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OPTIMIZING SUPPLY CHAIN PERFORMANCE

Information Sharing and Coordinated Management

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Preface

Supply chain management has attracted much attention in the past decade. There has been a noticeable shift from a traditional individual organisation-based management to an integrated management across the supply chain network since the end of the past century. The shift contributes to better decision making in the supply chain context, as it is necessary for a company to cooperate with other supply chain members by utilising relevant information such as inventory, demand and resource capacity. In other words, information sharing and coordinated management are essential mechanisms to improve supply chain performance.

Supply chains may differ significantly in terms of industry sectors, geographic locations and firm sizes. This study was based on case studies from small- and medium-sized manufacturing supply chains in the Peoples' Republic of China. The study was motivated by the following facts. Firstly, small and medium enterprises have made a big contribution to China's economic growth. Several studies revealed that most of the Chinese manufacturing enterprises became aware of the importance of supply chain management, but compared to Western firms, the supply chain management level of Chinese firms had been lagging behind. Research on supply chain management and performance optimisation in Chinese small- and medium-sized enterprises (SMEs) was very scarce. Secondly, there had been plenty of studies in the literature that focused on two or three level supply chains whilst considering a number of uncertain factors (e.g., customer demand) or a single supply chain performance indicator (e.g., cost). However, the research on multiple stage supply chain systems with multiple uncertainties and multiple objectives based on real industrial cases had been sparse and deserved more attention. One reason was due to the lack of reliable industrial data that required an enormous effort to collect, and there was a serious concern about data confidentiality from the industry aspect.

This study employed two SME manufacturing companies as case studies. The first one was in the aluminium industry and the other was in the chemical industry. The aim was to better understand the characteristics of the supply chains in Chinese SMEs through performing in-depth case studies and utilising models and tools to evaluate different strategies for improving their supply chain performance.

The main contributions of this study include the following aspects. Firstly, this study generalised a supply chain model including a domestic supply chain part and an international supply chain part based on deep case studies, with the emphasis on identifying key characteristics in the case supply chains, such as uncertainties, constraints and cost elements in association with flows and activities in the domestic and international supply chain. Secondly, two important supply chain management (SCM) issues, that is, integrated raw material procurement and finished goods production planning, and international sales planning, were identified. Thirdly, mathematical models were formulated to represent the supply chain model, taking into account multiple uncertainties. Fourthly, several operational strategies utilising the concepts of just-in-time, safety-stock/capacity, Kanban and vendor managed inventory were evaluated and compared with the case company's original strategy in various scenarios through simulation methods, which enabled quantification of the impact of information sharing on supply chain performance. Fifthly, a single objective genetic algorithm was developed to optimise the integrated raw material ordering and finished goods production decisions under (s, S) policy (a dynamic inventory control policy), which enabled the impact of coordinated management on supply chain performance to be quantified. Finally, a multiple objective genetic algorithm considering both total supply chain cost and customer service level was developed to optimise the integrated raw material ordering and finished goods production with the international sales plan decisions under (s, S) policy in various scenarios. This also enabled the quantification of the impact of coordinated management on supply chain performance.

List of Abbreviations

DSC	Domestic Supply Chain
ICT	Information Communication Technology
ISC	International Supply Chain
JIT	Just-in-Time
MOGA	Multiple Objective Genetic Algorithm
PM-JIT	Parameterised-Just-in-Time in Multiple Objective Genetic Algorithm
PM-VMI	Parameterised-Vendor Management Inventory in Multiple Objective Genetic Algorithm
PS-JIT	Parameterised-Just-in-Time in Single Objective Genetic Algorithm
PS-VMI	Parameterised-Vendor Management Inventory in Single Objective Genetic Algorithm
SC	Supply Chain
SCM	Supply Chain Management
SCP	Supply Chain Performance
SME	Small- and Medium-Sized Enterprise
SOGA	Single Objective Genetic Algorithm
VMI	Vendor Management Inventory

1

Introduction

This chapter presents the background and motivation for this study, followed by its aim and specific research objectives. The research methodology is briefly discussed, and the organisation and structure for the book are outlined.

Background

Logistics management essentially integrates a process that seeks to optimise material flow and supplies to cover the organisation and its operations to the customer. The concept of supply chain management (SCM) extends the scope of logistics and emphasises more the interactions among channel members with information and operation-based activity. According to Simchi-Levi *et al.* (2008, 1), SCM could be defined as "a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimise systemwide cost while satisfying service level requirements." It was increasingly recognised that SCM could improve supply chain performance (SCP) under integrated decision making. In the past decade there have been many studies focusing on SCM and SCP improvement (e.g., Gunasekaran *et al.*, 2004; Brewer and Speh, 2000; Slade *et al.*, 2009; Bossert *et al.*, 2007).

China has experienced rapid economic development in the past few decades. According to the world statistics pocketbook from the United Nations Statistics Division (UNSD, 2012), its gross domestic product (GDP) has grown rapidly since 2000 from US$1,192,840 million to US$4,984,430 million in 2009 (nearly 318%). The unemployment rate in urban areas in 2009 was only 4.2%, which was lower than that in the UK and USA. From the trade aspect, after several years of continuous growth, the market peak was US$1,430.7 billion in 2008; however, the value of China's exports had dropped in 2009 by 16.0% but had bounced back in 2010 by 31.3% to amount to US$ 1,578.2 billion. Imports showed a similar development with an increase of 38.6% to US$1,394.2 billion in 2010. The trade surplus dropped from US$196.1 billion in 2009 to US$184.0 billion in 2010. Referring to the USA, trade fell significantly compared with Developed Asia-Pacific (-US$89.9 billion) and Eastern Asia (-US$54.3 billion). China's trade diversified across partners: in 2010, 24 major partners accounted for 80% of exports.

A number of studies have been conducted on the development of SCM in China. For example, issues such as infrastructure and technology (Martinsons, 2004), labour and product quality (Zhang and Goffin, 1999; Chien *et al.*, 2009), business culture and government policy (Cai *et al.*, 2010) and the risk of poor quality (Franca *et al.*, 2010) in the supply chain (SC) context had been addressed. The results showed that these issues could lead to poor production quality, low productivity, unfilled orders, low operational performance and low customer satisfaction. It was reported that the quality and safety issues that stemmed from Chinese products increased the USA import risk (Cai *et al.*, 2009) and outsourcing quality management risk (Franca *et al.*, 2010). In addition, the Chinese special business culture and governmental attitude, enterprise ownership and relationship management all had significant impacts on the role and performance of Chinese companies. For example, Cai *et al.* (2010) investigated the impacts of Chinese companies' institutional environment, for example, legal protection, government support and *Guan Xi* (interpersonal relationships) on the development of trust and information integration between buyers and suppliers, and claimed that the institutional environment positively influences SC integration (Zhao *et al.*, 2011).

More specific to the area of manufacturing SC, Pyke *et al.* (2000) undertook a survey of state-owned, collectively owned and privately owned enterprises in order to understand the status of SCM in Chinese manufacturing firms, for example, how sophisticated were they? Do they understand modern principles of manufacturing strategy and SCM? What was the level of installed technology from traditional production planning systems, like material requirement planning (MRP), to robotics? Based on a survey of 100 firms in the Shanghai area, they found that those enterprises were indeed using advanced manufacturing strategies but were not as advanced in SCM as many Western firms (Pyke *et al*., 2000). Pyke surveyed 100 manufacturing enterprises in China and found that most of the enterprises were aware of the importance of SCM. Robb *et al*. (2008) surveyed 72 furniture manufacturers in China. Their research revealed that Chinese furniture manufacturers were actively engaged in many forms of improvement relating to operations and SCM. However, compared with the Western firms, generally the SCM level of Chinese firms was lagging behind (Chen and Yang, 2003; Su *et al*., 2008a).

Small and medium enterprises (SMEs) made a big contribution to China's economic growth, and it was reported that they made up over 99% of all enterprises in China in 2007 (Liu, 2008). The output value of SMEs accounted for at least 60% of the country's GDP, generating more than 82% of employment opportunities in China (Liu, 2008). It was pointed out that the definition of SME in China was complicated and different from Europe. The Interim Categorising Criteria for SMEs, published in 2003 and based on the SME Promotion Law of China, set the guidelines for classifying SMEs. Guidelines for the industrial sector required SMEs to employ a maximum 2,000 people and to have an annual revenue not exceeding RMB300 million. Their total assets could not exceed RMB400 million. Those employing more than 300 people were classed as medium-sized enterprises. Small-sized enterprises could employ up to 300 people, with the annual revenue and total assets not exceeding RMB30 million and 40 million, respectively (China, 2003). Although the SME sector was very important in China, research on their SCM and performance optimisation was very scarce.

This study conducted two case studies of Chinese SME manufacturers. Case company A was in the aluminium industry located in the north of China, and case company B was a chemical company located in the south of China. Case company A made its main sales to mainland China. Case company B produced different types of finished goods that served as raw materials of other chemical products for many other companies in mainland China and the international market (Spain, South Korea and Brazil). However, after the financial crisis, the amount of exports declined over 20%. Meanwhile, in order to keep a certain percentage of international market share (because of government policy and the company's own strategy), case company B had to satisfy a certain amount of international customer orders. The main purpose of this research was to better understand the characteristics of SCs in Chinese SMEs through in-depth case studies and specifically built models and tools to evaluate different strategies to improve SCP.

Research motivation

This research was motivated by two research gaps. Firstly, the literature showed that most of the Chinese manufacturing enterprises became aware of the importance of SCMs, but compared to Western firms, the SCM level of Chinese firms was lagging behind. The SMEs were a very important industrial sector in China, but the research on SCM and performance optimisation in Chinese SME manufacturers was very rare.

Secondly, although there had been plenty of studies in the literature that focused on two or three level SCs while considering a number of uncertain factors (e.g., customer demand) or a single SCP indicator (e.g., cost), the research on multiple stage SC systems with multiple uncertainties and multiple objectives based on real industrial cases had been sparse and deserved more attention. One reason was due to the lack of reliable industrial data and the impact of data confidentiality which remains important to the industry.

Research objectives

The aims of this study were two-fold. Firstly, to provide insights into understanding the key characteristics and differences of domestic SCs (DSC) and international SCs (ISC) in China based on case studies. The key characteristics were discussed in terms of three aspects: uncertainties, constraints and cost elements. This led to a reasonably generalised model for Chinese DSCs and ISCs. Secondly, simulation-based tools were to be developed to evaluate different management strategies incorporating information sharing and coordinated management mechanisms, which could assist managers to make better decisions in terms of raw material procurement, finished goods production and international sales strategy.

