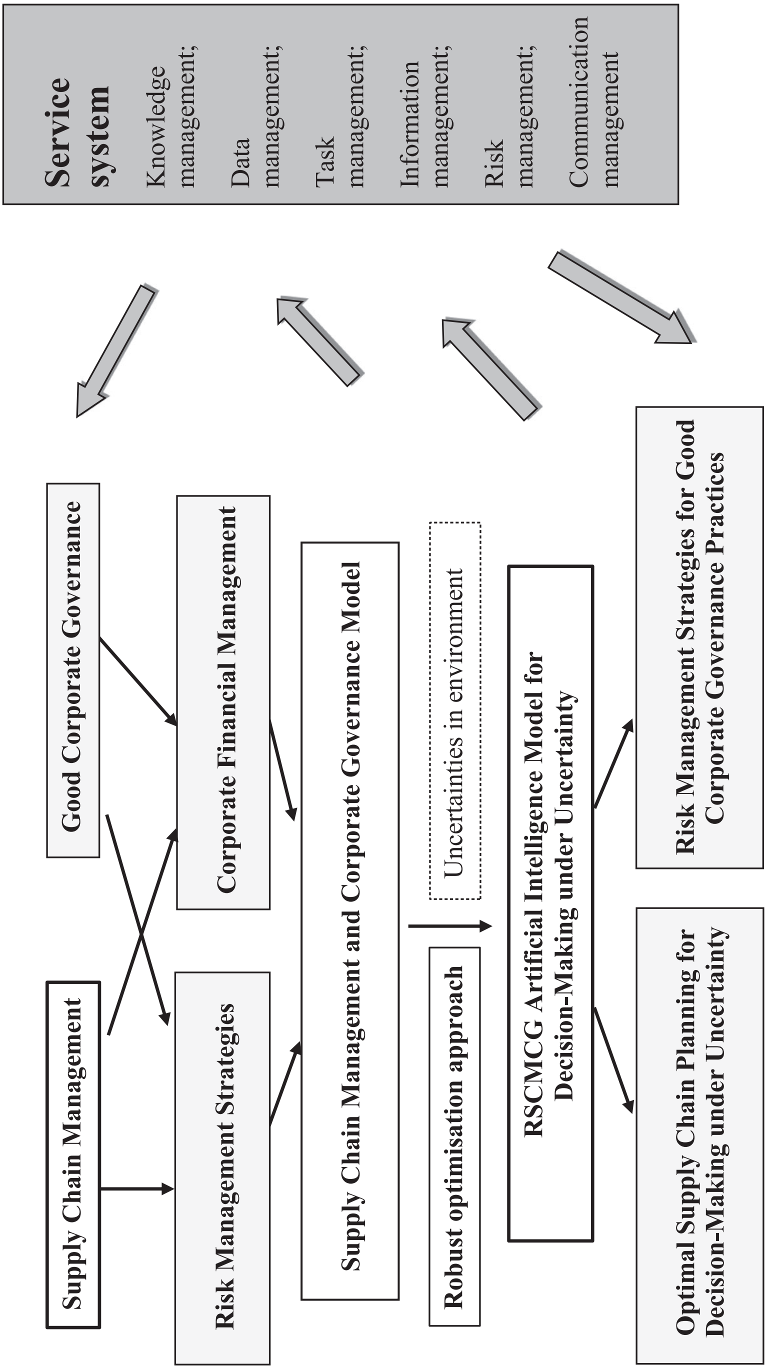

Figure 6.2 Extended RSCMCG framework with service system.

Summary

Decisions regarding the arrangement of resources to maximise profit while accounting for risk have a great impact on the success of the company. Today's fiercely competitive business environment calls for good management of the supply chain. Essentially, this leads to the integrated RSCMCG model framework designed in this study. The normative corporate governance principles and risk management strategies drawn from GCG practices are incorporated into the RSCMCG model to manage risk and enhance the company's supply chain performance, thereby enhancing the company's reputation and the trust of its customers.

To summarise, the integrated RSCMCG model framework as presented in the hypothetical case study results significantly improves supply chain performance in an uncertain market environment. The RSCMCG model has been empirically tested to demonstrate improved efficiency in company performance by incorporating the GCG practices into the model. GCG policies and risk management strategies reduce operational and financial risks, thus leading to more reliable supply chain performance and GCG being applied to global networking operations. The key findings from this study are as follows:

- A robust optimisation model framework is more stable and maintains optimality in the presence of uncertainty in the environment.
- Risk management strategies can be applied to improve the stability of the model framework to find an optimal solution in an uncertain environment.
- The objective value of robust optimisation may not be the best value one can achieve through the optimisation framework compared with traditional deterministic optimisation frameworks or simulation optimisation methods. However, it is the best option for decision-makers who seek robust operations and long-term benefits for the company.
- GCG practices can be incorporated to improve SCM performance in terms of operations, relevant financial management and external relationships such as agent specialists.

By applying risk management strategies developed using the proposed integrated RSCMCG model and following the supply chain strategic plan developed from this reliable approach, a company can achieve long-term benefits for its shareholders. The proposed RSCMCG framework and models in this study can be further extended to manage specific risks for other companies.

Notes

1 Set as 1 in the hypothetical case study, which made the policy that long-term debt be less than equity in the same period.

2 Liquid ratio refers to 'current ratio' in this case, calculated by (current assets/current liabilities); see Chapter 2 for more information.

3 Packaging assembly coefficients are randomly generated from [5, 7] and [12, 14] for products A and B, respectively, in the RSCMCG-4 model; more discussions can be found in 'Constraints' for numerical model presentation and 'Findings and decision analysis from the robust supply chain management and corporate governance model' for results.
4 See RSCMCG-4 model example in 'Findings and decision analysis from the robust supply chain management and corporate governance model' and Appendix 9 for further detailed information on performance.
5 See Chapter 2, 'Supply chain management theories developed and research streams for forming a supply chain framework' for more discussion on supply chain theories.
6 See Chapter 2, 'Key corporate governance issues pertaining to supply chain management' for more discussion.
7 Enterprise risk management, discussed in Chapter 2, 'Risk management in supply chain management and corporate governance'.

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Appendices

Appendix 1: Summary for risk modelling in uncertainty of SCM and corporate governance

No.	*Area*	*Resources*	*What has been proposed*	*Model/methods*
1	Financial management	Markowitz (1952)	The first model using optimisation to balance between risk and return in portfolio selection was developed by Harry Markowitz and was based on the Capital Asset Pricing Model.	Capital Asset Pricing Model
2	Corporate governance	Modigliani & Merton (1958)	Efficiency of risk management can and does affect shareholders' value in the company.	Modigliani and Miller established the proposition for the relationship between a firm's value and its financial policies, called the M&M proposition
3	Corporate governance	Smith (1985); Froot (1993)	Relating it to risk management, this proposition leads to a consequence: if risk management can influence a firm's value by increasing its real cashflow, it could add value by reducing taxes, reducing the cost of financial distress or facilitating optimal investment.	

(*Continued*)

No.	*Area*	*Resources*	*What has been proposed*	*Model/methods*
4	Financial management	Jorion (2001)	An intuitive definition of Value at Risk (VAR): 'summarizes the worst loss over a target horizon with a given level of confidence' under normal market conditions.	
5	Risk management	Labbi (2004)	Enterprises face various risks, including market risk, credit risk, operational risk and business risk.	
6	Corporate governance	Dorfman (2007)	The techniques used to manage the risk can be generally placed into the following four categories: avoidance, reduction, sharing and retention.	
7	SCM	Léautier (2007)	How to measure volatility.	VAR and hedging
8	SCM	Shapiro (2007)	This book adds risk management of supply chains at the section of supply chain decision-making under uncertainty; supports managers making decisions with the help of data-driven models.	Data-driven models; real options and heuristic perspective
9	Corporate governance	Collier (2009)	Risks report has been recognised as an important component and incorporated into annual reports in international firms such as Adidas-Salomon AG, Nestle SA, Sony Corporation.	
10	SCM & corporate governance	Chorafas (2008)	The types of corporation risks include three core categories: credit risk, market risk and operational risk.	
11	Corporate governance	Gaffikin (2008)	Corporation, with holding initial purpose of accumulating capital to enable high-cost business ventures to be undertaken, became more significant with growing industrialisation and birth and growth.	
12	Corporate governance	Collier (2009)	Risk management has been syncretised into corporate governance with legislation.	

No.	*Area*	*Resources*	*What has been proposed*	*Model/methods*
13	SCM	You, Wassick, & Grossmann (2009)	They worked out the risk management for global chemical supply chain planning by incorporating risk measures into the stochastic programming model, trying to solve the demand and freight.	Applying robust optimisation method by considering minimising variance of cost in the objective function; proposes several ways to address risk management in supply chain optimisation modelling
14	SCM, risk management & robust optimisation	Hahn & Kuhn (2012b)	Hahn and Kuhn investigated robust optimisation application for risk management in supply chains. They developed a framework for integrated value-based performance and risk optimisation, considering physical flows as well as financial performance in supply chains on a mid-term level. Their study considered the model and solution robustness incorporated them into the objective function to pursue a decision balance depending on the decision-maker's risk preference.	Robust optimisation, Economic Value Added, model robustness and solution robustness

Appendix 2: Robust optimisation development

Year	*Authors*	*Topic*	*Problem or issues addressed (innovations)*
1973	Soyster	Convex programming with set-inclusive constraints and applications to inexact LP	Handle column-wise uncertainty in LP problems. Every uncertain parameter has to be taken equal to its worst-case value in the set.
1995	Mulvey, Vanderbe & Zenios	Robust optimisation of large-scale systems	Robust mathematical programming includes penalty functions akin to the Markowitz mean-variance model. Candidature solution is allowed to violate the 'scenario realisations' of the constraints; the violations are included via penalty terms in the objective, which takes care of the stability of the resulting solution.
1997	El Ghaoui & Lebret	Robust solutions to least-squares problems with uncertain data	This paper developed robust solutions by applying it to problems of least squares.
1998	El Ghaoui, Oustry & Lebret	Robust solutions to uncertain semi-definite programs	This paper developed robust solutions by applying it to problems of semi-definite programs.
1998	Ben-Tal & Nemirovski	Robust convex optimisation	Laid the foundation of robust convex optimisation; proposed robust counterpart approach. Applied robust optimisation to LP problems with ellipsoidal uncertainty sets.
1999	Ben-Tal & Nemirovski	Robust solution of uncertain linear programs	Analytical and computational optimisation tools; LP with ellipsoidal uncertainty set is computationally tractable, leading to a conic quadratic program. Used interior-point methods/ polynomial time. Solved the problem via corresponding convex robust counterpart program.
2000	Ben-Tal, Margalit & Nemirovski	Robust modelling of multistage portfolio problems	Discussed and illustrated by simulated numerical results a new model of multistage asset allocation problem. The model was given from a new methodology for optimisation under uncertainty: the Robust Counterpart approach.

Year	*Authors*	*Topic*	*Problem or issues addressed (innovations)*
2000	Ben-Tal & Nemirovski	Robust solutions of LP problems contaminated with uncertain data	Optimal solutions to LP problems may become severely infeasible if the nominal data are slightly perturbed. This paper demonstrated this phenomenon by studying 90 LPs from the well-known NETLIB collection and found some robust solutions that lost nearly nothing in optimality.
2002/ 2000	Ben-Tal & Nemirovsk	Robust optimisation methodology and applications	Uncertain LP/quadratic programming/ semi-definite programming; discussed the applications and described a specific 90LPs from NETLIB collection; applied in antenna design, truss topology design, stability analysis/synthesis.
2003/	Ben-Tal, Goryashko, Guslitzer & Nemirovski	Adjustable robust solutions of uncertain linear programs	The first consideration of the robust multistage formulation.
2003	El Ghaoui	Worst-case VAR and robust portfolio optimisation: A conic programming approach	This paper proposed a way to alleviate the problem that classical formulations of portfolio optimisation problems (such as mean variance or VAR approaches) result in a portfolio extremely sensitive to errors in the data, in a tractable manner. It defined the worst-case VAR as the largest VAR attainable, given the partial information on the returns' distribution.
2004/ 2001	Bertsimas & Sim	The price of robustness	LP/mixed-integer programming with data uncertainties; ensure the solution remains feasible and near optimal when the data changes; the level of conservatism; applied in portfolio optimisation, knapsack problem.
2003/ 2002	Bertsimas & Sim	Robust discrete optimisation and network flows	Proposed an approach to address data uncertainty for discrete optimisation and network flow problems that allowed for controlling the degree of conservatism of the solution. It used robust approximation algorithm and can be applied to integer programming and network flows.