The specific research objectives included:

1. systematically reviewing and gaining knowledge about information sharing and coordinated management mechanisms and SCP improvement methods;
2. analysing the case study companies' domestic/international SCs and mapping the identified SCs in terms of information flows, material flows and financial flows; then identifying the key characteristics and differences between DSCs and ISCs from three aspects: uncertainties, constraints and cost elements;
3. identifying important SCM issues, that is, integrated raw material procurement and finished goods production planning and international sales planning;
4. mathematically formulating an optimised model for Chinese DSCs and ISCs;
5. developing a Matlab simulation model to evaluate several operational strategies including optimised strategies using the concepts of just-in-time (JIT), safety-stock/capacity, Kanban and vendor managed inventory (VMI), in comparison with the case companies' original strategy in various scenarios, which enabled quantification of the impact of an information sharing mechanism on SCP;
6. developing a single objective genetic algorithm (SOGA) tool to optimise the integrated raw material ordering and finished goods production decisions under (s, S) policy (the record point is denoted by s. If the inventory level drops to or below s, then place an order with sufficient size to bring the inventory level up to the maximum level S [Axsäter,2006]), which enabled the quantification of the impact of coordinated management on SCP;
7. developing a multiple objective genetic algorithm (MOGA) tool that considered both total SC cost and customer service level to optimise the integrated raw material ordering and finished goods production with the international sales plan decisions under the (s, S) policy in various scenarios, which enabled quantification of the impact of coordinated management on the SCP.

Research methodology

The following describes the research process adopted in this study including data collection methods and model development techniques. Firstly, a systematic literature review was conducted in order to gain knowledge about SCM, SCP, information sharing and coordinated management mechanisms and the research context (e.g., SCM in China and Chinese SMEs).

Secondly, primary data were collected from two Chinese SME manufacturers through a series of individual interviews, group interviews, observations and archived data. The case companies' domestic and international SCs were selected, mapped and analysed. The key characteristics of the case SCs were identified and categorised. This led to a reasonably generalised SC model.

Thirdly, important SCM issues in the case SCs were identified. The generalised SC model was formulated mathematically.

Fourthly, a set of operational strategies that utilise the concepts of JIT, safety-stock/capacity, Kanban and VMI are presented in comparison with the case companies' original strategy in various scenarios. This was achieved by developing a Matlab simulation tool. The tool enabled the impact of an information sharing mechanism on SCP to be quantified.

Fifthly, a SOGA and MOGA tool were developed to optimise several parameterised operational strategies in various scenarios. The experimental results from the tools enabled the impact of coordinated management on SCP to be quantified.

Finally, the extension of the model for its general applicability is discussed.

What follows

Chapter 2 focuses on a literature review and on research gap identification. Studies related to SCM, SCP, uncertainties in SC, SC mapping and integration, information sharing strategies, coordinated management strategies, optimisation and the current status of SCM in China are reviewed. Based on those reviews, the research gap is identified.

Chapter 3 explains the research methodology and the relevant techniques. The benefits and disadvantages of employing multiple case studies are discussed. Then the data collection methods including interview and observation are introduced and discussed with the consideration of advantages and disadvantages of using these methods. Modelling techniques such as simulation and simulation-based optimisation methods are then introduced.

Chapter 4 describes the case companies' SCs. The background of the case companies including the reasons for their selection is provided and the data collection process is described. Finally, case companies' SCs are mapped and analysed and the important SCM issues are identified.

Chapter 5 shows the model development. Based on two in-depth case studies, a generalised model including DSC and ISC is developed. Then the key characteristics and differences between the DSC and the ISC are identified and classified into three aspects: uncertainties, constraints and cost elements.

Chapter 6 presents the mathematical model underlying the generalised SC model. The mathematical model consists of four sub-models taking into account multiple uncertain factors in the system. The non-parameterised and parameterised operational strategies are shown.

Chapter 7 describes how a simulation tool, a tailored SOGA tool and a tailored MOGA tool are developed. The tools could be used to optimise parameterised operational strategies and to assist decision making.

Chapter 8 discusses the simulation experiments that are undertaken to evaluate non-parameterised operational strategies which investigate the impact of the information sharing mechanism on SCP.

Chapter 9 discusses the simulation-based experiments using the SOGA tool which are undertaken under parameterised operational strategies, which investigated the impact of the coordinated management mechanism on SCP.

Chapter 10 discusses the simulation-based optimisation experiments which are undertaken using the MOGA tool under parameterised operational strategies, which investigate the impact of the coordinated management mechanism on SCP.

Chapter 11 discusses and highlights key results and contributions. The limitations of this study and further research are discussed.

2

Literature Review

This chapter reviews the studies related to SCM, SCP, uncertainties in SC, SC mapping and integration, information sharing strategies, coordinated management strategies, optimisation, and the current status of SCM in China. Based on these reviews, the research gap is identified.

Supply chain management

The concept of SCM emerged at the end of the past century. There are many definitions in the literature. For example, Cooper and Ellram (1992, 2) defined SCM as "an integrating philosophy to manage the total flow of a distribution channel from supplier to ultimate customer." Monczka and Morgan (1997, 69) defined SCM thus: "Integrated supply chain management is about going from the external customer and then managing all the processes that are needed to provide the customer with value in a horizontal way." These two definitions show that SCM not only focuses on a single company, but also on integrating processes across companies from the suppliers to the end customers.

In 1999, Lummus and Vokurka (1999, 11) defined SCM as "all the activities involved in delivering a product from raw material through to the customer, including sourcing raw materials and parts, manufacturing and assembly, warehousing and inventory tracking, order entry and order management, distribution across all channels, delivery to the customer, and the information systems necessary to monitor all of these activities." This definition summarised SCM activities in terms of functions. Brian J.Gibson *et al.* reported that a large majority of respondents from a survey felt SCM encompassed supplier and customer collaboration (80.8%), while a much smaller percentage felt information technology (IT) (49.7%), marketing (39.4%), finance (32.4%), sales (32.4%) and product design (24.3%) were encompassed in SCM.

A well-known definition of SCM was given by the professional body Council of Supply Chain Management Professionals (NP) in 2007: "Supply Chain Management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all Logistics Management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, Supply Chain Management integrates supply and demand management within and across companies." From this definition, SCM was focusing on a set of related activities across different subjects. It also highlighted the coordination and collaboration between channel partners. Thus, SCM could be seen as a complex system that included many functionally different partners and activities. The advantage of looking at SCM from a systematic viewpoint was that it represented the nature of a chain and provided a macro map to managers. However, complexity made the management of SC difficult.

As previously noted, more recently, a textbook (Simchi-Levi *et al.*, 2008, 1) gave a definition for SCM thus: "Supply chain management is a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimise systemwide cost while satisfying service level requirements."

From these definitions of SCM, it had been observed that SCM focused on the integrating and coordinating of all activities (as a system) in the chain including departments within an organisation and the external partners such as suppliers, carriers, logistics service providers and information systems providers.

Supply chain performance

The SCP can be measured in many different ways. This section introduces different SCP metrics and then discusses the SCP improvement methods.

The SCP metrics

Financial metrics

In SCP evaluation proposals, many metrics were related to financial performance measures because they clearly present the interrelationship between organisational financial information such as the balance sheet, cash flow statement and the overall performance of a business unit (Swink *et al.*, 2010). For example, the data from a balance sheet included assets, current liabilities, debt and equity terms (Langley, 2008) and SC cash flow (Chen, 2011). Besides this, some studies concluded that financial measurements could be useful, such as total inventory turnover, return on assets (ROA), return on sales (ROS), net sales, and general and administrative fees could all influence SCP (Dehning *et al.*, 2007). Protopappa-Sieke and Seifert (2010) illustrated the use of working capital requirement, profit margin, return on investment (ROI) and cash flow on financial SCM. Although numerous financial performance metrics were used to measure SCP, cost was the easy and direct way to evaluate SCP. The costs in the SC included finished goods inventory turns, days' sales outstanding, cost to serve, cash-to-cash cycle time, total delivery cost, cost of excess capacity and cost of capacity shortfall (Keebler *et al.*, 1999; Laua *et al.*, 2008).

Information metrics

Information quality, information sharing effectiveness and the bullwhip effect was recognised as affecting SCP significantly. Information quality could be measured by accuracy, frequency, credibility and availability of forecast (McCormack, 1998). Langley (2008) stated that accessibility, relevance, accuracy, timeliness and transferability were key drivers. Li and Lin (2006) believed that trust in SC partners was the most important aspect. Measures of the effectiveness of information sharing (Zhou and Benton Jr., 2007) such as order fulfilment rate and order cycle time (Fu-ren *et al.*, 2002), response time, order cycle time variability, on time delivery/receipt and forecasting/planning cycle time influenced the overall SCP (Keebler *et al.*, 1999). The bullwhip effect was an observed phenomenon in the SC (Forrester, 1961, 1999) which leads to longer lead time and poorer inventory decisions (Fiala, 2005). Reducing the bullwhip effect by an information sharing strategy could improve customer demand forecasting and inventory decisions and reduce lead time. According to Chen *et al.* (2000a), compared with deterministic demand, demand fluctuation led to a greater bullwhip effect that essentially could not be completely avoided. However the effects on cost could be minimised by sharing information. Sharing demand information can smooth forecasts. For example, if centralised demand information is shared in a simple two-stage SC, the bullwhip effect can be reduced to achieve more accurate forecasting and shorter lead times (Chen *et al.*, 2000b; Agrawal *et al.*, 2009).

Operation metrics

The coordination strategies include buyer-vendor coordination, production-distribution coordination and inventory-distribution coordination (Thomas and Griffin, 1996). However, their implementation is complicated and depends on the characteristics of the SC. For example, coordination in a decentralised SC with stochastic demand and/or lead time should consider: (1) an operational plan; (2) a structure to share information among the members; and (3) an incentive scheme to allocate the benefits of coordination (Li and Wang, 2007). In a centralised SC, the incentive scheme and the coordination strategy must be developed together as a single mechanism (De Treville *et al.*, 2004).

The metrics for operational performance measurement can cover different areas, for example, quality, cost, delivery, workforce and volume flexibility (Flynn *et al.*, 1995). Robb *et al.*, (2008) analysed SC operational performance in terms of delivery dependability, product reliability, after-sales service, consistent quality, product durability, low production cost, production time, new products, delivery time, new product development time, product mix flexibility, volume flexibility, modification flexibility and order cycle time. Chase *et al.* (2006, 378) believed that operational performance in the SC includes production design and engineering (products or parts), plant and equipment (plant) management, organisation and processes management, labour and staffing (people) and production planning and control planning. Skinner (1974, 1985) classified operations in SC based upon five key characteristics: process technologies, market demands, product volumes, quality levels and manufacturing tasks.