(*Continued*)

Year	*Authors*	*Topic*	*Problem or issues addressed (innovations)*
2005/ 2004	Chen, Sim & Sun	A robust optimisation perspective of stochastic programming	This paper introduced an approach for constructing uncertainty sets for robust optimisation using new deviation measures for random variables termed the forward and backward deviations, which can capture distributional asymmetry and lead to a better approximations. It also proposed a tractable approximation approach for solving a class of multistage chance-constrained stochastic linear optimisation problems. In the paper, the authors also proposed a new framework feature of converting original model into an SOCP. The framework was demonstrated through an application example of a project management problem with uncertain activity completion time.
2007	Benati & Rizzi	A mixed-integer LP formulation of the optimal mean/VAR portfolio problem	This paper considered an extension of the Markovitz model in which the variance has been replaced with the VAR, so a new portfolio optimisation problem was formulated.
2008	Ranvindran	Operations research and management science handbook	Minimax regret; worst-case hedge; simple case of interval uncertainty.
2011/ 2008	Bertsimas, Brown & Caramanis	Theory and applications of robust optimisation	Discussed computational attractiveness of robust optimisation approaches, as well as the modelling power and broad applicability of the methodology. Robust optimisation can be applied for multistage decision-making problems. This paper also discussed different uncertainty sets, including ellipsoidal, polyhedral uncertainty, cardinality constrained uncertainty and norm. For robust quadratic optimisation, uncertainty sets have single ellipsoid and polyhedral/intersection of ellipsoids. For robust semi-definite optimisation, they have ellipsoidal/polyhedral uncertainty sets, which are NP-hard. Applied domains: finance, statistics, learning and engineering. Polynomial-time cutting plane algorithm.

Appendix 3: Comparison of methods

Methods	*Key process*	*Data/probability; uncertainty feature*	*Optimisation criteria*	*Algorithm*	*Approaches*	*Results/applications*	*Software/ tools*
Robust optimisation	The main idea behind the technique is to allow for multiple possible values of the uncertain parameters to be taken into consideration during the optimisation procedure	Uncertainty in boundary sets; probabilistic; non-probabilistic; uncertainties are independent of the decisions	Optimal in some sense, under some constraints to keep robustness; stable solution	Interior-point methods; branch-and-bound; genetic algorithm; decomposition	(Basic: decision theory); worst-case analysis (Wald's max-min model); semi-infinite robust counterparts the original problems	Scenarios; the conservative result trading off between the cost and optimal; finance: is particularly useful for portfolio managers interested in computationally efficient ways to incorporate uncertainty in statistical estimates of parameters in traditional portfolio optimisation	Solver/AIMMS/ ROME (MATLAB)
Simulation optimisation	Random number generation and determination of the probability distributions	Known the feature of history data, mapping the random numbers used by the known/ experienced probability distributions; uncertainties may depend on the decisions	Optimal value of all the simulated ones; best solution	Random number generation genetic and evolutionary algorithms, and tabu and scatter search		Best value	GPSS, DYNAMO, GASP IV and SIMSCRIPT

(*Continued*)

Methods	*Key process*	*Data/probability; uncertainty feature*	*Optimisation criteria*	*Algorithm*	*Approaches*	*Results/applications*	*Software/ tools*
Stochastic optimisation	Solve the second-stage optimisation problem based on the deterministic results of the first stage	Uncertainty in data with known probability distribution—history data; uncertainties are independent of the decisions	Optimal results based on the deterministic first-stage results; optimal solution		Multistage stochastic	Asset-liability management, bond portfolio management and pension fund management	AIMMS; FuncDesigner; SAMPL
					Mean-risk Chance constrained	Be related to different risk measures in portfolio optimisation and provide the setup for some of the advanced robust modelling topics in Chapter 13 (Fabozzi 2007); especially, chance constrained works quite well in case of large portfolios of stocks whose return distributions are fairly close to normal	

Appendix 4: Example of SCM and corporate governance framework through managers' remuneration

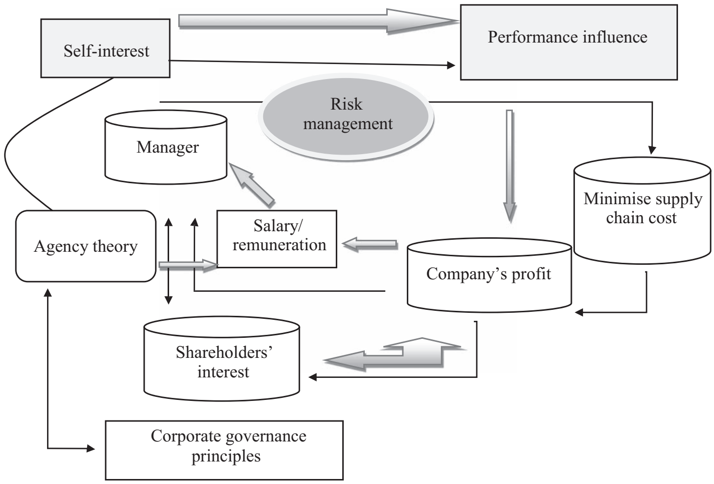

Figure A4.1 An example of SCM and corporate governance framework through managers' remuneration.

Appendix 5: Spreadsheet modelling for the RSCMCG model framework and four RSCMCG models summary table

1 Spreadsheet modelling summary for applying the RSCMCG model framework in the hypothetical case

	Corporate governance principles	*Variables—elements*	*Proxy*	*Spreadsheet modelling examples*
Objective function	Respect the rights of shareholders	Maximise shareholders' wealth (minimise the cost): maximise EBIT/ equity	$\boldsymbol{Max}\ f(\boldsymbol{equity}) = Z(t)_E = Z(1)_E + \sum_t [\Delta Z(t)_E]$ $= \sum_t \{Z(1)_E + (1 - r_{PR})[\mathrm{EBIT}(t) - i_{IrD} * Z(t)_L] - Z(t)_D\}$	Max final year equity $\left(\sum_t Z(t)_E, \mathrm{O2}\right)$: Maximise O2 = F82 + PsiOutput ()
	Encourage enhanced performance			
	Recognise the legitimate interests of stakeholders			
Constraints	A. Definitional supply chain operational and financial equations			
	Financial equations		$Z(t)_{CA} + Z(t)_{FA} - Z(t)_{CL} - Z(t)_L - Z(t)_E = 0$ $\Delta Z(t)_{CA} + \Delta Z(t)_{FA} - \Delta Z(t)_{CL} - \Delta Z(t)_L - \Delta Z(t)_E = 0$ $\Delta Z(t)_E = Z(t)_{PR} - Z(t)_D = (1 - r_{PR})[EBIT(t) - i(t)_{IrD} * Z(t)_L] - Z(t)_D$ $Z(t)_{PR} = (1 - r_{PR})[EBIT(t) - i(t)_{IrD} * Z(t)_L]$	For Year 1, the equity ($Z(t)_E$, F76): F76 = B76 + C76 – D76–E76; Change of the equity for the end of Year 1 ($\Delta Z(t)_E$,F77): F77 = H78−I77; After-tax profit ($Z(t)_{PR}$,H78): H78 = (1−O76)*(G77−P76*E78)

	Corporate governance principles	*Variables—elements*	*Proxy*	*Spreadsheet modelling examples*
	Supply chain operations		$R(t)_{sale} = \sum_k \left[X(t)_{sold_k} * c(t)_{sold_k} \right]$ $C(t)_{MA} = \sum_k C(t)_{MA_k}$ $= \sum_k \left[c(t)_{MA_k} * X(t)_{qMA_k} \right]$ $C(t)_{TR} = \sum_k \sum_{m,n}^{M,N} \left[Y(t)_{qTR_{k_{mn}}} * c(t)_{TR_{k_{mn}}} \right]$ $C(t)_{inv} = \sum_k \sum_j \left[c(t)_{invj_k} * X(t)_{invj_k} \right]$	See sections below
	B. Supply chain management and financial management equations			
	B.1 Supply chain operational equation constraints			
	Manufacturing functions	Manufacturing expense	$C(t)_{MA} = \sum_k \left[X(t)_{qMA_k} * c(t)_{MA_k} \right]$ $= \sum_k \left[X(t)_{qMA_k} \times c(0)_{MA_k} * (1 + r_{MA_k})^{t-1} \right]$	Year 1: Production expense ($C(1)_{MA}$, E2): E2 = B8 * B9 + C8 * C9 + D8 * D9

(*Continued*)

	Corporate governance principles	*Variables—elements*	*Proxy*	*Spreadsheet modelling examples*
	Shipping balance	Shipping equation; shipping expense	$\sum_{k}\sum_{m,n}^{M,N}\theta_{k_{mn}} Y(t)_{qTR_{k_{mn}}} = Y(t)_{qTR_{mn}}$ $C(t)_{TR} = \sum_{k}\sum_{m,n}^{M,N}\left[Y(t)_{qTR_{k_{mn}}} * c(t)_{TR_{k_{mn}}}\right]$	Year 1, shipping amount on shipping lines for Product A ($Y(1)_{qTR_A}$, I12): I12 = SUMPRODUCT (E12:H12,E14:H14); Year 1, transportation expense ($C(1)_{TR}$, I10): I10 = SUMPRODUCT (E14:H14,$E15:$H15)
	Mass balance	Distribution—transportation–inventory	$X(t)_{invjk} = X(t-1)_{invjk} + Y(t)_{qTR_{k_{mn}}} - D(t)_{M_k{}^i}$	Year 1, the end-year inventory for Product A in Distribution Centre 1 ($X(1)_{inv1A}$, Q18): Q18 = SUMPRODUCT(E18:H18,E22:H22)+ SUMPRODUCT(I18:L18,I22:L22)+ SUMPRODUCT(M18:P18,M22:P22)
	Inventory expense	Inventory cost	$C(t)_{inv} = \sum_{k}\sum_{j}\left[c(t)_{invjk} * X(t)_{invjk}\right]$	Year 1, inventory expense ($C(1)_{inv}$, M16):M16 = I22 * I23 + J22 * J23 + K22 * K23 + L22 * L23
	Marketing equation	Revenue on sales	$R(t)_{sale} = \sum_{k}\left[D(t)_{M_k{}^i} * c(t)_{sold_k}\right]$	Year 1 revenue ($R(1)_{sale}$ B17): B17 = SUMPRODUCT (M22:P22,M23:P23)
	B.2 Financial planning constraints			
	Financial balance		$Z(t)_{CA} + Z(t)_{FA} - Z(t)_{CL} - Z(t)_{L} - Z(t)_{E} = 0$ $\Delta Z(t)_{CA} + \Delta Z(t)_{FA} - \Delta Z(t)_{CL} - \Delta Z(t)_{L} - \Delta Z(t)_{E} = 0$	For Year 1: equity ($Z(1)_E$, F76): F76 = B76 + C76–D76–E76;

	Corporate governance principles	*Variables—elements*	*Proxy*	*Spreadsheet modelling examples*
	Funds flow equation		$\Delta Z(t)_E = Z(t)_{PR} - Z(t)_D = (1 - r_{PR})[\text{EBIT}(t) - i(t)_{IrD} * Z(t)_L] - Z(t)_D$ $Z(t)_{PR} = (1 - r_{PR})[\text{EBIT}(t) - i(t)_{IrD} * Z(t)_L]$	For Year 1: Change of equity ($\Delta Z(1)_E$, F77): F77 = H78-I77; After-tax profit ($Z(1)_{PR}$,H78): H78=(1-O76) * (G77-P76*E78)
	Investment balance		$\Delta Z(t)_{FA} = \Delta Z(t)_L + Z(t)_{Inv/CA}$	Year 1, the change on fixed assets ($\Delta Z(1)_{FA}$, C77): C77 = J76 + E77
	C. Corporate governance policies: Risk management for supply chain management and accounting policy			
	C.1 Good corporate governance practices for optimal supply chain operational management from a risk management strategies perspective			
	Supply chain specialised agent governance		$X(t)_{qMA_k} = \sum_i \sum_k \alpha_{i_k} X(t)_{qMA_k^i}$ $Y(t)_{qTR_{mn}} = \sum_i \sum_k \beta_{i_k} Y(t)_{qTR^i{}_{k_{mn}}}$	Year 1 manufacturing quantity of Product A ($X(1)_{qMA_A}$, F6): F6 = SUMPRODUCT(B6:D6,B8:D8) Year 1 shipping amount on line 1 ($Y(1)_{qTR_A}$ I12): I12 = SUMPRODUCT (E12:H12,E14:H14)
	Risk management strategies for supply chain operational system			
	Manufacturing risk management strategies	Manufacturing capacity	$X(t)_{qMA_k} \leq CAP(t)_{fac_k} = CAP(0)_{fac_k} * \left(1 + r_{capfac_k}\right)^{t-1}$	Year 1, the manufacturing quantity for Product A ($X(1)_{qMA_A}$, F6) has a capacity limitation ($CAP(1)_{fac_A}$, J6): F6 < = J6

(Continued)

	Corporate governance principles	*Variables—elements*	*Proxy*	*Spreadsheet modelling examples*
	Packaging equations	Labour for packaging assembly	$LA(t)_{qMA_k} = \sum_i \sum_k \alpha_{i_k} X(t)_{qMA_k}{}^{i}$	Year 1, packaging assembly labour requirement ($LA(1)_{qMA}$, F5): F5 = SUMPRODUCT(B5:D5,B8:D8)
		Capacity of packaging procedure	$LA(t)_{qMA_k} \leq P(t)_{qMA_k}$	Year 1, the labour ($LA(1)_{qMA}$, F5) has limitation for assembly ($P(t)_{qMA_k}$, J5): F65 <= J5
		Expansion	$P(t)_{qMA_k} = P(0)_{qMA_k} * \left(1 + r_{pac_k}\right)^{t-1}$	Year 2, For Product A ($P(2)_{qMA_A}$, J31): J31 = J6* (1+$N$31)
	Distribution risk management strategies	Shipping line limitation	$Y(t)_{qTR_{k_{mn}}} \leq CAP(t)_{QTR_{k_{mn}}}$ $CAP(t)_{QTR_{k_{mn}}} = Y(t)_{qMA_k}$	For Year 1, shipping line to distribute Product A ($Y(1)_{qTR_A}$, I12) has a limitation (CAP_{QTR_A}, K12): I12 <= K12; Year 1, the limitation of shipping quantity of Product A ($CAP(1)_{QTR_A}$, K12) is equal to the quantity of manufacturing Product A ($Y(1)_{qMA_A}$, F6): K12 = F6
	Inventory risk management strategies	Safety inventory	$B(t)_{\text{safej}_k} = k(t)_{\text{safe}} * D(t)_{M_k^i}$	Year 1, the inventory quantity of Product A ($X(1)_{inv1_A}$, I22) has a safety level ($B(1)_{\text{safe1}_A}$, I25): I22>= I25; Year 1 for Product A, safety level ($B(1)_{\text{safe1}_A}$, I25) is set as 10% of demand ($D(1)_{M_A^1}$, sales quantity Q25, which copy to Cell I26, stand for demand) of the year: I25 = G25 * I26

	Corporate governance principles	*Variables—elements*	*Proxy*	*Spreadsheet modelling examples*
	Marketing risk	Prices and costs with considering indexation	$c(t)_{\text{sold}} = c(0)_{\text{sold}_k} * \left(1 + r_{\text{sold}}\right)^{t-1}$; $c(t)_{MA_k} = c(0)_{MA_k} * \left(1 + r_{MA_k}\right)^{t-1}$; $c(t)_{TR_{mn}} = c(0)_{TR_{mn}} * \left(1 + r_{TR_{mn}}\right)^{t-1}$; $c(t)_{\text{invj}} = c(0)_{\text{invj}} * \left(1 + r_{\text{invj}}\right)^{t-1}$ c	Year 2, unit sales price for Product A considering indexation ($c(2)_{\text{sold}_A}$, M44): M44 = M23 * (1+$S$44); Year 2, unit manufacturing cost of Product A with considering indexation ($c(2)_{MA_A}$, B34): B34 = B9* (1 + B35); Year 2, Product A unit shipping cost considering indexation ($c(2)_{TRA_{mn}}$, E38): E38 = E15* (1+$D$38); Year 2 unit inventory cost of production A in distribution centre 1 considering indexation ($c(2)_{inv1_A}$, I44): I44= =I23* (1+$D$45)
	C.2 Corporate financial and accounting practices for corporate governance performance			
	Internal control	Debt-to-equity constraint	$Z(t)_L \le K_{D/E} * Z(t)_E$	For Year 2, the long-term debt ($Z(2)_L$, E78) is less than 50% ($K_{D/E}$) of equity ($Z(2)_E$, F78): E78 < = 0.5 * F78
		Investment restriction constraint	$Z(t)_{Inv/CA} \le \kappa_{inv} * Z(t)_{CA}$	Year 1, the investment from current assets $Z(1)_{Inv/CA}$, J76): J76 = J75 * B76
		Debt service constraint	$\text{EBIT}(t) \ge \lambda(t)_{EB/L} * i(t)_{IrD} * Z(t)_L$	Year 1 equity ($EBIT(1)$, G77) should satisfy the debt service constraint with long-term debt ($Z(1)_L$, E76): G77 > = 5 * P76 * E76

(*Continued*)

	Corporate governance principles	*Variables—elements*	*Proxy*	*Spreadsheet modelling examples*
		Minimum working capital constraint	$Z(t)_{CA} \geq \lambda(t)_{WC} * Z(t)_{CL}$	For Year 2, current assets ($Z(2)_{CA}$, B78), is more than twice $(\lambda(2)_{WC})$ of current liabilities ($Z(2)_{CL}$, D78): B78 > = 2 * D78
		Leverage constraint	$Lev(t) = \frac{Z(t)_L}{TA(t)} \leq \delta(t)_{Lev}$	For Year 2, the proportion of long-term debt ($Z(2)_L$, E78) to total $TA(2)$ assets needs to be less than $\delta(2)_{Lev}$: E78/(B78 + C78) < = 0.375
	Principal–agent problem	Agency cost constraint	$C^{CG}(t)_{AC} = C(t)_{AC} * [1 - \gamma(t)]$	Agency cost is reduced because of the good corporate practices. For Year 1, agency cost ($C^{CG}(1)_{AC}$, N77): N77 = 3000 * (1–66.7%)
	Good corporate governance performance measures (accounting measures)	Operating margin constraint	$\xi(t)_{\text{ISARITO}_k} = \frac{\text{EBIT}(t)}{R(t)_{\text{sale}}} \geq \xi'(t)_{\text{ISRATIO}}$	For Year 1, EBIT ($EBIT(1)$, G77) should be more than $\xi'(1)_{ISRATIO}$ of revenue ($R(1)_{sale}$, B17): G77/B17 > = 0.3

2 Four RSCMCG models with different conditions and strategies applied

Strategies / *Models*	*Safety inventory policy*	*Indexations*	*Agency cost*	*Manufacturing expansion*
RSCMCG-1 Model	Yes	No	No	No
RSCMCG-2 Model	No	Yes	Yes	No
RSCMCG-3 Model	Yes	Yes	Yes	No
RSCMCG-4 Model	Yes	Yes	Yes	Yes

Appendix 6: Settings in the risk solver platform for the RSCMCG model in the Excel

1 Settings for 'Model' component

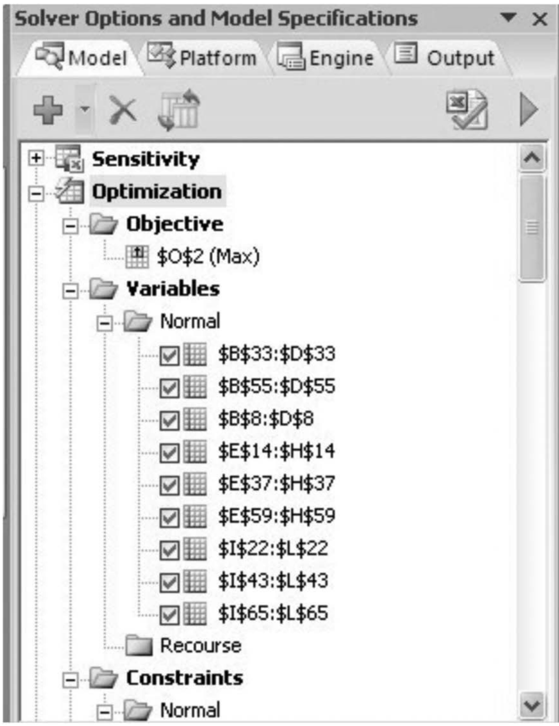

Figure A6.1-1 Settings for 'Model' component (part 1).

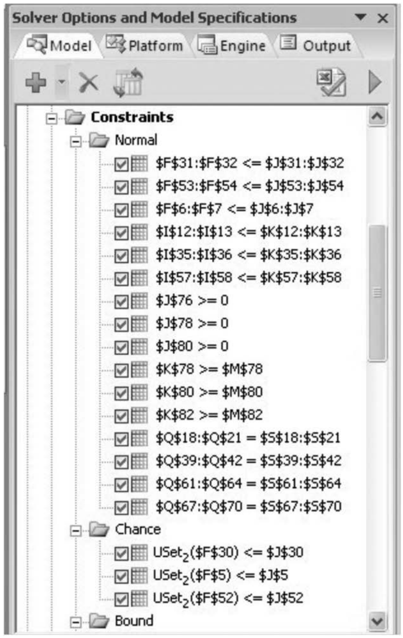

Figure A6.1-2 Settings for 'Model' component (part 2).

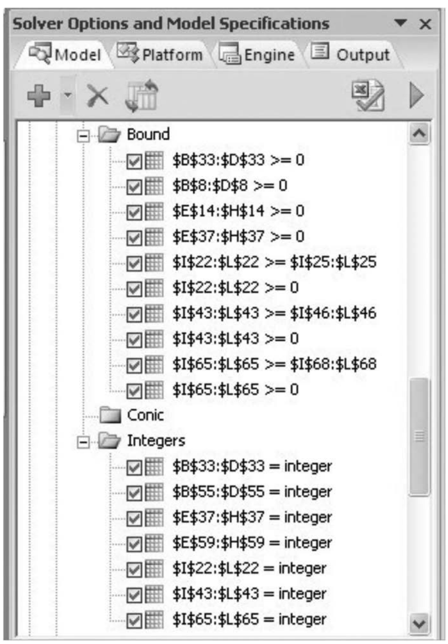

Figure A6.1-3 Settings for 'Model' component (part 3).

2 Settings for ‘Engine’ component

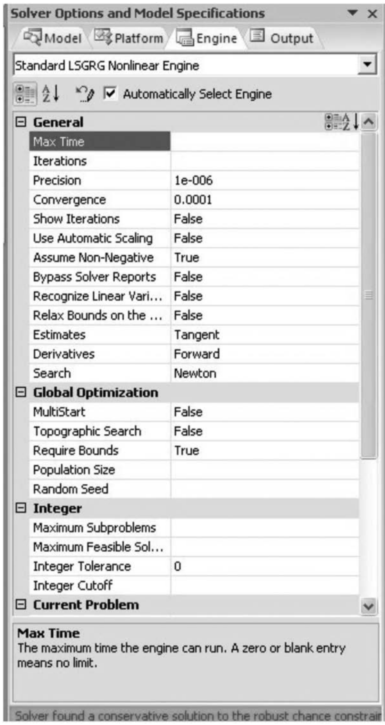

Figure A6.2 Settings for ‘Engine’ component.