Customer services metrics

Customer service quality was one of the key metrics representing SCP (Reiner, 2005). Lots of studies report the direct relationship between performance expectations and customer satisfaction, for example, Voss *et al.* (1998). High-quality customer services that could be considered include pre-sale customer services, product support, responsiveness, customer delivery speed and delivery dependability (Vickery *et al.*, 2003).

Customer satisfaction is one of the most important performance metrics in customer-driven SCs (Jammernegg and Kischka, 2005; Christopher and Towill, 2000). Availability, operational performance, services reliability, service platforms and perfect order are employed in customer services evaluation (Bowersox *et al.*, 2009).

Additionally, four metrics and six gaps between customer expectation and organisation are used to identify the services level. The metrics are product availability, lead-time performance, services reliability and the perfect order. The gaps are knowledge gap, standards gap, performance gap, communication gap, perception gap and satisfaction gap (Swink *et al.*, 2010). However, the metrics used in the electronic business-to-customer (B2C) fields are different (Thirumalai and Sinha, 2005). Customer satisfaction can comprise the following seven variables in B2C business: ease of placing order, product selection, product information, product prices, website performance, shipping and handling charges and options (Reiner, 2005).

The main SCP metrics and their associated literature based on the earlier discussions are summarised in Table 2.1.

Supply chain performance improvement methods

The purpose of measuring SCP is to understand how the SC system operates and then to seek to identify SCP improvement opportunities. Therefore, measuring SCP is closely related to SCP improvement, for example, improving customer service level, reducing inventory, lowering operating cost and improving the use of fixed assets (Braithwaite and Wilding, 2004). This section reviews the commonly used SCP measurement methods in current industries including supply chain operations reference (SCOR), balanced scorecard (BSC), the benchmarking method and key performance indicator (KPI).

Table 2.1 Main SCP metrics

Category	Metrics	Reference
Financial	Total supply chain cost Return on supply chain fixed assets Return on investment Return on equity Return on assets Total inventory turnover Return on sale Net sale Finished goods inventory turn Cost for goods Net working capital Financial expenses/income Total delivery cost (cost of goods, transportation costs, inventory carrying cost, material handling cost, re-handling cost) Cash-to-cash cycle Inventory cost Information management cost Warranty cost Administrative cost Cost of excess capacity Cost of capacity shortfall	Keebler 1999; Dehning *et al.*, 2007; R.S.M. Laua *et al.*, 2008; Langley, 2008; Protopappa-Sieke and Seifert, 2010; Swink *et al.*, 2010.
Information	Information quality Order fulfilment Customer demand information forecast accuracy Plan accuracy Information flow lead time Order cycle time variability Forecasting/planning cycle time Response time Information reliability Information accuracy/frequency/credibility	Keebler *et al.*, 1999; McCormack, 1998; Langley, 2008; Li and Lin, 2006; Zhou and Benton Jr., 2007; Forrester, 1999; Fiala, 2005; Chen *et al.*, 2000a; Chen *et al.*, 2000b.
Operations	Operational plan Coordination strategy Delivery flexibility Manufacturing/production flexibility Order cycle time for material flow Procurement flexibility Quality Delivery speed Volume flexibility Productivity	Skinner, 1974, 1985; Flynn *et al.*, 1995; Thomas and Griffin, 1996; De Treville *et al.*, 2004; Chase *et al.*, 2006; Fawcett *et al.*, 2007; Li and Wang, 2007; Robb *et al.*, 2008.

continued

Table 2.1 Continued

Category	Metrics	Reference
Customer services	Customer satisfaction Services knowledge Competencies Employee satisfaction and customer loyalty Pre-sale customer services Product support Responsiveness Customer delivery quality (speed, dependability) Finished goods/product availability Operational performance Services reliability Service platforms and the perfect order Lead-time performance Perfect order Business-to-customer transaction performance	Kaplan and Norton, 1992; Vickery *et al.*, 2003; Voss *et al.*, 1998; Christopher and Towill, 2000; Jammernegg and Kischka, 2005; Thirumalai and Sinha, 2005; Bowersox *et al.*, 2009; Swink *et al.*, 2010.

Source: Authors.

Supply chain operations reference

The SCOR model that is widely used in different industries originated in the USA and consists of three basic levels with predefined metrics:

Level 1 metrics are diagnostics for the overall health of the SC. These metrics are also known as strategic metrics and key performance indicators (KPIs). Level 1 metrics helps establish realistic targets that support strategic objectives

Level 2 metrics serve as diagnostics for the Level 1 metrics. The diagnostic relationship helps to identify the root cause or causes of a performance gap for a Level 1 metric

Level 3 metrics serve as diagnostics for Level 2 metrics

Using the SCOR model to identify and analyse a SC process that comprises lots of links (plan-source-make-deliver and return process) could lead to a better understanding of and improvement to the SCP (Fawcett *et al.*, 2007, 225).

In theory, the metrics in the SCOR model include delivery reliability (delivery performance, fill rates, perfect order fulfilment), responsiveness (order fulfilment lead times), flexibility (SC response time, production flexibility), cost (cost of goods sold, total SCM cost, value-added employee productivity, warranty and return processing costs) and assets (e.g., cash-to-cash cycle time, inventory days of supply, asset turns) (Huang *et al.*, 2005). In practice, adopting SCOR in a working environment involves four steps, namely: (1) analysing the basis of competition; (2) configuring the SC; (3) aligning performance levels, practices and systems; and (4) implementing SC processes and systems (Lohtia *et al.*, 2004). The SCOR model can finally improve SCP by examining SC processes (Harelstad *et al.*, 2004) and by achieving six sigma quality objectives (Bolstorff, 2003). However, although more critically the SCOR model can be used to assist managers for strategic decision making (Huan *et al.*, 2004), it is difficult to institutionalise the SCOR model as a measurement and benchmarking framework if data collection is not automated (Gulledge and Chavusholu, 2008).

Balanced scorecard

The BSC is an approach to measure performance by weighing different metrics and then marking the performance with different scores. The BSC was originally used in business performance measurement and currently is employed in SC. The BSC provides certain development guidelines with key implementation obstacles (Bhagwat and Sharma, 2007). Financial (e.g., long-term profitability) (Kaplan and Norton, 1992), business process, customer, innovation and learning perspectives (Brewer and Speh, 2000) can be included in the BSC. Fawcett *et al.*, (2007, 424) analysed the benefits of using a BSC, for example: (1) it helps companies select and monitor world-class suppliers; (2) it supports suppliers' recognition programs; (3) it benchmarks leading-edge practices; (4) it disseminates best practice throughout the supply base; and (5) it identifies deficiencies that could be overcome through continuous improvement efforts.

Benchmarking methods

The benchmarking method is "the process of comparing and measuring organisations against others, anywhere in the world, to gain information on philosophies, practice, and measures that will help the organisation take action to improve its performance" (Coers *et al.*, 2002, 2–3). Benchmarking identifies the problems and gaps and then makes improvements (Zairi, 1996; Feigenbaum, 1991; Venetucci, 1992). Ordinarily, there are seven types of benchmarking:

performance, process, strategic, internal, competitive, functional and generic benchmarking (Bhutta and Huq, 1999). In addition, the benchmarking wheel includes five cycle steps that have clearly explained the systemic benchmarking process, including: (1) select and document the process to be benchmarked; (2) identify who performs this process best; (3) observe and analyse how the benchmarking partner performs this process; (4) analyse the causes for the gap in performance; and (5) implement improvements based on this analysis (Andersen and Pettersen, 1996). In practice, benchmarking methods have been employed to measure in a number of different industries, for example, port performance (Bichou, 2007) and Finnish high-tech industry (Hurmelinna *et al.*, 2002). Internal benchmarking is one of the most tangible manifestations in the process of identifying, capturing and leveraging knowledge (Elmuti *et al.*, 1997). Additionally, Handfield (2006, 420) analysed benchmarking in SCM and identified three main benefits: (1) it provided milestones to gauge progress on the voyage to maturity; (2) it used internal benchmarking to leverage organisational learning and deploy best practices across the business; (3) it applied a maturity model and standards and compared with best-in-class companies outside of the industry to bring in best practices and improve processes.

Key performance indicator

A KPI is a quantitative method to measure SCP, which identifies indicators and then measures the performance (Bititci, 1995). There are two main measurement aspects including the number giving a magnitude (how much) and the unit of measure giving a meaning (what) (Artley and Stroh, 2001). In industry oriented project performance assessment, KPI includes: (1) on time; (2) on budget; (3) free from defects; (4) efficiently; (5) right first time; (6) safely; and (7) by profitable companies. In SCM, the indicators are related to quality (or reliability), flexibility and innovation, cost, time (Cai *et al.*, 2009), customer service, suppliers' delivery performance, and inventory and logistics costs (Gunasekaran *et al.*, 2001).

Uncertainties in a SC

Uncertainty has been recognised as one of the most important factors that challenges SCM (Simchi-Levi *et al.*, 2008). There are many sources that cause uncertainties in SC systems. For example, Agnihothri and Kenett (1995) believed that one of the reasons was defective or imperfect production in terms of product quality. Defective products required reworking due to non-conformance to these requirements, which increases production time (Bohn and Terwiesch, 1999). Xu (2010) identified four reasons, namely: (1) delay and inaccuracy of information flow between the manufacturer and the suppliers; (2) using a small number of suppliers or even just one supplier for each of its key raw materials/components; (3) the uncertain production yield of components from suppliers, particularly in the electronics, semiconductor and chemical industries; and (4) the situation when suppliers may adopt a conservative production plan to reduce the downstream inventory risk.

Uncertainty in customer demands are well recognised, for example, Zhou (2009) studied an incentive model of information-sharing with customer demand uncertainty. Davis (1993) categorised uncertainties within SC into three different sources, including supply uncertainty, process uncertainty and demand uncertainty, which referred to the variability or the suppliers' performance in terms of late or defective deliveries, of the unreliability of the production process and of the volatile demands or inaccurate forecasts. Fynes *et al.* (2004) discussed uncertainties from an external environment such as its competitors' actions, technology and consumer tastes and preferences, which were characterised by an absence of pattern, unpredictability and unexpected change. Wagner and Bode (2008) categorised the SC uncertainties into internal aspects including the demand and supply side and external aspects including regulatory, legal and bureaucratic, infrastructure and catastrophic. The uncertainty in SC relationship quality significantly influences SCP (Srinivasan *et al.*, 2011). Supply uncertainty influences manufacturers in a SC because of the balance of different raw materials, raw material availability, the associated cost and the production plan (Bowersox *et al.*, 2009).

Supply chain process mapping and integration

In practice, process mapping is often a first step in understanding an SC system. This section introduces SC process mapping and then discusses the SC integration issues.

Supply chain process mapping

Swink *et al.* (2010, 54) defined a process as “a system of structured activities that use resources to transform inputs (such as energy, materials, and information) into valuable outputs.” In this conception, process thinking is a way of viewing activities in an organisation. In SC, process thinking includes inputs, outputs and flows that encompasses information flow and material flow (Rother and Shook, 2003). According to the Theory of Constraints (TOC), there are five points that should be considered in process thinking, namely: (1) every process has a constraint; (2) every process contains variance that consumes capacity; (3) every process must be managed as a system; (4) performance measures are crucial to the process's success; and (5) every process must be continually improved (Goldratt and Cox, 2004).

Process mapping is a graphical tool that depicts components (Bashford, 2002). It is commonly used for process improvement purposes. It simplifies the actual work processes and provides a clear picture of the processes so that the problems and the improvement alternatives can be easily identified (Rahimnia and Moghadasian, 2010; Bashford, 2002; Ungan, 2006).

SC process mapping is defined as the procedure whereby a process mapping technique is applied to SC systems in order to make the complex systems visible and to facilitate identifying the SC problems such as poor coordination of effort, incompatible information systems and longer cycle time (Fawcett *et al.*, 2007). Step-by-step, value stream mapping and process flow diagramming are the main approaches that have been used in SC process mapping and in performance improvement. The step-by-step approach aims at better understanding and improving SCP and includes nine steps: (1) identify the item which should be involved; (2) identify all processes; (3) determine who performs each process in the chain; (4) communicate with other entities that perform a process for you and determine how long the process will take; (5) draw the map with horizontal and vertical lines; (6) analyse the SC; (7) prioritise the ideas from the previous step; (8) analyse the new SC; and (9) improve the SC (Scott and Westbrook, 1991).

Value stream SC mapping engages flow kaizen and process-level kaizen across suppliers to the end customers (Rother and Shook, 2003). Within this kind of mapping process there are 12 common types of data that have been standardised, namely: cycle time, changeover time, on-demand machine uptime, production batch sizes, number of operators, number of product variations, pack size, working time minus breaks, scrap rate, value-creating time, lead time and reverse flows (Rother and Shook, 2003; Langer *et al.*, 2009).

Moreover, from the process flow diagramming approach, Cachon and Terwiesch (2008) discussed how to draw process flow diagrams and how to evaluate process from a functional capacity aspect. There are six steps to be followed in order to minimise the cost and lead time and maximise the quality and reliability: (1) identify the desired outcomes in advance; (2) identify and place boundaries around the critical process; (3) document the existing process; (4) analyse the process and identify the opportunities for improvement; (5) recommend appropriate changes to the process; and (6) implement the changes and monitor improvements (Swink *et al.*, 2010, 82).

In practice, value stream mapping is used in a SC. McDonald *et al.* (2002) employed the value stream mapping approach to improve SCP in manufacturing and found that it created a common basis for the production process and thus could facilitate more thoughtful decisions to improve the value stream. Abdulmalek and Rajgopal (2007) applied the value stream mapping approach to the process based application sector for a large integrated steel mill.

Supply chain integration

As we noted in the earlier discussion, SC integration is one of the most important areas in SCM. The idea of SC integration consists of inventory flow and information flow integration, which can be achieved through information sharing and coordination management. The concept of integrating SC is illustrated as the competency that links the suppliers and customers with information flow, material (inventory) flow and internal integration (Bowersox and Closs, 1996). The internal integration in traditional practices includes organisation structure, measurement systems, inventory ownership, IT and knowledge transfer capability. Integrating in the SC is the process combining interrelation efforts, inventory flow and information flow. In Figure 2.1, the shaded area gives an example of a simplified SC integration (Bowersox and Closs, 1996).

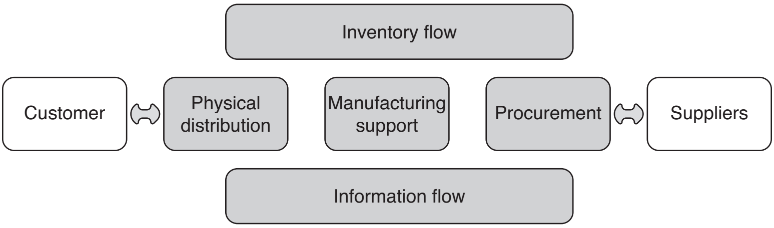


Figure 2.1 The integrated SC
Source: Bowersox and Closs, 1996.

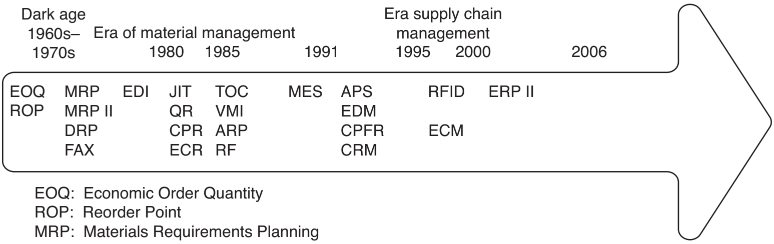
Development of SC initiatives: technique perspective

In this section, an overview of the development of the SCM initiative is presented from the technique perspective. The concepts of inventory flow integration and information flow integration are then reported. Finally, the advantages and barriers to integration are discussed.

The combination of technology advance and business process innovation contributes to the development of the SCM initiative. The time-phased development history of SCM initiatives from the technique perspective is shown in Figure 2.2 (Fawcett *et al.*, 2007). These technologies have enhanced the integration of SC.

Inventory flow integration

Inventory flow includes the movement and storage of materials and finished goods, which starts with the initial shipment of raw materials or component parts from suppliers and then to manufacturers or processes, products and finally deliveries to end customers. The linkages in material flows integrate physical distribution, manufacturing support and procurement areas (Bowersox and Closs, 1996). The integration of material flow leads to better channel relationship, shorter lead time, higher flexibility and reduced total cost. The early integrated inventory models (e.g., economic order quantity) are only designed to solve single supplier and single customer problems in which optimising order time interval and production cycle time are the main concerns (Goyal, 1977). Later, various integrated inventory models were developed, for example, one-vendor multi-buyer integrated inventory with equal sized shipment (Lu, 1995), three-echelon



EOQ: Economic Order Quantity
ROP: Reorder Point
MRP: Materials Requirements Planning
MRP II: Materials Requirements Planning II
DRP: Distribution Resource Planning
FAX: Facsimile Transmission
EDI: Electronic Data Interchange
JIT: Just-In-Time
QR: Quick Response
CPR: Continuous Product Replenishment
ECR: Efficient Consumer Response
TOC: Theory of Constraints
VMI: Vendor Managed Inventory
ARP: Automatic Replenishment Programs
RF: Radio Frequency Systems
MES: Manufacturing Execution Systems
ERO: Enterprise Resources Planning
APS: Advanced Planning Systems
EDM: Extended decision Management
CPFR: Collaborative Planning Forecasting and Replenishment
CRM: Customer Relationship Management
RFID: Radio Frequency Identification
ERP II: Enterprise Resource Planning II
ECM: Enterprise Commerce Management (similar with ERP)

Figure 2.2 Development of SCM initiative from the technique perspective
Source: Based on Bowersox and Closs, 1996.

inventory models (Rau *et al.*, 2003; Shen and Honda, 2009), single-vendor single-buyer SC (Boute *et al.*, 2007) and the single manufacturer with multiple buyers integrated inventory SC (Hoque, 2008).

Bhatnagar *et al.* (1993) considered that integrating inventory solves three main types of coordination problems: (1) supply and production planning; (2) production and distribution planning; and (3) inventory and distribution planning. Moreover, with a range of specific strategies in the integrated inventory models, the SCP is improved. For example, using the (s, Q) policy according to Horst (2006, 2011), if the inventory position has reached the reorder points (from earlier), then launching a replenishment order of size Q is used to replenish the inventory level of distributors (Arora *et al.*, 2010). With the (s, S) policy, according to Axsäter (2006), if the inventory level drops to or below s, then an order is placed to bring the inventory level up to the maximum level S. Just-in-time is defined as "the term used to indicate that a process is capable of instant response to demand without the need for any overstocking, either in expectation of the demand being forthcoming or as a result of inefficiencies in the process" (Hutchins, 1999, 7). A replenishment policy aims to minimise the combination of production and inventory costs (Rau and Ouyang, 2008). Batch shipment policies can significantly reduce SC total cost (Hsiao, 2008). Additionally, the importance of reducing lead time (or/and cost) has been widely studied (Pan and Yang, 2002; Chang *et al.*, 2006; Chen and Kang, 2007; Yang, 2010).

Information integration

Information integration in a SC brings together coordination and operation activities. Coordination activities include overall information systems and concentrate on: (1) strategic objectives; (2) capacity constraints; (3) logistical requirements; (4) inventory deployment; (5) manufacturing requirements; (6) procurement requirements; and (7) forecasting (Bowersox and Closs, 1996). Coordination activities essentially include all activities necessary to schedule procurement, production and logistics resource allocation throughout the firm. Operational activities include transaction activities necessary to manage and process orders, operate facilities, schedule transport and integrate procurement resources and place more focus on (1) order management; (2) order processing; (3) distribution operations; (4) inventory management; (5) transportation and shipping; and (6) procurement (Bowersox and Closs, 1996).

Information integration facilitates information sharing and collaborative planning, which is emphasised by information exchange between SC members through media such as face-to-face meetings, telephone, fax, mail and the Internet (Mohr and Spekman, 1994). Collaborative planning involves developing various plans such as production planning and scheduling, new product development, inventory replenishment and promotions and advertising, which rely on good business relationships, information sharing and information integration (Claro *et al.*, 2003).

How to integrate information flow and its key elements have been widely discussed. Information technology has been recognised as an important mechanism to enhance the integration of SC information flow in information systems (IS) and value-adding activities

(Gunasekaran and Ngai, 2004). However, using IT to integrate a SC may be hindered by various issues, such as a lack of integration between IT and the business model, lack of proper strategic planning, poor IT infrastructure, insufficient IT application in virtual enterprises and inadequate implementation knowledge of IT in SCM (Motwani *et al.*, 2000). Trust plays a crucial role in achieving information integration successfully in a SC (Handfield and Bechtel, 2002). In China, the situation becomes even more complicated because legal protection, government support and the importance of *Guan Xi* (business relationships) influence the degree of trust and information integration between buyers and suppliers (Cai *et al.*, 2010).