‘Engine’ component in the Risk Solver Platform for the robust optimisation model with Standard LSGRG Nonlinear Engine

Appendix 7: The results of the RMSCG-1 model in spreadsheet

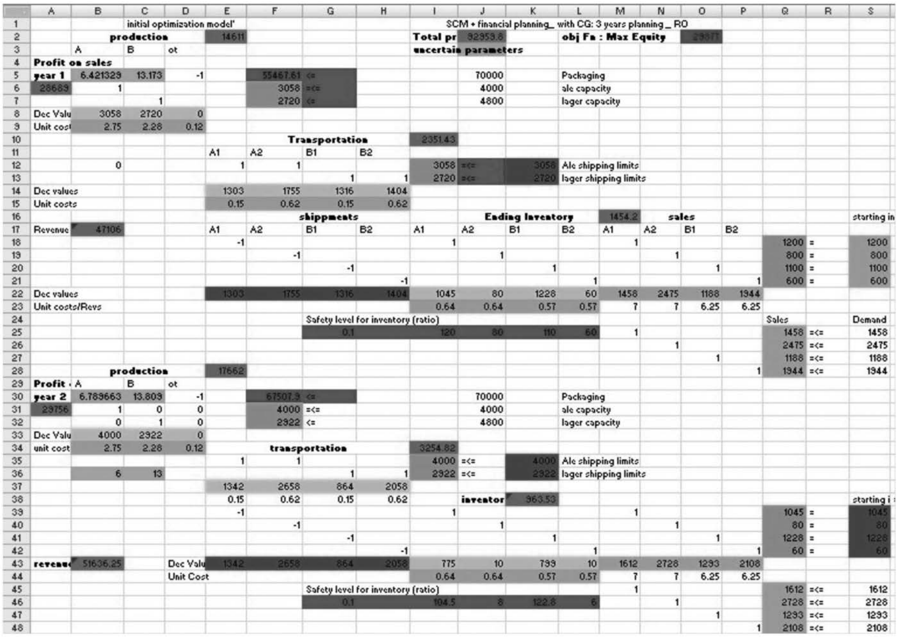

Figure A7.1-1 The results of the RSCMCG-1 model in spreadsheet (part 1).

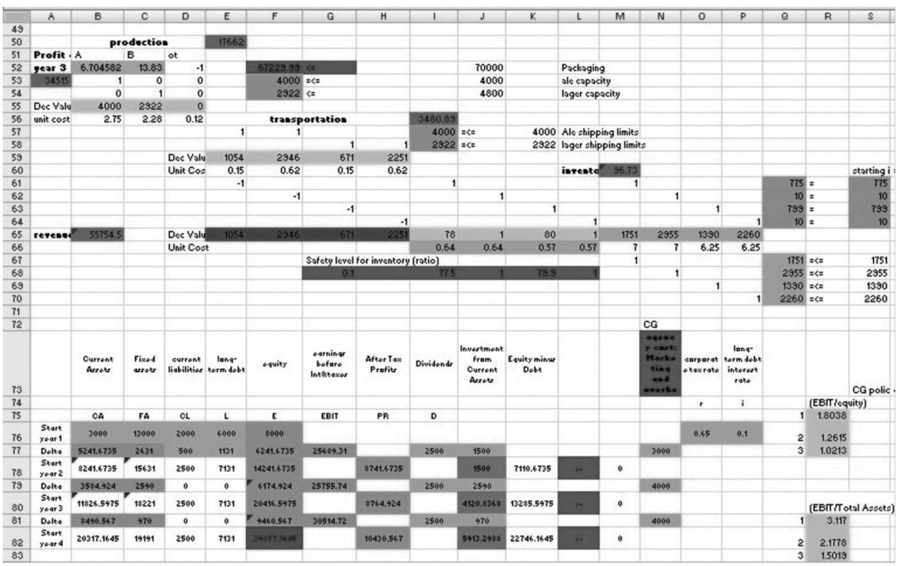

Figure A7.1-2 The results of the RSCMCG-1 model in spreadsheet (Part 2).

Appendix 8: Simulation reports for the RSCMCG-2 model and results for the RSCMCG-3 model

1 The structure report for the RSCMCG-2 model
Microsoft Excel 12.0 Structure Report
Model Type: LP Convex Assumption: NLP
Statistics

	Variables	*Functions*	*Dependents*
All	75	73	306
Smooth	75	73	306
Linear	75	73	306

2 The answer report for the RSCMCG-2 model

Microsoft Excel 12.0 answer report

Worksheet: [RSCMCG_2.xlsx]RSCMCG_2
Result: Solver found a conservative solution to the robust chance-constrained problem. All constraints are satisfied.
Engine: Standard LP/Quadratic
Solution Time: 00 Seconds
Iterations: 0
Subproblems: 0
Incumbent Solutions: 0

Objective cell (Max)

Cell	Name	Original value	Final value
$O$2	obj Fn: Max equity	0	35524.06063

Decision Variable Cells

Cell	Name	Original value	Final value	Type
$B$8	Dec values A (MA)-Y1	0	2979	Normal
$C$8	Dec values B (MA)-Y1	0	2648	Normal
$D$8	Dec values ot (MA)-Y1	0	0	Normal
$B$33	Dec values A (MA)-Y2	0	4000	Normal
$C$33	Dec values B (MA)-Y2	0	2923	Normal
$D$33	Dec values ot (MA)-Y2	0	0	Normal
$B$55	Dec values A (MA)-Y3	0	4000	Normal
$C$55	Dec values B (MA)-Y3	0	2912	Normal
$D$55	Dec values ot (MA)-Y3	0	5	Normal
$E$14	Dec values A1 (TR)-Y1	0	258	Normal
$F$14	Dec values A2 (TR)-Y1	0	2721	Normal
$G$14	Dec values B1 (TR)-Y1	0	88	Normal
$H$14	Dec values B2 (TR)-Y1	0	2560	Normal
$E$37	Dec values A1 (TR)-Y2	0	1612	Normal
$F$37	Dec values A2 (TR)-Y2	0	2388	Normal

(*Continued*)

Microsoft Excel 12.0 answer report

$G$37	Dec values B1 (TR)-Y2	0	1293	Normal
$H$37	Dec values B2 (TR)-Y2	0	1630	Normal
$E$59	Dec values A1 (TR)-Y3	0	1751	Normal
$F$59	Dec values A2 (TR)-Y3	0	2249	Normal
$G$59	Dec values B1 (TR)-Y3	0	1390	Normal
$H$59	Dec values B2 (TR)-Y3	0	1522	Normal
$I$22	Dec values A1 (INV)-Y1	0	0	Normal
$J$22	Dec values A2 (INV)-Y1	0	1046	Normal
$K$22	Dec values B1 (INV)-Y1	0	0	Normal
$L$22	Dec values B2 (INV)-Y1	0	1216	Normal
$I$43	Dec values A1 (INV)-Y2	0	0	Normal
$J$43	Dec values A2 (INV)-Y2	0	706	Normal
$K$43	Dec values B1 (INV)-Y2	0	0	Normal
$L$43	Dec values B2 (INV)-Y2	0	738	Normal
$I$65	Dec values A1 (INV)-Y3	0	0	Normal
$J$65	Dec values A2 (INV)-Y3	0	0	Normal
$K$65	Dec values B1 (INV)-Y3	0	0	Normal
$L$65	Dec values B2 (INV)-Y3	0	0	Normal

Constraints

Cell	Name	Cell value	Formula	Status	Slack
$F$5	Packaging assembly uncertainty-Y1	51188.56268	USet_2($F$5)<=$J$5	100% satisfied	13233.8627
$F$6	Manufacturing risk management (Capacity)-Y1	2979	$F$6<=$J$6	Not Binding	1021
$F$7	Manufacturing risk management (Capacity)-Y1	2648	$F$7<=$J$7	Not Binding	2152
$B$8	Dec values A (MA) non-negative-Y1	2979	$B$8>=0	Not Binding	2979
$C$8	Dec values B (MA) non-negative-Y1	2648	$C$8>=0	Not Binding	2648
$D$8	Dec values ot (MA) non-negative-Y1	0	$D$8>=0	Binding	0
$I$12	Shipping capacity constraint A-Y1	2979	$I$12<=$K$12	Binding	0
$I$13	Shipping capacity constraint B-Y1	2648	$I$13<=$K$13	Binding	0
$E$14	Dec values A1 (TR) non-negative-Y1	258	$E$14>=0	Not Binding	258
$F$14	Dec values A2 (TR) non-negative-Y1	2721	$F$14>=0	Not Binding	2721
$G$14	Dec values B1 (TR) non-negative-Y1	88	$G$14>=0	Not Binding	88

Microsoft Excel 12.0 answer report

$H$14	Dec values B2 (TR) non-negative-Y1	2560	$H$14>=0	Not Binding	2560
$Q$18	Market sales-A1-Y1	1200	$Q$18=$S$18	Binding	0
$Q$19	Market sales-A2-Y1	800	$Q$19=$S$19	Binding	0
$Q$20	Market sales-B1-Y1	1100	$Q$20=$S$20	Binding	0
$Q$21	Market sales-B2-Y1	600	$Q$21=$S$21	Binding	0
$I$22	Safety inventory level A1-Y1	0	$I$22>=$I$25	Not Binding	0
$J$22	Safety inventory level A2-Y1	1046	$J$22>=$J$25	Not Binding	1046
$K$22	Safety inventory level B1-Y1	0	$K$22>=$K$25	Not Binding	0
$L$22	Safety inventory level B2-Y1	1216	$L$22>=$L$25	Not Binding	1216
$I$22	Dec values A1 (INV) non-negative-Y1	0	$I$22>=0	Not Binding	0
$J$22	Dec values A2 (INV) non-negative-Y1	1046	$J$22>=0	Not Binding	1046
$K$22	Dec values B1 (INV) non-negative-Y1	0	$K$22>=0	Not Binding	0
$L$22	Dec values B2 (INV) non-negative-Y1	1216	$L$22>=0	Not Binding	1216
$F$30	Packaging assembly uncertainty-Y2	63685.41625	$USet_2$($F$30)<=$J$30	100% satisfied	12707.31331
$F$31	Manufacturing risk management (Capacity)-Y2	4000	$F$31<=$J$31	Not Binding	0
$F$32	Manufacturing risk management (Capacity)-Y2	2923	$F$32<=$J$32	Not Binding	1877
$B$33	Dec values A (MA) non-negative-Y2	4000	$B$33>=0	Not Binding	4000
$C$33	Dec values B (MA) non-negative-Y2	2923	$C$33>=0	Not Binding	2923
$D$33	Dec values ot (MA) non-negative-Y2	0	$D$33>=0	Binding	0
$I$35	Shipping capacity constraint A-Y2	4000	$I$35<=$K$35	Binding	0
$I$36	Shipping capacity constraint B-Y2	2923	$I$36<=$K$36	Binding	0
$E$37	Dec values A1 (TR) non-negative-Y2	1612	$E$37>=0	Not Binding	1612
$F$37	Dec values A2 (TR) non-negative-Y2	2388	$F$37>=0	Not Binding	2388
$G$37	Dec values B1 (TR) non-negative-Y2	1293	$G$37>=0	Not Binding	1293
$H$37	Dec values B2 (TR) non-negative-Y2	1630	$H$37>=0	Not Binding	1630
$Q$39	Market sales A1-Y2	0	$Q$39=$S$39	Binding	0
$Q$40	Market sales A2-Y2	1046	$Q$40=$S$40	Binding	0
$Q$41	Market sales B1-Y2	0	$Q$41=$S$41	Binding	0
$Q$42	Market sales B2-Y2	1216	$Q$42=$S$42	Binding	0
$I$43	Safety inventory level A1-Y2	0	$I$43>=$I$46	Not Binding	0
$J$43	Safety inventory level A2-Y2	706	$J$43>=$J$46	Not Binding	706
$K$43	Safety inventory level B1-Y2	0	$K$43>=$K$46	Not Binding	0

(*Continued*)