Advantages and disadvantages of SC integration

There is much research discussing the benefits of and barriers to SC integration. The benefits of integrating SC can be categorised in accordance with different approaches or viewpoints. For example, Lan and Unhelkar (2006) presented the benefits of integrating SC into different groups (finance, customer, planning, production and implementation). In the financial group, the cost is reduced and the financial information reliability is improved. The total cost in some manufacturing organisations is reduced by 20–40% (Cottril, 1997). Some organisations have achieved a 25% cost reduction per transaction, and an increase in orders of 20% has been achieved by using centralised databases (Turner, 1993). The customer group focuses on customer retention, behaviour and promise, which helps the integrated SC system (customer portals) to improve customer service levels (Lan and Unhelkar, 2006). The production group is influenced by inventory management and the efficiency of an integrated SC system that provide the opportunity for managers to respond quickly, for example, 50% overtime reduction (Turner, 1993), and to minimise the negative impacts on production (Lan and Unhelkar, 2006). The implementation group considers that in some case companies (e.g., Nike), rapid integration and seamless linking reduces the effort required (e.g., the third part integration software to assimilate their partners) for integrating the whole SC with the rest of the partners (Lan and Unhelkar, 2006).

However, from the system viewpoint, the benefits of SC integration are related to economic, market and relevancy values (Bowersox *et al.*, 2009). The economic value refers to lowest total cost, economy-of-scale efficiency and product and service creation, which is evaluated by procurement and manufacturing strategy. The market value is influenced by market and distribution strategy in terms of attractive assortment, economy-of-scope effectiveness and product and services presentation. Value relevancy originally comes from accounting, and it implies the ability of the financial information contained in the financial statements to explain the stock market measures (Bowersox *et al.*, 2009). On the subject of SC, it means the implementation of the ability including customisation, segmental diversity, product and service in a SC. Therefore, the integration may simultaneously achieve: (1) responsiveness; (2) variance reduction; (3) inventory reduction; (4) shipment consolidation; (5) quality; and (6) life cycle support. Thus, effective information sharing can significantly enhance information integration (Devaraj *et al.*, 2007) and then promote SC practices (Zhou and Benton Jr., 2007).

Although SC integration improves SCP, many barriers have been discussed. Lan and Unhelkar (2006) reported that only a quarter of users utilised the full suite of SC integration applications, and only 12% of users received the data from suppliers and customers in the SC. Lan and Unhelkar (2006, 7–8) also summarised the barriers to integrated SC, namely: (1) a focus on transaction systems over a strategic system to manage a SC; (2) putting too much effort on the technical aspect but neglecting the fundamental business processes; (3) abandoning the geographical, relational and environmental considerations between buyer and supplier; (4) inaccurately identifying the cost and benefits of applying an integrated SC system; and (5) insufficient capability.

Integration barriers may originate from traditional practices related to the organisation structure, measurement system, inventory ownership, information technology and knowledge transfer capability (Bowersox and Closs, 1996). These authors explain that in the traditional organisation structure, most organisations are concerned with achieving their own excellence rather than that of the SC. The traditional measurement system makes cross-functional coordination difficult, so it is necessary to develop a new performance measure system for the whole SC using the SC goal instead of the organisation's. Furthermore, the main issue in the inventory ownership is the cost-benefit relationship. However, the risks include incorrectly located or obsolete inventory.

Information sharing

This section describes the role and types of information in a SC and then reviews the information sharing mechanisms from two aspects: information communication technology (ICT) and ICT-based application.

Role of information sharing in the SC

Information sharing between partners in a SC has been seen as a key initiative towards SCM (Lee *et al.*, 2000). The type of information in a SC can be classified in different ways, for example, strategic, tactical, operational or pertaining to consumers (Baihaqi *et al.*, 2008). Lee *et al.* (2000) and Lee and Whang (2003) gave a list of information that could be shared across a wide range of industries and firms. Byrne and Heavey (2006) summarised the information including: demand information and sales data; inventory level and position, order status for tracking and tracing, sales forecast and production and delivery schedule. Huang *et al.* (2003) classified information into six categories pertaining to product, process, resource, inventory, order and planning. However, the dominant type of information is demand information (Baihaqi *et al.*, 2008). Sharing demand information is a major strategy to counteract the bullwhip effect. For example, letting the supplier have visibility of point-of-sales data; thus channel members can forecast demands more accurately and avoid demand distortion. Demanding information sharing downstream to suppliers is the cornerstone of initiatives such as quick response (QR) and efficient consumer response (ECR) (Lee *et al.*, 2000).

The magnitude of the benefits of information sharing has been recognised from both theoretical research (e.g., Lee *et al.*, 2000) and empirical case studies (e.g., Byrne and Heavey, 2006). Within the organisation, effective internal information sharing across departments improves the organisational performance (Samaddar *et al.*, 2006). In the SC, building a trust relationship contributes to sharing sensitive information such as forecasts and customer demand between buyer and supplier (Swink *et al.*, 2010). Buyers' scheduling information helps suppliers to set priorities and do a better job of operations planning. Additionally, using applications to enhance information sharing promotes interaction between sellers and customers (Chopra and Meindl, 2007). Thirdly, more information sharing helps improve performance in uncertain market conditions (Li *et al.*, 2006). Finally, applying IT may reduce transaction costs and facilitate outsourcing (Grover and Malhotra, 2003).

The focus of SCM associated with information sharing has shifted from functions to processes, from products to customers, from revenue to performance, from inventory to information and from transactions to relationships (Christopher and Michael, 2004). More often, information sharing is embedded in managerial programs such as VMI and continuous replenishment programs (CRP). VMI is "an approach managing inventory and order fulfilment whereby the supplier, not the customer, is responsible for managing and replenishing inventory" (Harrison and Hoek, 2008, 252–253). CRP is an electronic data interchange (EDI)-based inter-organisational system. It aims to match product flow with consumer demand, yielding improvements in inventory management and logistics in order to increase organisational flexibility (Kopanaki and Smithson, 2002, 15).

Information sharing technologies

Information sharing only became possible and practicable after the development of relevant technologies. This section reviews the major ICT and some relevant ICT-based applications.

Information communication technology

Major ITs that have been used to promote the communication systems' capability include the Internet, EDI, extensible markup language (XML), bar codes and scanning and radio frequency identification (RFID). In the 1990s, Wal-Mart used Internet technology to provide an online summary of point-of-sales data to suppliers. Known as the retail link program, it is regarded as the most celebrated implementation of demand information sharing (Gill and Abend, 1997; Lee *et al.*, 2000). Nowadays, many companies (e.g., logistics service providers, shipping lines) provide online services to their customers to allow them to track and trace their products and make claims.

EDI is the exchange of information between independent computer applications, using standard formats without human intervention. Compared with traditional information exchange methods among organisations such as mail, courier, telephone and fax, EDI is much more effective, reliable and faster and therefore can (1) increase internal productivity; (2) improve channel relationships; (3) increase external productivity; (4) increase the ability to compete internationally; and (5) decrease the total operating cost (Bowersox and Closs, 1996). EDI is more useful for an industry buyer with several suppliers (Agi *et al.*, 2005). Moreover, EDI effectively connects suppliers and customers and thus improves the efficiencies of the SC (Hill and Scudder, 2002) and also encourages long-term partnership in the SC. On the other hand, the application of EDI has been facing some difficult issues, for example, lacking EDI universal standards, trans-border security and the legal status of EDI transactions between different nations (Rosenberg and Valiant, 1992).

Since 1998, the World Wide Web consortium has suggested that XML is a flexible computer language that facilitates information transfer among a wide range of applications such as systems, databases and web browsers. There are three main reasons leading to wider use of XML compared to EDI: it is inexpensive to install (Bowersox *et al.*, 2009), is easy to maintain (Yen *et al.*, 2002) and is more flexible (Forsyth, 2000). Implementing XML in a SC can accelerate data exchange and support the communication between different partners (Makris *et al.*, 2008) and therefore, improve SC's overall performance (Chryssolouris *et al.*, 2003).

Bar coding and scanning is an auto-identification system, which was developed for information collection and exchange. Bar coding is the placement of computer-readable codes on items, cartons, containers, pallets and rail cars (Bowersox *et al.*, 2009, 104). In SCM, bar-code scanning has proved to be an effective tool for achieving inventory control (Jesitu, 1995), for example, utilising an integrated bar-code system in inventory and marketing enhances inter-organisational and further business relationships in terms of connected data systems and encourages information sharing (Manthou and Vlachopoulou, 2001). Using proprietary codes maximises industries' competitive positions (Richardson, 2004). Scanning, both handheld and fixed position, supports bar-code systems to reduce scanning error and increase flexibility. In order to minimise the use of resources and improve performance, terrain scanning methodology (TSM) can be used to provide an insight for SC proficiency in both individual business processes and the whole SC (Barker *et al.*, 2000).

RFID is an automated data-capture technology that is used to electronically identify, track and store information about objects and people through radio waves or electromagnetic waves. RFID consists of three components: an RFID tag which emits radio signals; an RFID reader which picks up the signal; and the middleware which provides the operating system, data repository and processing algorithms to convert and handle the data (Simchi-Levi *et al.*, 2008, 448). A number of studies have discussed the application of RFID in SCM and its impact on SCP. For example, RFID positively influences IT infrastructure, information flow, physical flow and financial flow integration regarding data consistency and cross-functional application integration (Angeles, 2008). RFID reduces stock-out, labour costs and transaction costs and improves inventory management in the SC (Twist, 2005). It increases the accuracy, efficiency and speed of executing processes (Li *et al.*, 2006). The SC RFID investment evaluation model can be presented to serve as a platform to enhance the understanding of RFID value creation and measurement (Lee and Lee, 2010). Sari (2010) stated that RFID was more useful in a longer lead-time SC.

Information technology-based applications

Information technology becomes more powerful when it is integrated with an innovative business process. Therefore many ICT-based business applications or programs have been developed, for example, available-to-promise (ATP) planning, manufacturing resource planning (MRP II), decision support system (DSS) and enterprise resource planning (ERP). These applications can significantly improve SCP internally and externally (Manrodt *et al.*, 2005).

ATP is an IT-enabled business practice that provides a response to customer order enquiries based on resource availability. It supports order promising and fulfilment, aiming to manage and match the demand to production plans (Kotzab, 2001). There are two types of ATP practices: push-based and pull-based. The former is to compute ATP quantities and dates based on forecast demands, whereas the latter is based on actual customer demands. The ATP model supports decision making (Lin *et al.*, 2010; Xiong *et al.*, 2003), enhances customer service (Tsai and Wang, 2009) and promotes order promising responsiveness and order fulfilment reliability (Pibernik, 2005).

The core of MRP II is a computer-based approach to calculate time-phased materials requirements on what components are required and when they are required by the factory. It expands MRP I by including more organisational functions regarding long-term strategic and business planning, demand planning, materials planning, resource planning and production and vendor scheduling and execution (Swink *et al.*, 2010). It emphasises a single database to provide a platform for integrating sub-systems and for sharing common information and parameters (Harrison and Hoek, 2008). The benefits of MRP II have been shown in operation, management, strategy and SCM competencies (Su and Yang, 2010). Cost reduction (Sum and Yang, 1993), competitive position (Chang *et al.*, 2008), productivity enhancement, decision quality and resource control improvement (Grabot and Botta-Genoulaz, 2005) and achievement in meeting industrialised needs (Bergström and Stehn, 2005) are the major benefits of adopting MRP II in a company. On the other hand, the exploratory study shows there are four key limitations in its application: (1) insufficient extended enterprise functionality in crossing organisational boundaries; (2) inflexibility to ever-changing SC needs; (3) lack of functionality beyond managing transactions; and (4) closed and non-modular system architecture (Akkermans *et al.*, 2003).

According to Sol *et al.* (1987), the definition and scope of DSS was initially described as “interactive computer-based systems which help decision-makers utilise databases and models to solve ill-structured problems.” Since the 1980s, DSS has been used as an important tool to improve the effectiveness of managerial and professional activities. DSS is able to integrate services (Das and Tyagi, 1994) and simulate behavioural issues with the user interface (Igbaria *et al.*, 1996; Power and Sharda, 2007). This enables DSS to perform strategic and tactical planning at a cheaper price and with less requirement of employees’ skill (Simchi-Levi *et al.*, 2008). For example, a decision support system DESSCOM (decision support for SCs through object modelling) is developed and used to support decision making in SC at strategic, tactical and operational levels (Biswas and

Narahari, 2004). There are many examples of DSS applications in industries, for example, for routing and scheduling purposes in a downstream oil company (Gayialis and Tatsiopoulos, 2004), addressing semi-structured problems in a complex delivery process of oil products from a number of distribution centres to all customers (Turban, 1995). In a DSS system, all information regarding production, warehousing and distribution has been constantly exchanged between buyers and suppliers so as to fulfil promised orders in terms of quoted due dates and prices (Venkatadri *et al.*, 2006). Customer value and business targets can be integrated into a DSS as well (Marquez and Blanchar, 2006).

ERP extends the function of MRP II by integrating the functions of finance, accounting and human recourse capability. Bowersox *et al.* (2009, 223) suggest that ERP is to "facilitate integrated operations and reporting to initiate, monitor, and track critical activates such as fulfilment and replenishment, ERP also incorporates an integrated corporate wide database, sometimes referred to as a data warehouse, along with appropriate transactions to facilitate logistics and supply chain planning and operation." ERP has been widely used in various industries since its emergence in the 1990s, particularly in large companies. There are many types of ERP software that have been developed by different companies, with similar functions. The most popular one in the European Union (EU) is the System Analysis and Program Development (SAP) ERP system. The current version is SAP ERP 6.0. Its previous name was R/3 where the "R" of SAP R/3 stood for real time, and "3" related to the three-tier architecture: database, application server and client. SAP ERP is one of five enterprise applications in SAP's Business Suite. The other four applications are (SAP 2013):

1. Customer relationship management (CRM) – helps companies acquire and retain customers and gain marketing and customer insight
2. Product lifecycle management (PLM) – helps manufacturers with product-related information
3. Supply chain management (SCM) – helps companies with the process of resourcing its manufacturing and service processes
4. Supplier relationship management (SRM) – enables companies to procure from suppliers.

According to SAP (2013, NP), ERP delivers role-based access to crucial data, applications and analytical tools. The functions of SAP ERP include:

1. Financial – Ensure compliance and predictability of business performance – so an organisation can gain a deeper financial insight across the enterprise and tighten its control of finances. SAP ERP Financial automates financial and management accounting and financial supply chain management. The solution also provides rigorous support for corporate-governance mandates such as Basel II and Sarbanes-Oxley;
2. Human Capital Management – The optimization of HR processes with a complete, integrated, and global human capital management (HCM) solution. SAP ERP provides this HCM solution for organizations of all sizes and in all industries. It can maximise the potential of the workforce, while supporting innovation, growth and flexibility. The SAP ERP HCM solution automates talent management, core HR processes, and workforce deployment – enabling increased efficiency and better compliance with changing global and local regulations;
3. Operations – It manages end-to-end procurement and logistics business processes for complete business cycles – from self-service requisitioning to flexible invoicing and payment – optimizing the flow of materials. SAP ERP Operations also helps discrete and process manufacturers manage the entire life cycle of product development and manufacturing. The solution automates the entire manufacturing process and reduces costs by controlling and adapting the manufacturing process in real time – and increases customer satisfaction by delivering higher-quality products.

Later case studies focus upon SCM in China where the most popular ERP system was developed by a leading Chinese software company: Kingdee. The ERP system (Kingdee K/3) is a mature and comprehensive ERP system which can deliver solutions to applications ranging from financial accounting, human resources, SCM for trading business and production and costing management for manufacturing companies (Kingdee, 2012). The ERP system integrates eight applications: finance, SC, manufacturing, sales and distribution, human

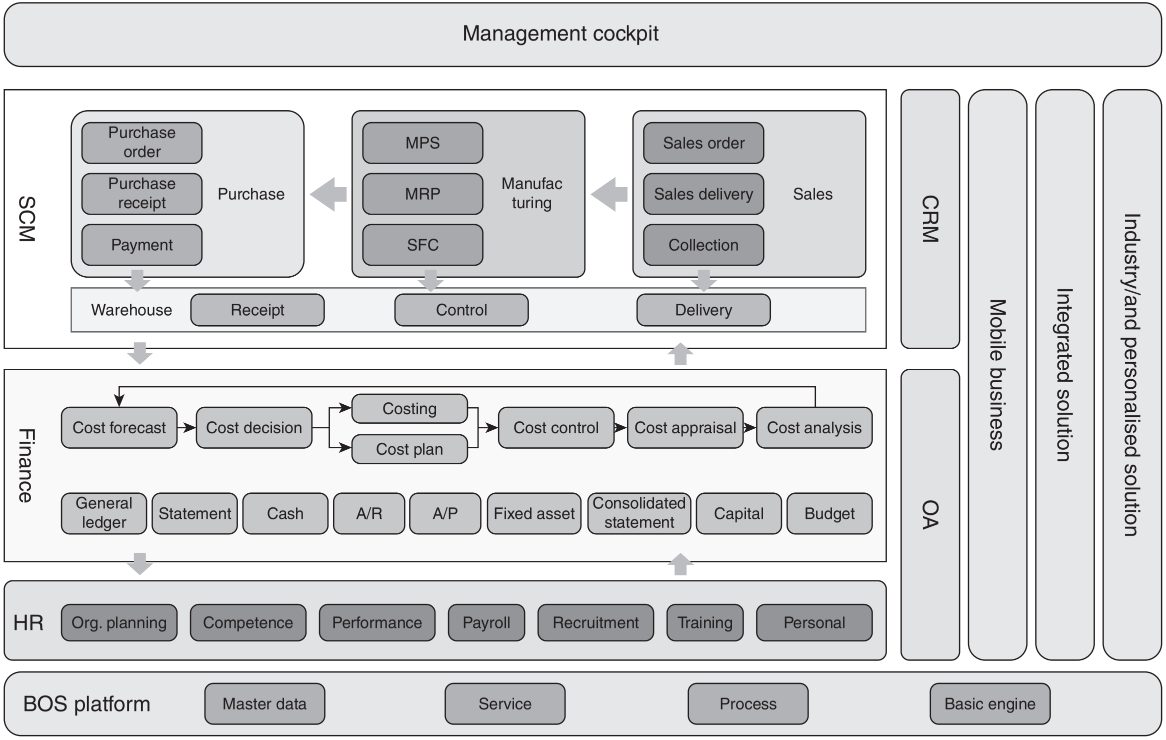


Figure 2.3 The overall flowchart of the Kingdee K/3 ERP system

recourse management, operations management, customer relationship management and business intelligence. Its ERP includes 12 subsystems: (1) overview of finance and logistics; (2) sales price management; (3) sales credit management; (4) purchase requirement management; (5) execution of purchase and sales order; (6) inventory valuation; (7) stock management for material; (8) stock control; (9) inventory operations; (10) SC transactions; (11) introduction to master data; and (12) general ledger and financial reports.

Its application to academic studies is noted in Olhager and Selldin (2003) who investigated the use of ERP, for example, ERP system penetration, the pre-implementation process, implementation experience, ERP system configuration, benefits and future directions in Swedish manufacturing firms. Newell *et al.* (2003) examined the interactions and effect of the implementation of ERP and knowledge management (KM) in a single organisation and discussed the influences of ERP and KM for improving the organisation's efficiency and flexibility. Kayas *et al.* (2008) studied whether ERP technology, organisational culture or a combination of both could support the development of the panoptic gaze in a UK organisation. Moreover, ERP can enhance the management of production data. For example, in order to optimise the management of related documents and computer aided design (CAD) drawings and to change orders during new product design, by integrating a company's product data management (PDM) and ERP systems because the modifications to the PDM and ERP software systems can achieve better tracking and management of product design changes (Rockville, 2013).

Although ERP is successful in many cases, it has also faced many barriers. For example, Fawcett *et al.* (2007) addressed the ERP implementation problems including: (1) never-ending implementation; (2) importance of process mapping; (3) process redesign; (4) use of consultants; (5) excessive cost; (6) resistance to change; (7) errors; and (8) rapid technological change. The cost and time factors critically influenced companies' willingness to implement ERP, particularly SMEs. This is because the investment of installing ERP is very high due to pre-implementation involvement and training and extensive time, money and effort and is also related to an individual's length of time with the firm and position (Abdinnour-Helm *et al.*, 2003). In sum, technology, organisation and people are three important risk factors in ERP implementation (Sumner and Rijk, 2007).

Coordinated management

Traditional SC consists of a set of independent links. Each link has its own specific task and seeks its own optimisation independently. This type of management results in inconsistency when one link adopts a strategy, which conflicts with the strategy adopted by the previous or the next link. Information sharing can help members to make better decisions by using more timely and accurate information. However, information sharing does not imply managerial coordination between channel members in the SC.