Microsoft Excel 12.0 answer report

\$L\$43	Safety inventory level B2-Y2	738	\$L\$43>=\$L\$46	Not Binding	738
\$I\$43	Dec values A1 (INV) non-negative-Y2	0	\$I\$43>=0	Not Binding	0
\$J\$43	Dec values A2 (INV) non-negative-Y2	706	\$J\$43>=0	Not Binding	706
\$K\$43	Dec values B1 (INV) non-negative-Y2	0	\$K\$43>=0	Not Binding	0
\$L\$43	Dec values B2 (INV) non-negative-Y2	738	\$L\$43>=0	Not Binding	738
\$F\$52	Packaging assembly uncertainty-Y3	62724.24585	$USet_2$(\$F\$52)<=\$J\$52	100% satisfied	7601.882974
\$F\$53	Manufacturing risk management (Capacity)-Y3	4000	\$F\$53<=\$J\$53	Not Binding	0
\$F\$54	Manufacturing risk management (Capacity)-Y3	2912	\$F\$54<=\$J\$54	Not Binding	1888
\$B\$55	Dec values A (MA) non-negative-Y3	4000	\$B\$55>=0	Not Binding	4000
\$C\$55	Dec values B (MA) non-negative-Y3	2912	\$C\$55>=0	Not Binding	2912
\$D\$55	Dec values ot (MA) non-negative-Y3	5	\$D\$55>=0	Binding	5
\$I\$57	Shipping capacity constraint A-Y3	4000	\$I\$57<=\$K\$57	Binding	0
\$I\$58	Shipping capacity constraint B-Y3	2912	\$I\$58<=\$K\$58	Binding	0
\$E\$59	Dec values A1 (TR) non-negative-Y3	1751	\$E\$59>=0	Not Binding	1751
\$F\$59	Dec values A2 (TR) non-negative-Y3	2249	\$F\$59>=0	Not Binding	2249
\$G\$59	Dec values B1 (TR) non-negative-Y3	1390	\$G\$59>=0	Not Binding	1390
\$H\$59	Dec values B2 (TR) non-negative-Y3	1522	\$H\$59>=0	Not Binding	1522
\$Q\$61	Market sales-A1-Y3	0	\$Q\$61=\$S\$61	Binding	0
\$Q\$62	Market sales-A2-Y3	706	\$Q\$62=\$S\$62	Binding	0
\$Q\$63	Market sales-B1-Y3	0	\$Q\$63=\$S\$63	Binding	0
\$Q\$64	Market sales-B2-Y3	738	\$Q\$64=\$S\$64	Binding	0
\$I\$65	Dec values A1(INV) non-negative-Y3	0	\$I\$65>=0	Not Binding	0
\$J\$65	Dec values A2(INV) non-negative-Y3	0	\$J\$65>=0	Not Binding	0
\$K\$65	Dec values B1(INV) non-negative-Y3	0	\$K\$65>=0	Binding	0
\$L\$65	Dec values B2(INV) non-negative-Y3	0	\$L\$65>=0	Binding	0
\$J\$76	Investment restriction-Y1	1500	\$J\$76>=0	Not Binding	1500
\$J\$78	Investment restriction-Y2	4383.04275	\$J\$78>=0	Not Binding	4383.04275
\$J\$80	Investment restriction-Y3	6455.534128	\$J\$80>=0	Not Binding	6455.534128
\$K\$78	Debt-to-equity constraint-Y1	7635.0855	\$K\$78>=\$M\$78	Not Binding	7635.0855
\$K\$80	Debt-to-equity constraint-Y2	16163.11101	\$K\$80>=\$M\$80	Not Binding	16163.11101
\$K\$82	Debt-to-equity constraint-Y3	28393.06063	\$K\$82>=\$M\$82	Not Binding	28393.06063

3 The result for the RSCMCG-3 model

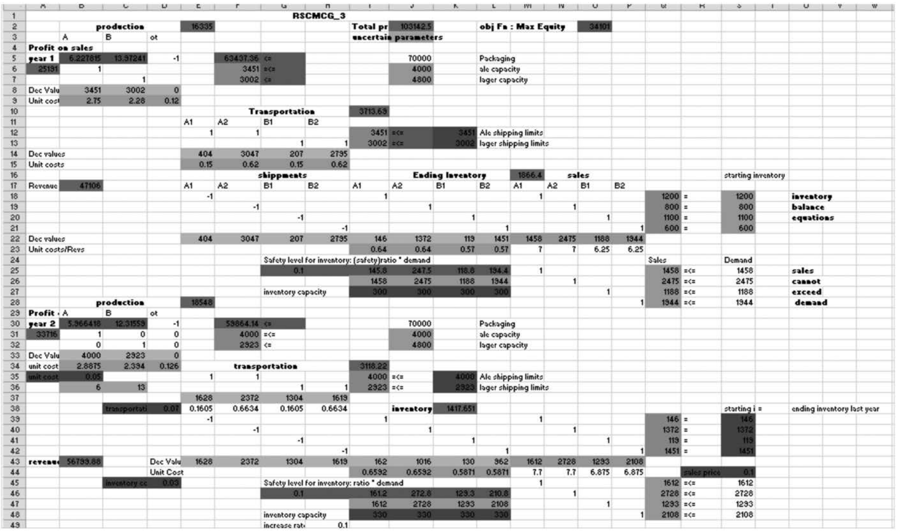

Figure A8.1-1 The results of the RSCMCG-3 model in spreadsheet (Part 1).

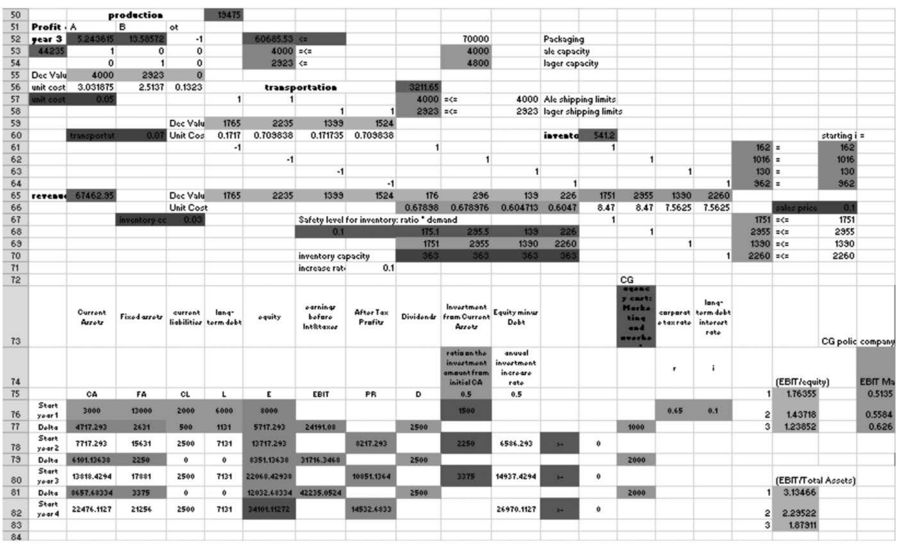

Figure A8.1-2 The results of the RSCMCG-3 model in spreadsheet (part 2).

Appendix 9: Model results for the RSCMCG-4 model

1 Results for the RSCMCG-4 model in spreadsheet

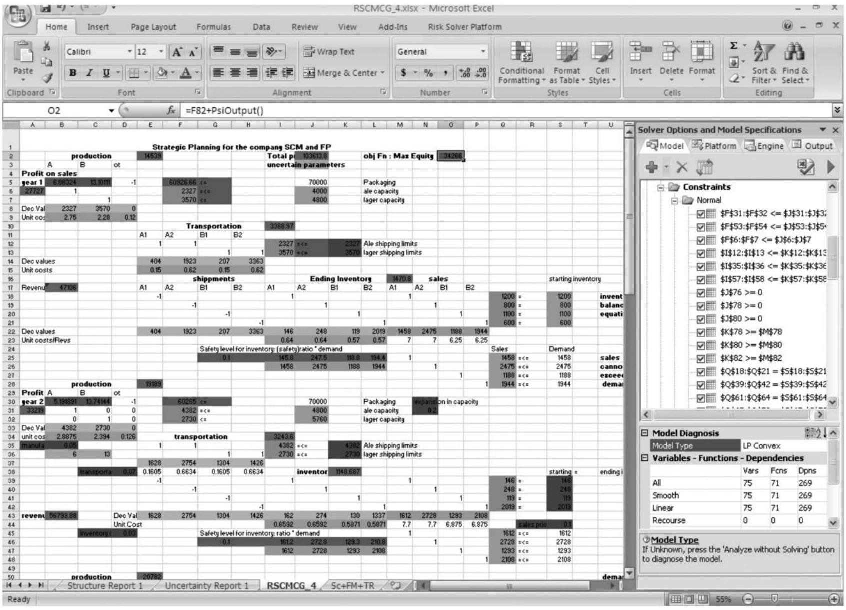

Figure A9.1-1 The results of the RSCMCG-4 model in spreadsheet (part 1).

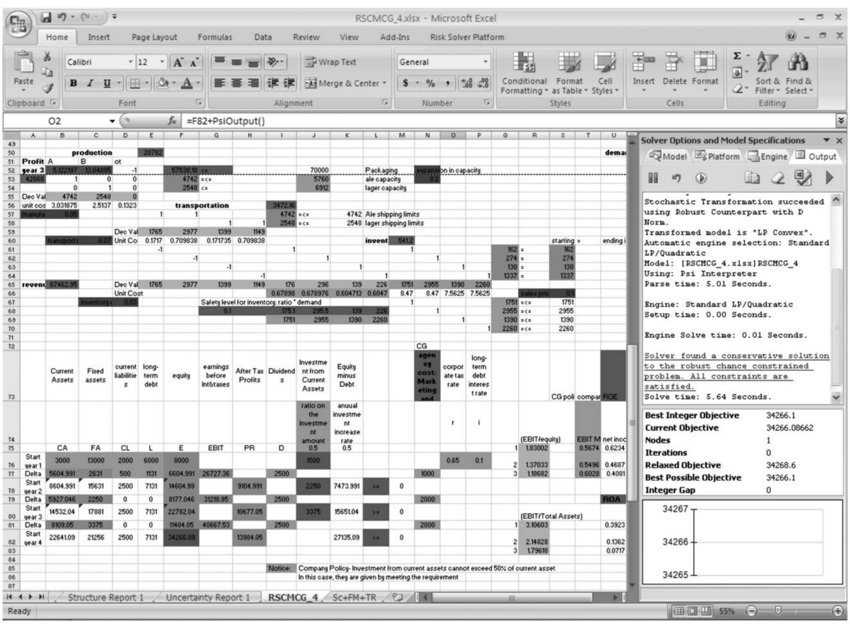

Figure A9.1-2 The results of the RSCMCG-4 model in spreadsheet (part 2).

2 Uncertainty report for the RSCMCG-4 model statistics

	Variables	*Functions*	*Dependents*
All	75	71	269
Recourse	0	0	0
Uncertain	0	0	0

3 Structure report for the RSCMCG-4 model

	Variables	*Functions*	*Dependents*
All	75	71	269
Smooth	75	71	269
Linear	75	71	269

4 Answer Report for the RSCMCG-4 model

Microsoft Excel 12.0 answer report
Worksheet: [RSCMCG_4.xlsx]RSCMCG_4
Result: Solver found a conservative solution to the robust chance-constrained problem. All constraints are satisfied.
Engine: Standard LP/quadratic
Solution Time: 00 seconds
Iterations: 0
Subproblems: 0
Incumbent solutions: 0

Objective cell (max)

Cell	Name	Original value	Final value
$O$2	obj Fn: max equity	0	34266.08662

Decision variable cells

Cell	Name	Original value	Final value	Type
$B$8	Dec values A (MA)-Y1	0	2327	Normal
$C$8	Dec values B (MA)-Y1	0	3570	Normal
$D$8	Dec values ot (MA)-Y1	0	0	Normal
$B$33	Dec values A (MA)-Y2	0	4382	Normal
$C$33	Dec values B (MA)-Y2	0	2730	Normal
$D$33	Dec values ot (MA)-Y2	0	0	Normal
$B$55	Dec values A (MA)-Y3	0	4742	Normal
$C$55	Dec values B (MA)-Y3	0	2548	Normal
$D$55	Dec values ot (MA)-Y3	0	0	Normal
$E$14	Dec values A1 (TR)-Y1	0	404	Normal
$F$14	Dec values A2 (TR)-Y1	0	1923	Normal
$G$14	Dec values B1 (TR)-Y1	0	207	Normal
$H$14	Dec values B2 (TR)-Y1	0	3363	Normal
$E$37	Dec values A1 (TR)-Y2	0	1628	Normal

$F$37	Dec values A2 (TR)-Y2	0	2754	Normal	
$G$37	Dec values B1 (TR)-Y2	0	1304	Normal	
$H$37	Dec values B2 (TR)-Y2	0	1426	Normal	
$E$59	Dec values A1 (TR)-Y3	0	1765	Normal	
$F$59	Dec values A2 (TR)-Y3	0	2977	Normal	
$G$59	Dec values B1 (TR)-Y3	0	1399	Normal	
$H$59	Dec values B2 (TR)-Y3	0	1149	Normal	
$I$22	Dec values A1 (INV)-Y1	0	146	Normal	
$J$22	Dec values A2 (INV)-Y1	0	248	Normal	
$K$22	Dec values B1 (INV)-Y1	0	119	Normal	
$L$22	Dec values B2 (INV)-Y1	0	2019	Normal	
$I$43	Dec values A1 (INV)-Y2	0	162	Normal	
$J$43	Dec values A2 (INV)-Y2	0	274	Normal	
$K$43	Dec values B1 (INV)-Y2	0	130	Normal	
$L$43	Dec values B2 (INV)-Y2	0	1337	Normal	
$I$65	Dec values A1 (INV)-Y3	0	176	Normal	
$J$65	Dec values A2 (INV)-Y3	0	296	Normal	
$K$65	Dec values B1 (INV)-Y3	0	139	Normal	
$L$65	Dec values B2 (INV)-Y3	0	226	Normal	

Constraints

Cell	Name	Cell value	Formula	Status	Slack
$F$5	Packaging assembly uncertainty-Y1	60926.6556	USet2($F$5)<=$J$5	100% satisfied	7870.310617
$F$6	Manufacturing risk management (capacity)-Y1	2327	$F$6<=$J$6	Not Binding	1673
$F$7	Manufacturing risk management (capacity)-Y1	3570	$F$7<=$J$7	Not Binding	1230
$B$8	Dec Values A (MA) non-negative-Y1	2327	$B$8>=0	Not Binding	2327
$C$8	Dec Values B (MA) non-negative-Y1	3570	$C$8>=0	Not Binding	3570
$D$8	Dec Values ot (MA) non-negative-Y1	0	$D$8>=0	Binding	0
$I$12	Shipping capacity constraint A-Y1	2327	$I$12<=$K$12	Binding	0
$I$13	Shipping capacity constraint B-Y1	3570	$I$13<=$K$13	Binding	0
$E$14	Dec values A1 (TR)-non-negative Y1	404	$E$14>=0	Not Binding	404
$F$14	Dec values A2 (TR)-non-negative Y1	1923	$F$14>=0	Not Binding	1923
$G$14	Dec values B1 (TR)-non-negative Y1	207	$G$14>=0	Not Binding	207

(Continued)

$H$14	Dec values B2 (TR)-non-negative Y1	3363	$H$14>=0	Not Binding	3363
$Q$18	Market sales-A1-Y1	1200	$Q$18=$S$18	Binding	0
$Q$19	Market sales-A2-Y1	800	$Q$19=$S$19	Binding	0
$Q$20	Market sales-B1-Y1	1100	$Q$20=$S$20	Binding	0
$Q$21	Market sales-B2-Y1	600	$Q$21=$S$21	Binding	0
$I$22	Safety inventory level A1-Y1	146	$I$22>=$I$25	Not Binding	0.2
$J$22	Safety inventory level A2-Y1	248	$J$22>=$J$25	Not Binding	0.5
$K$22	Safety inventory level B1-Y1	119	$K$22>=$K$25	Not Binding	0.2
$L$22	Safety inventory level B2-Y1	2019	$L$22>=$L$25	Not Binding	1824.6
$I$22	Dec values A1(INV)-non-negative Y1	146	$I$22>=0	Not Binding	0.2
$J$22	Dec values A2(INV)-non-negative Y1	248	$J$22>=0	Not Binding	0.5
$K$22	Dec values B1(INV)-non-negative Y1	119	$K$22>=0	Not Binding	0.2
$L$22	Dec values B2(INV)-non-negative Y1	2019	$L$22>=0	Not Binding	1824.6
$F$30	Packaging assembly uncertainty-Y2	60264.99936	USet_2($F$30)<=$J$30	100% satisfied	3896.690942
$F$31	Manufacturing risk management (capacity)-Y2	4382	$F$31<=$J$31	Not Binding	418
$F$32	Manufacturing risk management (capacity)-Y2	2730	$F$32<=$J$32	Not Binding	3030
$B$33	Dec values A (MA) non-negative-Y2	4382	$B$33>=0	Not Binding	4382
$C$33	Dec values B (MA) non-negative-Y2	2730	$C$33>=0	Not Binding	2730
$D$33	Dec values ot (MA) non-negative-Y2	0	$D$33>=0	Binding	0
$I$35	Shipping capacity constraint A Y2	4382	$I$35<=$K$35	Binding	0
$I$36	Shipping capacity constraint B Y2	2730	$I$36<=$K$36	Binding	0
$E$37	Dec values A1 (TR)-non-negative Y2	1628	$E$37>=0	Not Binding	1628
$F$37	Dec values A2 (TR)-non-negative Y2	2754	$F$37>=0	Not Binding	2754
$G$37	Dec values B1 (TR)-non-negative Y2	1304	$G$37>=0	Not Binding	1304
$H$37	Dec values B2 (TR)-non-negative Y2	1426	$H$37>=0	Not Binding	1426
$Q$39	Market sales-A1-Y2	146	$Q$39=$S$39	Binding	0
$Q$40	Market sales-A2-Y2	248	$Q$40=$S$40	Binding	0
$Q$41	Market sales-B1-Y2	119	$Q$41=$S$41	Binding	0
$Q$42	Market sales-B2-Y2	2019	$Q$42=$S$42	Binding	0
$I$43	Safety inventory level A1-Y2	162	$I$43>=$I$46	Not Binding	0.8
$J$43	Safety inventory level A2-Y2	274	$J$43>=$J$46	Not Binding	1.2
$K$43	Safety inventory level B1-Y2	130	$K$43>=$K$46	Not Binding	0.7
$L$43	Safety inventory level B2-Y2	1337	$L$43>=$L$46	Not Binding	1126.2

$I$43	Dec values A1(INV)-non-negative Y2	162	$I$43>=0	Not Binding	0.8
$J$43	Dec values A2(INV)-non-negative Y2	274	$J$43>=0	Not Binding	1.2
$K$43	Dec values B1(INV)-non-negative Y2	130	$K$43>=0	Not Binding	0.7
$L$43	Dec values B2(INV)-non-negative Y2	1337	$L$43>=0	Not Binding	1126.2
$F$52	Packaging assembly uncertainty-Y3	57538.18024	USet$_2$($F$52)<=$J$52	100% satisfied	9697.169477
$F$53	Manufacturing risk management (Capacity)-Y3	4742	$F$53<=$J$53	Not Binding	1018
$F$54	Manufacturing risk management (Capacity)-Y3	2548	$F$54<=$J$54	Not Binding	4364
$B$55	Dec values A (MA) non-negative-Y3	4742	$B$55>=0	Not Binding	4742
$C$55	Dec values B (MA) non-negative-Y3	2548	$C$55>=0	Not Binding	2548
$D$55	Dec values ot (MA) non-negative-Y3	0	$D$55>=0	Binding	0
$I$57	Shipping capacity constraint A-Y3	4742	$I$57<=$K$57	Binding	0
$I$58	Shipping capacity constraint B-Y3	2548	$I$58<=$K$58	Binding	0
$E$59	Dec values A1 (TR)-non-negativeY3	1765	$E$59>=0	Not Binding	1765
$F$59	Dec values A2 (TR)-non-negativeY3	2977	$F$59>=0	Not Binding	2977
$G$59	Dec values B1 (TR)-non-negativeY3	1399	$G$59>=0	Not Binding	1399
$H$59	Dec values B2 (TR)-non-negativeY3	1149	$H$59>=0	Not Binding	1149
$Q$61	Market sales-A1-Y3	162	$Q$61=$S$61	Binding	0
$Q$62	Market sales-A2-Y3	274	$Q$62=$S$62	Binding	0
$Q$63	Market sales-B1-Y3	130	$Q$63=$S$63	Binding	0
$Q$64	Market sales-B2-Y3	1337	$Q$64=$S$64	Binding	0
$I$65	Safety inventory level A1-Y3	176	$I$65>=$I$68	Not Binding	0.9
$J$65	Safety inventory level A2-Y3	296	$J$65>=$J$68	Not Binding	0.5
$K$65	Safety inventory level B1-Y3	139	$K$65>=$K$68	Binding	0
$L$65	Safety inventory level B2-Y3	226	$L$65>=$L$68	Binding	0
$I$65	Dec values A1(INV)-non-negative Y3	176	$I$65>=0	Not Binding	0.9
$J$65	Dec values A2(INV)-non-negative Y3	296	$J$65>=0	Not Binding	0.5
$K$65	Dec values B1(INV)-non-negative Y3	139	$K$65>=0	Binding	0
$L$65	Dec values B2(INV)-non-negative Y3	226	$L$65>=0	Binding	0
$J$76	Investment restriction-Y1	1500	$J$76>=0	Not Binding	1500
$J$78	Investment restriction- Y2	2250	$J$78>=0	Not Binding	2250
$J$80	Investment restriction-Y3	3375	$J$80>=0	Not Binding	3375
$K$78	Debt-to-equity constraint-Y1	7473.991	$K$78>=$M$78	Not Binding	7473.991
$K$80	Debt-to-equity constraint-Y2	15651.03679	$K$80>=$M$80	Not Binding	15651.03679
$K$82	Debt-to-equity constraint-Y3	27135.08662	$K$82>=$M$82	Not Binding	27135.08662

Appendix 10: Simulation for the SCM model through deterministic optimisation

1 Mathematical model of the initial SCM model through deterministic optimisation

$$\textbf{Objective}: Max\ f(equity) = Z(t)_E = Z(1)_E + \sum_t \left[\Delta Z(t)_E\right] \tag{4-1}$$

Constraints:

$$Z(t)_{CA} + Z(t)_{FA} - Z(t)_{CL} - Z(t)_L - Z(t)_E = 0 \tag{4-2}$$

$$\Delta Z(t)_{CA} + \Delta Z(t)_{FA} - \Delta Z(t)_{CL} - \Delta Z(t)_L - \Delta Z(t)_E = 0 \tag{4-3}$$

$$\begin{aligned}\Delta Z(t)_E &= Z(t)_{PR} - Z(t)_D \\ &= (1 - r_{PR})[EBIT(t) - i(t)_{IrD} * Z(t)_L] - Z(t)_D\end{aligned} \tag{4-4}$$

$$Z(t)_{PR} = (1 - r_{PR})[EBIT(t) - i(t)_{IrD} * Z(t)_L] \tag{4-5}$$

$$\begin{aligned}&\Delta Z(t)_{CA} + \Delta Z(t)_{FA} - \Delta Z(t)_{CL} - \Delta Z(t)_L \\ &\quad - (1 - r_{PR})[EBIT(t) - i(t)_{IrD} * Z(t)_L] + Z(t)_D = 0\end{aligned} \tag{4-6}$$

$$EBIT(t) = R_{sale} - \left(C_{MA} + C_{Inv} + C_{TR}\right) - C_{AC} \tag{4-7}$$

$$R(t)_{sale} = \sum_k \left[X(t)_{sold_k} * c(t)_{sold_k}\right] = \sum_k \left[D(t)_{M_k^i} * c(t)_{sold_k}\right] \tag{4-8}$$

$$C(t)_{MA} = \sum_k C(t)_{MA_k} = \sum_k \left[c(t)_{MA_k} * X(t)_{qMA_k}\right] \tag{4-9}$$

$$C(t)_{TR} = \sum_k \sum_{m,n}^{M,N} \left[Y(t)_{qTR_{k_{mn}}} * c(t)_{TR_{k_{mn}}}\right] \tag{4-10}$$

$$C(t)_{inv} = \sum_k \sum_j \left[c(t)_{invj_k} * X(t)_{invj_k}\right] \tag{4-11}$$

$$\sum_k \sum_{m,n}^{M,N} \theta_{k_{mn}} Y(t)_{qTR_{k_{mn}}} = Y(t)_{qTR_{mn}} \tag{4-12}$$

$$X(t)_{invj_k} = X(t-1)_{invj_k} + Y(t)_{qTR_{k_{mn}}} - D(t)_{M_k{}^i} \tag{4-13}$$

$$X(t)_{qMA_k} \le CAP(t)_{fac_k} \tag{4-14}$$

$$Y(t)_{qTR_{mn}} \le CAP_{QTR_{mn}} = CAP_{QTR_{k_{mn}}} = Y(t)_{qMA_k} \tag{4-15}$$