This section focuses on coordinated management in the SC. It discusses the role of coordinated management, its interface with SC and the coordinated management mechanisms including (s, S) policy, QR, ECR, VMI and collaborative planning, forecasting, and replenishment (CPFR).

Role of coordinated management in the SC

A SC covers multiple functions such as procurement, operations (production), inventory, warehousing, transportation and both external-organisational and inter-organisational relationships. The smooth functioning of entities in a SC is the result of well-coordinated entities (Arshinder *et al.*, 2008). A lack of coordination in a SC may lead to poor SCP including inaccurate forecasts, low capacity utilisation and excessive inventory, inadequate customer services, inventory turns, higher inventory cost, longer lead time, longer order fulfilment response, lower quality and lower customer focus and satisfaction (Ramdas and Spekman, 2000; Arshinder *et al.*, 2008). On the other hand, a coordinated SC reduces lead time, improves customer services, reduces inventory level, reduces cost and increases flexibility to uncertain demand (Fisher *et al.*, 1994; Lee *et al.*, 1997).

One widely accepted definition of coordination is: "the act of managing dependencies between entities and the joint effort of entities working together towards mutually defined goals" (Malone and Crowston, 1993, 4). Arshinder *et al.* (2008) identify the following difficulties in coordinating SC:

1. The differences in the interest of SC members due to local perspectives and opportunistic behaviour
2. Conflicts in goals and objectives, disagreements over decision domains, differences in perceptions of reality used in joint decision making

3. Traditional performance measures based on individual members, may be irrelevant to the SCP in a coordinated manner
4. Traditional policies and rules may not be applicable to the new conditions of inter-organisational relationship
5. Difficulties involved in dynamically interchanging products (with a short life cycle) and partners in the fast changing business environment

Coordinated management at the interface of a SC

The SC consists of various processes including procurement, production and distribution (Thomas and Griffin, 1995). A process further consists of various activities, for example, the procurement process comprises supplier management, ordering, acquisition, replenishment and inspection (Park, 2005). According to the systems approach, these processes should be coordinated and optimised simultaneously instead of independently or sequentially, in order to achieve global optimisation. As a result, coordinated management can be performed at the interfaces of SC including: procurement-production; production-distribution; production-inventory; and distribution-inventory (Arshinder *et al.*, 2008).

Procurement-production interface. Goyal and Deshmukh (1992) studied literature on integrated procurement-production systems. They classified the models based on criteria such as number of products, planning horizon, solution method, replenishment orders and algorithmics. More research has been done since then including optimal production cycles, procurement schedules and joint investment (Hong, 1997). An integrated purchasing-production model was presented to compare centralised SC and decentralised SC (Munson and Rosenblatt, 2001). Kim *et al.* (2006) proposed an analytical model to effectively integrate and synchronise the procurement, production and delivery activities in a SC consisting of a single raw material supplier, a single manufacturer and multiple retailers. Mukhopadhyay and Ma (2009) considered the optimal procurement and production quantities for a remanufacturing company with uncertain market demand. Song (2009) investigated optimal integrated ordering and production control in a SC with multiple types of uncertainties in lead time, processing time and demand.

Production-inventory interface. Many studies have focused on internal interfaces in manufacturing systems, for example, (1) optimal control in production/inventory systems under continuous review

(Gavish and Graves, 1980; Li, 1992; Veatch and Wein, 1994); (2) optimal control in production/inventory systems under periodic review (Federgruen and Zipkin, 1986a; Federgruen and Zipkin, 1986b; Chen and Zheng, 1994); (3) optimal production control for continuous material flow with uncertainties (such as machine breakdowns) (Gershwin, 1994; Sethi and Zhang, 1994). With respect to the interface between supplier and buyer, Hill (1997) developed a production and shipment schedule for an integrated system to minimise the average total cost. Hoque and Goyal (2000) presented an optimal solution procedure for optimising production quantity in a single-vendor single-buyer production-inventory system with unequal and equal sized shipments. Grubbström and Wang (2003) introduced a model that included a multi-stage capacity-constrained production-inventory system with uncertain demand. Ashayeri *et al.* (2006) studied a production-inventory planning and control system in the process industry and pointed out that advanced planning and scheduling (APS) software tools did not fit well in the process industry due to the complexities involved in the software solutions. They proposed a simple cyclic production-inventory optimisation model to improve the performance of the batch process company. It was observed that control theories were frequently applied in production-inventory systems in either discrete parts of manufacturing industry (Ortega and Lin, 2004) or in the continuous batch process industry (Schwartz and Rivera, 2010).

Production-distribution interface. Note that a SC often consists of several plants that include production capacities, distribution centres and a number of customer zones (Geoffrion and Graves, 2010). Multi-plants can be coordinated in different ways, for example, "general coordination" focuses on functional integration, and "multi-plant coordination" focuses on linking decisions within the same function at different echelons of the organisation (Bhatnagar *et al.*, 1993). Vidal and Goetschalckx (1997) provided a review of strategic production-distribution models with an emphasis on global SC using mixed-integer programming methods. The main characteristics of the selected models were identified. However, in multi-national companies (MNCs), varying inflation and exchange rates should be considered as a key factor influencing integrated production planning (Mohamed, 1999). Later, guidelines about how to integrate production and distribution were designed by the Kellogg Company (Brown *et al.*, 2001). Some studies have focused on the impacts of production-distribution coordination on SCP. For example, Boissière *et al.* (2008) tested an N-stage serial production-distribution system with limited production capacity in order to find effective inventory management policies (minimising the global logistic cost). Chen (2010) showed that item substitution strategies contributed to SCP in production-distribution networks.

Distribution-inventory interface. A risk pooling approach is often used to coordinate distribution and inventory in uncertain demand situations. For example, coordinated inventory management between warehouse and multiple retail outlets reduces the risk of imminent shortage, and therefore the SCP can be improved (Tagaras, 1999). In a multi-stage distribution and inventory system, ordering policies for a central warehouse and multiple retailers are sought using heuristics methods (Abdul-Jalbar *et al.*, 2005), and a mixed-integer linear programming model is used to determine the optimal inventory and distribution plan (Monthatipkul and Yenradee, 2008). An integrated inventory-distribution optimisation model that incorporated issues such as location, production, inventory and transportation within a SC is presented in order to determine the optimal number and size of shipments in various production and shipping scenarios (Pujari *et al.*, 2008).

Coordinated management strategies

A range of coordinated management mechanisms have been developed and applied to business operations in the last two decades. With the emphasis on information sharing and inventory management, the best coordination mechanisms include: (s, S) policy, JIT strategy, VMI and CPFR.

(s, S) policy

The (s, S) policy has been employed in inventory management and production control for many years, especially in the context of uncertain situations. However, it has been generally undertaken in a single stage inventory system (Xiong, 2006). Traditionally, optimising the (s, S) policy by using functional equations, by a policy iteration method or by using the Markovian method are usually complex and time consuming, which leads to less interest (Graves *et al.*, 1993). More recently, there are many studies discussing (s, S) policy in the field of operations research or inventory management associated with cost functions (Mak *et al.*, 2005; Chen and Xu, 2010; Benkherouf and Sethi, 2010; Srinagesh, 2001). The reasons for applying the (s, S) policy to SC systems include: (1) (s, S) policy as a type of stochastic inventory control policy can be easy to use (Heisig, 2002, Axsäter, 2006); and (2) by choosing a common ordering period, synchronising and aggregating orders for different items with a common supplier results in a cost reduction (Brandimarte, 2011).

Although the (s, S) policy does not imply coordination between functions and channel members, it can be regarded as a type of coordinated management if the parameters s and S are designed cooperatively rather than independently. In a multiple-stage SC with suppliers, customers, process (information and material flow) uncertainties and constraints, it is essential to optimise the (s, S) policy to achieve SC coordination.

Just-in-time

Hutchins (1999, 7) described the goal of JIT as the total elimination of inventory in all stages in the process – "the ultimate process is represented by the entire network of events, including both products and services, which results in a response to given need, the process commences with the initial production of raw materials and ends with the satisfaction of the end users' needs." In manufacturing, JIT has been seen to reduce inventory levels, to improve the quality of incoming materials, to maintain consistent high-quality products, to improve operational efficiency, to achieve better cooperation with suppliers and customers and therefore to improve customer satisfaction (Yasin *et al.*, 2003). Sugimori *et al.* (1977) studied the Toyota production system and Kanban system by analysing two major distinctive features. They believed that JIT production was an important factor in an assembly industry such as automotive manufacturing. Under this system, only the necessary products, at the necessary time, in the necessary quantity were manufactured in order to minimise on-hand inventory level. Additionally, there are studies of JIT from the systems aspect, for example, Miltenburg (1989) developed a theoretical basis for scheduling these systems and presented new scheduling algorithms and heuristics in order to satisfy the JIT production systems' high requirements (levelling or balancing the schedule) which required keeping a constant rate of usage of all parts used by the line. However, quality is essential within a JIT system because any quality problem will negatively affect the next process and the whole system, and Schroeder (1999) also suggested that JIT requires nearly perfect quality for every process. However in SC, there are lots of uncertainties such as raw material supply in terms of supply defective quality or shipment delay and production quality problems.

Although the goal of JIT is to minimise the inventory at all stages in the processes, it is difficult to achieve zero inventory in most SCs. Coordination is often required to determine the inventory locations and levels along the SC when implementing the JIT strategy in practice. In that sense, JIT can be recognised as another type of coordinated management mechanism.

Vendor management inventory

Another commonly used approach to coordinate management in a SC is the concept of VMI. Under VMI, the upstream decides quantity and delivery time for the downstream. In practice, it appears the suppliers take the responsibility for monitoring sales and inventory and use this information to trigger replenishment orders. The potential benefits for suppliers are an increased profit margin (Kulp *et al.*, 2004), gaining data on customer sales, reviewing customers' inventory more frequently (Waller *et al.*, 1999) and then to better control the inventory level on downstream entities (Harrison and Hoek, 2008) so as to benefit both themselves and customers. Even in the long-term, the suppliers can better manage their production capability to fulfil the integrated demand. Manufacturers gain more market share by using incentive contracts with distributors in a VMI program (Yao *et al.*, 2010).