$$Z(t)_L \le \kappa_{D/E} * Z(t)_E \tag{4-16}$$

$$Z(t)_{Inv/CA} \le \kappa_{inv} * Z(t)_{CA} \tag{4-17}$$

2 Spreadsheet modelling for the initial deterministic optimisation SCM model

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1			initial optimization model'						M + financial planning without control on safety inventory: 3 years planning _											
2			production		11457				Total pr	34715.94		obj Fn : Max Equity			34052					
3		A	B	ot					uncertain parameters											
4	Profit on sales																			
5	year 1	6	13	-1		36490	<=			70000		Packaging								
6	32899	1				2979	=<=			4000		ale capacity								
7			1			1432	<=			4800		lager capacity								
8	Dec Valu	2979	1432	0																
9	Unit cost	2.75	2.28	0.12																
10							Transportation		2080.58											
11					A1	A2	B1	B2												
12		0			1	1			2979	=<=	2979	Ale shipping limits								
13							1	1	1432	=<=	1432	lager shipping limits								
14	Dec values				1304	1675	88	1344												
15	Unit costs				0.15	0.62	0.15	0.62												
16							shippments				Ending Inventory		669.44	sales					starting inventor	
17	Revenue	47106			A1	A2	B1	B2	A1	A2	B1	B2	A1	A2	B1	B2				
18					-1				1				1				1200	=	1200	
19						-1				1				1			800	=	800	
20							-1				1				1		1100	=	1100	
21								-1				1				1	600	=	600	
22	Dec values				1304	1675	88	1344	1046	0	0	0	1458	2475	1188	1944				
23	Unit costs/Revs								0.64	0.64	0.57	0.57	7	7	6.25	6.25				
24							Safety level for inventory (ratio)										Sales		Demand	
25							0.1		0	0	0	0	1				1458	=<=	1458	
26														1			2475	=<=	2475	
27															1		1188	=<=	1188	
28			production		19010											1	1944	=<=	1944	
29	Profit · A		B	ot																
30	year 2	6	13	-1		69669	<=			70000		Packaging								
31	28711	1	0	0		4000	=<=			4000		ale capacity								
32		0	1	0		3513	<=			4800		lager capacity								
33	Dec Valu	4000	3513	0																
34	unit cost	2.75	2.28	0.12			transportation		3399.87											
35					1	1			4000	=<=	4000	Ale shipping limits								
36		5.515994	12.65398				1	1	3513	=<=	3513	lager shipping limits								
37					1272	2728	1405	2108												
38					0.15	0.62	0.15	0.62		inventory	515.68								starting i =	
39					-1				1				1				1046	=	1046	
40						-1				1				1			0	=	0	
41							-1				1				1		0	=	0	
42								-1				1				1	0	=	0	
43	revenue	51636.25		Dec Valu	1272	2728	1405	2108	706	0	112	0	1612	2728	1293	2108				
44				Unit Cost					0.64	0.64	0.57	0.57	7	7	6.25	6.25				
45							Safety level for inventory (ratio)						1				1612	=<=	1612	
46							0.1		0	0	0	0		1			2728	=<=	2728	
47															1		1293	=<=	1293	
48																1	2108	=<=	2108	

Figure A10.1-1 Spreadsheet modelling for the initial deterministic optimisation SCM model (part 1)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
49																				
50			production		19067															
51	Profit · A		B	ot																
52	year 3	6	13	-1		69994	<=			70000		Packaging								
53	33106	1	0	0		4000	=<=			4000		ale capacity								
54		0	1	0		3538	<=			4800		lager capacity								
55	Dec Valu	4000	3538	0																
56	unit cost	2.75	2.28	0.12			transportation		3581.75											
57					1	1			4000	=<=	4000	Ale shipping limits								
58							1	1	3538	=<=	3538	lager shipping limits								
59				Dec Valu	1045	2955	1278	2260												
60				Unit Cos	0.15	0.62	0.15	0.62				invento	0						starting i =	
61					-1				1				1				706	=	706	
62						-1				1				1			0	=	0	
63							-1				1				1		112	=	112	
64								-1				1				1	0	=	0	
65	revenue	55754.5		Dec Valu	1045	2955	1278	2260	0	0	0	0	1751	2955	1390	2260				
66				Unit Cost					0.64	0.64	0.57	0.57	7	7	6.25	6.25				
67							Safety level for inventory (ratio)						1				1751	=<=	1751	
68							0.1		0	0	0	0		1			2955	=<=	2955	
69															1		1390	=<=	1390	
70																1	2260	=<=	2260	
71																				
72														CG						
73		Current Assets	Fixed assets	current liabilities	long-term debt	equity	earnings before Int&taxes	After Tax Profits	Dividends	Investment from Current Assets	Equity minus Debt			agency cost: Marketing and overhe	corporate tax rate	long-term debt interest rate			CG polic	compa
74										ratio on the investment amount from the CA					r	i		(EBIT/equity)		
75		CA	FA	CL	L	E	EBIT	PR	D	0.5							1	1.9026		
76	Start year1	3000	13000	2000	6000	8000				1500					0.65	0.1	2	1.0247		
77	Delta	6714.9845	2631	500	1131	7714.9845	29898.77		2500					3000			3	0.8548		
78	Start year2	9714.9845	15631	2500	7131	15714.9845		10214.9845		4857.49225	8583.9845	>=	0							
79	Delta	3541.79375	4857.49225	0	0	8399.286	24711.06		2500					4000						
80	Start year3	13256.7783	20488.4923	2500	7131	24114.2705		8399.286		6628.38913	16983.2705	>=	0					(EBIT/Total Assets)		
81	Delta	3309.16438	6628.38913	0	0	9937.5535	29106.11		2500					4000			1	3.0776		
82	Start year4	16565.9426	27116.8814	2500	7131	34051.824		9937.5535			26920.824	>=	0				2	1.864		
83																	3	1.757		

Figure A10.1-2 Spreadsheet modelling for the initial deterministic optimisation SCM model (part 2).

3 Settings in the Risk Solver Platform for the extended SCMFP model in the Excel

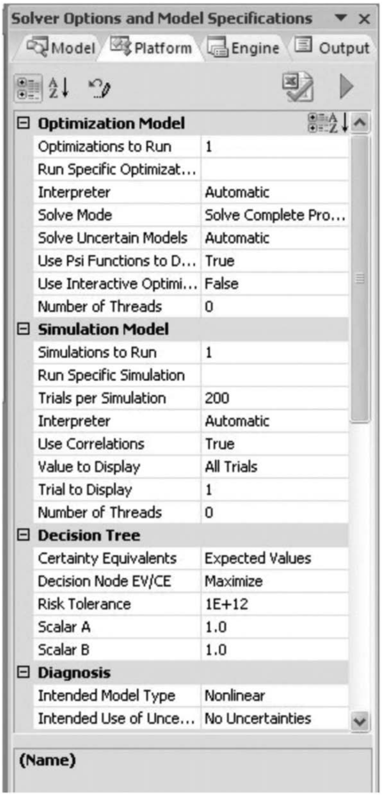

Figure A10.2-1 Settings in the Risk Solver Platform for the extended SCMFP model in the Excel (part 1).

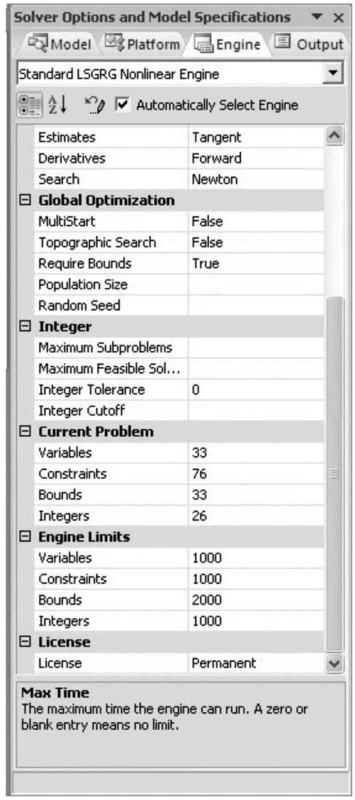

Figure A10.2-2 Settings in the Risk Solver Platform for the extended SCMFP model in the Excel (part 2).

4 Spreadsheet modelling for the SCMFP model

4.1 The results from the integrated SCMFP model with 6 and 13 as packaging assembly coefficients for products A and B, respectively

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1			initial optimization model'						SCM + financial planning_ with CG: 3 years planning _ DP										
2			production		12062				Total pr	34131.24		obj Fn : Max Equity			[illegible]				
3		A	B	ot					uncertain parameters										
4	Profit on sales																		
5	year 1	6	13	-1		39174	<=			70000		Packaging							
6	32043	1				3058	=<=			4000		ale capacity							
7			1			1602	<=			4800		lager capacity							
8	Dec Valu	3058	1602	0															
9	Unit cost	2.75	2.28	0.12															
10							Transportation		2183.73										
11					A1	A2	B1	B2											
12		0			1	1			3058	=<=	3058	Ale shipping limits							
13							1	1	1602	=<=	1602	lager shipping limits							
14	Dec values				1303	1755	198	1404											
15	Unit costs				0.15	0.62	0.15	0.62											
16							shippments				Ending Inventory		816.9	sales					starting in
17	Revenue	47106			A1	A2	B1	B2	A1	A2	B1	B2	A1	A2	B1	B2			
18					-1				1				1				1200	=	1200
19						-1				1				1			800	=	800
20							-1				1				1		1100	=	1100
21								-1				1				1	600	=	600
22	Dec values				1303	1755	198	1404	1045	80	110	60	1458	2475	1188	1944			
23	Unit costs/Revs								0.64	0.64	0.57	0.57	7	7	6.25	6.25			
24							Safety level for inventory (ratio)										Sales		Demand
25							0.1		120	80	110	60	1				1458	=<=	1458
26														1			2475	=<=	2475
27															1		1188	=<=	1188
28			production		18640											1	1944	=<=	1944
29	Profit	A	B	ot															
30	year 2	6	13	-1		67563	<=			70000		Packaging							
31	29106	1	0	0		4000	=<=			4000		ale capacity							
32		0	1	0		3351	<=			4800		lager capacity							
33	Dec Valu	4000	3351	0															
34	unit cost	2.75	2.28	0.12			transportation		3319.17										
35					1	1			4000	=<=	4000	Ale shipping limits							
36		6	13				1	1	3351	=<=	3351	lager shipping limits							
37					1342	2658	1293	2058											
38					0.15	0.62	0.15	0.62		inventory	570.8								starting i =
39					-1				1				1				1045	=	1045
40						-1				1				1			80	=	80
41							-1				1				1		110	=	110
42								-1				1				1	60	=	60
43	revenue	51636.25		Dec Valu	1342	2658	1293	2058	775	10	110	10	1612	2728	1293	2108			
44				Unit Cost					0.64	0.64	0.57	0.57	7	7	6.25	6.25			
45							Safety level for inventory (ratio)						1				1612	=<=	1612
46							0.1		104.5	8	11	6		1			2728	=<=	2728
47															1		1293	=<=	1293
48																1	2108	=<=	2108

Figure A10.3-1 The results from the integrated SCMFP model with 6 and 13 as packaging assembly coefficients for products A and B, respectively (part 1).

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
49																				
50			production		19081															
51	Profit	A	B	ot																
52	year 3	6	13	-1		70000	<=			70000		Packaging								
53	33042	1	0	0		4000	=<=			4000		ale capacity								
54		0	1	0		3542	<=			4800		lager capacity								
55	Dec Valu	4000	3542	46																
56	unit cost	2.75	2.28	0.12			transportation		3573.89											
57					1	1			4000	=<=	4000	Ale shipping limits								
58							1	1	3542	=<=	3542	lager shipping limits								
59				Dec Valu	1054	2946	1291	2251												
60				Unit Cos	0.15	0.62	0.15	0.62				invento	57.4						starting i =	
61					-1				1				1				775	=	775	
62						-1				1				1			10	=	10	
63							-1				1				1		110	=	110	
64								-1				1				1	10	=	10	
65	revenue	55754.5		Dec Valu	1054	2946	1291	2251	78	1	11	1	1751	2955	1390	2260				
66				Unit Cost					0.64	0.64	0.57	0.57	7	7	6.25	6.25				
67							Safety level for inventory (ratio)						1				1751	=<=	1751	
68							0.1		77.5	1	11	1		1			2955	=<=	2955	
69															1		1390	=<=	1390	
70																1	2260	=<=	2260	
71																				
72														CG						
73		Current Assets	Fixed assets	current liabilities	long-term debt	equity	earnings before Int&taxes	After Tax Profits	Dividends	Investment from Current Assets	Equity minus Debt			agency cost: Marketing and overheads	corporate tax rate	long-term debt interest rate			CG polic	company
74										ratio on the investment amount from the CA					r	i		(EBIT/equity)		
75		CA	FA	CL	L	E	EBIT	PR	D	0.5							1	1.884		
76	Start year1	3000	13000	2000	6000	8000				1500					0.65	0.1	2	1.0481		
77	Delta	6415.5735	2631	500	1131	7415.5735	29043.31		2500					3000			3	0.8575		
78	Start year2	9415.5735	15631	2500	7131	15415.5735		9915.5735		4707.78675	8284.5735	>=	0							
79	Delta	3829.72825	4707.78675	0	0	8537.515	25106		2500					4000						
80	Start year3	13245.3018	20338.7868	2500	7131	23953.0885		8537.515		6622.65088	16822.0885	>=	0					(EBIT/Total Assets)		
81	Delta	3292.43963	6622.65088	0	0	9915.0905	29041.93		2500					4000			1	3.0846		
82	Start year4	16537.7414	26961.4376	2500	7131	[illegible]		9915.0905			26737.179	>=	0				2	1.8955		
83																	3	1.7561		

Figure A10.3-2 The results from the integrated SCMFP model with 6 and 13 as packaging assembly coefficients for products A and B, respectively (part 2).

4.2 The results from the integrated SCMFP model with 7 and 14 as packaging assembly coefficients for products A and B, respectively

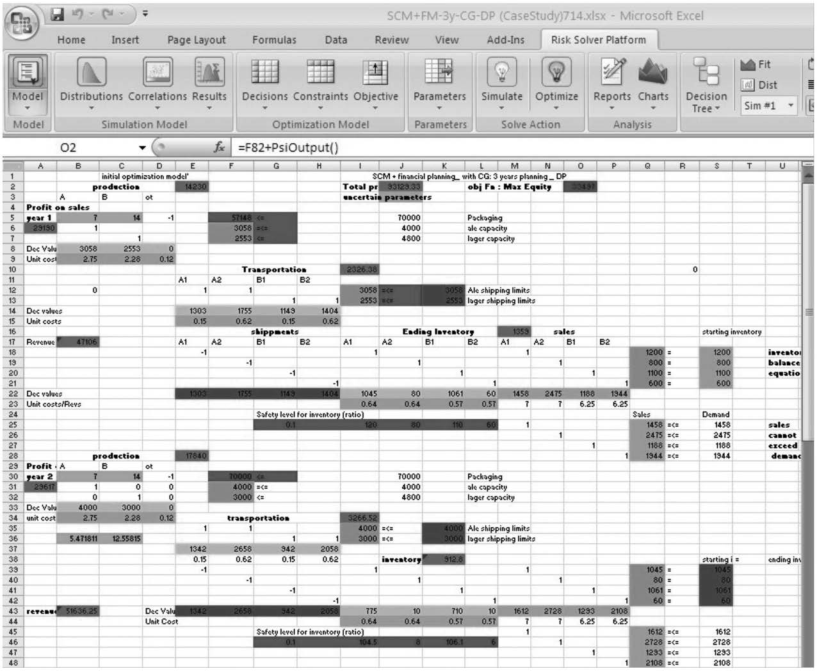

Figure A10.4-1 The results from the integrated SCMFP model with 7 and 14 as packaging assembly coefficients for products A and B, respectively (part 1).

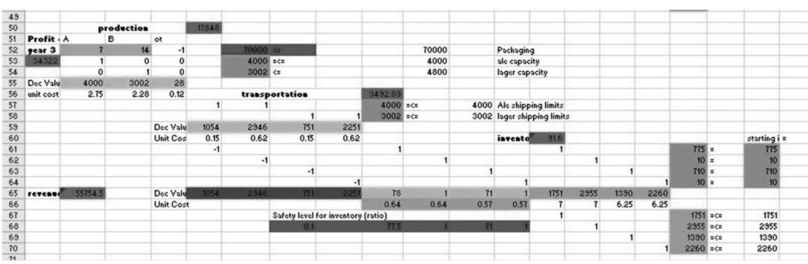

Figure A10.4-2 The results from the integrated SCMFP model with 7 and 14 as packaging assembly coefficients for products A and B, respectively (part 2).

71																	
72														CG			
73		Current Assets	Fixed assets	current liabilities	long-term debt	equity	earnings before Int&taxes	After Tax Profits	Dividends	Investment from Current Assets	Equity minus Debt			[illegible]	corporate tax rate	long-term debt interest rate	
74										ratio on the investment amount from the CA					r	i	
75		CA	FA	CL	L	E	EBIT	PR	D	0.5							
76	Start year 1	3000	13000	2000	6000	8000				1500					0.65	0.1	
77	Delta	5417.0235	2631	500	1131	6417.0235	26190.31		2500					3000			
78	Start year 2	8417.0235	15631	2500	7131	14417.0235		8917.0235		4208.51175	7286.0235	>=	0				
79	Delta	4507.82875	4208.51175	0	0	8716.3405	25616.93		2500					4000			
80	Start year 3	12924.8523	19839.5118	2500	7131	23133.364		8716.3405		6462.42613	16002.364	>=	0				
81	Delta	3900.72038	6462.42613	0	0	10363.1465	30322.09		2500					4000			
82	Start year 4	16825.5726	26301.9379	2500	7131	33496.5105		10363.1465			26365.5105	>=	0				
83																	
84																	

Figure A10.4-3 The results from the integrated SCMFP model with 7 and 14 as packaging assembly coefficients for products A and B, respectively (part 3).

5 Report on the SCMFP model (with packaging coefficient of 7 and 14 for products A and B, respectively)

General simulation information

Simulation options		**Value**
Simulations run		1
Trials per simulation		200
Number of error trials		0
Current simulation		1
Random number generator		CMRG
Sampling method		Latin hypercube
Random number stream		Independent stream
Simulation seed		0
Interpreter used		Automatic
Correlations used		Yes
Model information		**Quantity**
Uncertain variables		5
Uncertain functions		2
Correlated variables		0
Global bounds	**Measure**	**Value**
Lower cutoff	None	−1E+30
Upper cutoff	None	1E+30
Lower censor	None	−1E+30
Upper censor	None	1E+30

Uncertain variable summary information

Cell	*Name*	*Distribution*	*Mean*	*Std Dev*	*Minimum*	*Maximum*	*25th Percentile*	*50th Percentile*	*75th Percentile*
$B$36	A	PsiUniform(5,7)	6	0.57735027	5	7	5.5	6	6.5
$C$36	B	PsiUniform(12,14)	13	0.57735027	12	14	12.5	13	13.5
$N$89	Potential uncertain agency cost	PsiUniform(2500,3500)	3000	288.675135	2500	3500	2750	3000	3250
$N$91	Potential uncertain agency cost	PsiUniform(3500,4500)	4000	288.675135	3500	4500	3750	4000	4250
$N$93	Potential uncertain agency cost	PsiUniform(3500,4500)	4000	288.675135	3500	4500	3750	4000	4250

Uncertain function summary information

Cell	*Name*	*Formula*	*Mean*	*Std. Dev*	*Minimum*	*Maximum*	*25th Percentile*	*50th Percentile*	*75th Percentile*
$Q$2	objFn:MaxEquity	F82+PsiOutput()	33496.511	0	33496.511	33496.511	33496.5105	33496.5105	33496.5105
$R$10	Transportation	PsiOutput()	0	0	0	0	0	0	0

Appendix 11: Simulation of the SCM model through simulation optimisation in the Excel

1 Task pane settings in the 'Platform' component for the SCM model through simulation optimisation

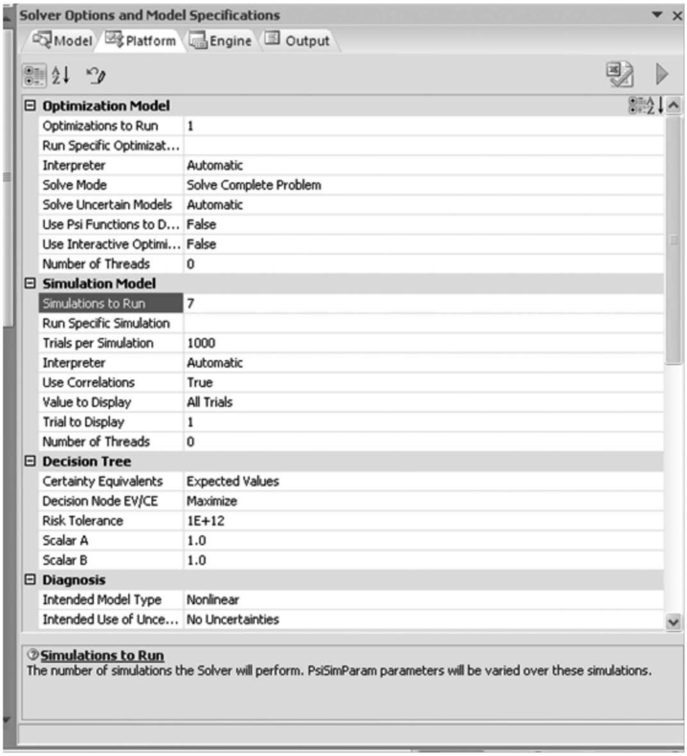

Figure A11.1 Task pane settings in the 'Platform' component for the SCM model through simulation optimisation.

2 Task pane settings in the 'Engine' component for the SCM model through simulation optimisation

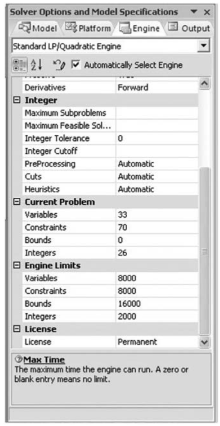

Figure A11.2-1 Task pane settings in the 'Engine' component for the SCM model through simulation optimisation (part 1).

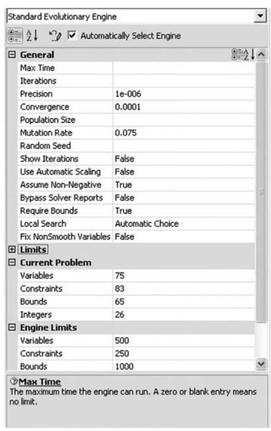

Figure A11.2-2 Task pane settings in the 'Engine' component for the SCM model through simulation optimisation (part 2).

3 Output of the SCM model through simulation optimisation

---- Start Solve ----
No uncertain input cells.
Using: Full Reparse.
Parsing started…
Diagnosis started…
Convexity testing started…
Model diagnosed as "LP Convex".
Automatic engine selection: Standard LP/Quadratic
Model: [4.2.1.2- SCM-20131218_uncertain parameters-SO.xlsx]
Using: Psi Interpreter
Parse time: 2.86 Seconds.
Engine: Standard LP/Quadratic
Setup time: 0.00 Seconds.
Engine Solve time: 20.75 Seconds.
The maximum number of subproblems was reached.
Solve time: 24.11 Seconds.

---- Start Simulation ----
Model: 4.2.1.2- SCM-20131218_uncertain parameters-SO.xlsx

Simulation finished successfully.
Successful Trials: 1000
Error Trials: 0
Total Trials: 1000
Simulation time: 2.42 Seconds.

4 Answer report for the SCM model through simulation optimisation

Microsoft excel12.0 simulation report
Simulation report [4.2.1.2- SCM-20131218_uncertain parameters-SO.xlsx]
Simulation time: 4.688 seconds.

General Simulation Information

Simulation options		**Value**
Simulations run		1
Trials per simulation		1000
Number of error trials		0
Current simulation		1
Random number generator		CMRG
Sampling method		Latin hypercube
Random number stream		Independent stream
Simulation seed		0
Interpreter used		Automatic
Correlations used		Yes
Model information		**Quantity**
Uncertain variables		12
Uncertain functions		2
Correlated variables		0
Global bounds	**Measure**	**Value**
Lower cutoff	None	−1E+30
Upper cutoff	None	1E+30
Lower censor	None	−1E+30
Upper censor	None	1E+30

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Note: Bold page numbers refer to tables; *italic* page numbers refer to figures and page numbers followed by "n" denote endnotes.