Sufficient evidence has shown that VMI significantly improves SCP such as reducing total SC cost and lead time. For example, VMI engages other applications such as ERP systems and a spreadsheet based decision support system in a SC, and therefore it is more convenient for data integration and contributes to decision making (Disney *et al.*, 2001). VMI reduces the bullwhip effect in the SC because it responds significantly better to volatile changes in demand and inventory recovery (Disney and Towill, 2003). Dong *et al.* (2007) conducted exploratory research discussing the adaptabilities of VMI in different environments. Van der Vlist *et al.* (2007) compared non-VMI and VMI in a single-buyer and single-supplier SC system. Song and Dinwoodie (2008) quantified the effectiveness of VMI in comparison with retail management inventory using dynamic programming theory in the context of uncertain replenishment lead times and uncertain demand. In a stochastic multi-product serial two-echelon system, it is shown that VMI reduces the order picking cost and transportation cost (Kiesm and Broekmeulen, 2010). Darwish and Odah (2010) developed a VMI model that included a contractual agreement between a single vendor and multiple retailers to achieve a global optimal solution. Guan and Zhao (2010) discussed the VMI program in short-term and long-term contracts with a continuous (r, Q) policy (according to Song *et al.* [2010, 68], under the [r, Q] policy, an order of fixed size Q was placed when the inventory position dropped to level r). They found that in the short-term contract it was suitable for single period models, such as the newsboy model, without sharing private information. For a long-term contract (with a tighter relationship between the vendor and the retailer), the (r, Q) policy was more suitable, in which firms were naturally willing to exchange some private information with partners in order to achieve long-term benefits.

Although there are lots of benefits of applying VMI, Harrison and Hoek (2008) raised some drawbacks: (1) unwillingness to share data; (2) hard forecasting for seasonal products; (3) investment and restructuring cost problems; (4) retail vulnerability; (5) lack of standard procedures; and (6) lack of system maintenance. Meanwhile, in practice, with VMI it is difficult to control data accuracy and data integrity (Cooke, 1998; Bruce and Ireland, 2002) and the appropriateness of profit allocation between the manufacturer and the retailer (possibly in favour of manufacturers) (Yu *et al.*, 2009).

Collaborative planning, forecasting and replenishment

The CPFR model has been defined as “a business practice that combines the intelligence of multiple partners in the planning and fulfilment of customer demand,” by the Voluntary Inter-industry Commerce Association (VICS) (Chopra and Meindl, 2007, 466). The key aspect leading to a successful CPFR model is to build foundations on which channel members can synchronise their data and then establish standards for information exchange.

According to VICS (2004), the CPFR model has been used in different industries with multiple-tier SC collaboration. The standard CPFR model focuses on customer, retailer and manufacturer. There are three levels. In the retail industry, assume the manufacturer is the seller and the retailer is the buyer. There are four activities in each level to engage seller and buyer to improve their performance. The VICS guideline reports activities including strategy and planning, demand and supply management, execution and analysis. Within the strategy and planning activity, a collaborative relationship should be established, and then in the demand and supply management activities, information such as point-of-sale data, order and shipment requirements can be shared. In execution, the operations mainly include: place order, prepare and deliver shipments, receive and stock products, record sales transactions and make payment. Finally, in analysis, the performance is evaluated and improved with insight-sharing.

There are sub-strategies that can be introduced under each activity. Under strategy and planning, a joint business plan can be used in order to define the goal of the relationship, the scope of collaboration and assigning roles and responsibilities, checkpoints and escalation procedures and key events that may affect supply and demand in the planning period. Under the demand and supply management activity, sales forecasting and order planning/forecasting could project consumer demand at the point-of-sale and determine future product ordering and delivery requirements. Under the execution activity, the execution process is broken into forecasts of demand and fulfilling the orders, which is the process of producing, shipping, delivering and stocking. Finally, under analysis activity, exception management and performance assessment are employed to monitor and evaluate the achievement of business goals, uncover trends or develop alternative strategies (VICS, 2004).

In practice, applying CPFR can be flexible because more collaboration tasks can be employed within CPFR, such as VMI, category management, point-of-sale (POS) forecasting, replenishment planning, buying and re-buying, logistics distribution, store execution and supplier scorecards. In addition, there are four main scenarios involved in the CPFR model, which include retail event collaboration, distribution centre (DC) replenishment collaboration, store replenishment collaboration and collaborative assortment planning (Chopra and Meindl, 2007).

There are multiple benefits of implementing CPFR in an organisation. For example, CPFR significantly accelerates consumer response by setting up automatic replenishment programs with a high level of cooperation and collaboration (Tosh, 1998). Comparing VMI with traditionally managed SC (TSS), Sari (2008) believed that CPFR led to greater benefits and improved SCP significantly. Ireland and Bruce (2000) suggested that CPFR projects achieved a 30–40% improvement in forecasting accuracy, a 15–60% improvement in sales, a significant increase in customer services and a 15–20% reduction in days of supply. According to AMR Research (2001), CPFR benefits both retailers and manufacturers. The benefits for the retailers included better store shelf stock rates (2–8%), lower inventory levels (10–40%), higher sales (5–20%) and lower logistics costs (3–4%). The benefits for manufacturers included lower inventory levels (10–40%), faster replenishment cycles (12–30%), higher sales (2–10%) and better customer service (5–10%). This may be explained from the following three aspects. Firstly, CPFR achieves a better match between demand and supply, and for that reason, inventory can be reduced and customer service level can be increased (Robins, 1998; Foote and Krishnamurthi, 2001). Secondly, within the organisation, not only are the inventory levels decreased, but also order cycle times are more predictable, redundant activities are eliminated and product availability and sales are increased (Stank *et al.*, 1999, 2001). Finally, communication and information flow can be standardised (Agrawal *et al.*, 2009).

On the other hand, there are some difficulties and barriers to the implementation of CPFR, for example: (1) reduced control and power: if the company is using an electronic marketplace for communicating CPFR information, it may result in a loss of information control; (2) problems with scalability: the electronic marketplace may have difficulties to balance tailored and standardised solutions in a way that both customer satisfaction and efficiency remain high; and (3) fees: although the company only needs to pay for investment in one communication link (the one to the electronic marketplace), it needs to pay transaction fees or service fees to the marketplace (Ferreira *et al.*, 2001). Sheffi (2002) addressed the perception that demand management, fulfilment, joint optimisation and real time collaboration was not covered by CPFR. According to his analysis, demand management in the stores and distribution centres involved collaborative merchandising, category management, promotional planning and even collaborative space management. However, from the manufacturers' side, demand management focused on collaborative product design and new product introductions. Thus, it was hard to match both sides and it may have caused inaccuracy in forecasts. Moreover, CPFR does not extend to many other parties involved in the fulfilment process, for example, transportation carriers, forwarders, public warehouse operators. Collaborative efforts rely on the foundation of trust and joint business processes that will enable future SCP optimisation; however, CPFR is only the start of collaborative relationships across entire SCs. Therefore it is hard to enable joint optimisation. Finally, CPFR only focuses on planning activities, however, a variety of problems will arise in real time while the product is moving and the unexpected happens.

Computational complexity and optimisation

In computational complexity theory, computational problems are classified according to their inherent difficulty. If a computational problem can be solved in polynomial time on a non-deterministic Turing machine, it is called an NP problem. A problem p in NP is termed as NP-complete if every other problem in NP can be transformed into p in polynomial time. At present, all known algorithms for NP-complete problems require time that is superpolynomial in the input size, and it is unknown whether there are any faster algorithms (Golderich, 2010).

Optimisation problems are one important category of computational problems in computational complexity theory. The common solution methods to optimisation problems can be classified into three groups: calculus-based methods, enumerative search methods and stochastic search methods. Calculus-based methods require knowledge of gradients or higher order derivatives, which are usually not available in many practical problems. Enumerative search methods evaluate every point within the objective function's solution space. The optimum solution can be found after testing all the solutions. It may be easy to implement and guarantee the optimality of the solution, but this usually requires significant computational time, which becomes practically inapplicable for problems with large solution spaces. Stochastic search methods use random choice as a mechanism to guide the search in order to find optimal or sub-optimal solutions (Floudas and Pardalos, 2008). There has been sufficient evidence showing that stochastic search methods are efficient for solving NP-complete problems. They can find very good solutions without needing a lot of pre-experience information relating to the problem and can be easily adapted to optimisation problems in different domains.

The main differences between an enumerative and stochastic search are that the enumerative search can guarantee an optimal solution from the given solution set but could be very time consuming; however, a stochastic search can search the solution space globally with less computational time but may find a sub-optimal solution.

NP refers to non-deterministic polynomial time. According to Roos and Rothe (2010, 1), complexity theory

> is an on-going area of algorithm research that has demonstrated its practical value by steering us away from inferior algorithms. It also gives us an understanding about the level of inherent algorithmic difficulty of a problem, which affects how much effort we spend on developing sharp models that mitigate the computation time. It has also spawned approximation algorithms that, unlike metaheuristics, provide a bound on the quality of solution obtained in polynomial time.

The classification principle of complexity classes is bounding the time or space used by the algorithm shown in Table 2.2 (Allender *et al.*, 1999).

In order to solve complex issues that are difficult or impossible to calculate, different search methods, for example, an enumerative search and a stochastic search, are employed. Enumerative search methods such as branch and bound and heuristic search are common approaches for solving optimisation problems. While branch and bound methods can guarantee an optimal solution, they require, in the worst case, exponential time. Heuristic search methods, on the other hand, need less computational resource but generally terminate at a local optimum (Fadlalla and Evans, 1995, 605).

Table 2.2 The complexity class

Complexity class	**Model of computation**	**Resource constraint**
DSPACE ($f(n)$)	Deterministic turing machine	Space $f(n)$
L	Deterministic turing machine	Space O(log n)
PSPACE	Deterministic turing machine	Space poly(n)
EXPSPACE	Deterministic turing machine	Space $2^{\text{poly}(n)}$
NSPACE ($f(n)$)	Non-deterministic turing machine	Space $f(n)$
NL	Non-deterministic turing machine	Space O(log n)
NPSPACE	Non-deterministic turing machine	Space poly(n)
NEXPSPACE	Non-deterministic turing machine	Space $2^{\text{poly}(n)}$
DSPACE ($f(n)$)	Deterministic turing machine	Space $f(n)$
DTIME ($f(n)$)	Deterministic turing machine	Time $f(n)$
P	Deterministic turing machine	Time poly(n)
EXPTIME	Deterministic turing machine	Time $2^{\text{poly}(n)}$
NTIME ($f(n)$)	Non-deterministic turing machine	Time $f(n)$
NP	Non-deterministic turing machine	Time poly(n)

Source: Authors.

Moreover, Fouskakis and Draper (2002) studied stochastic optimisation in which the search for the optimal solution involved randomness in some constructive way. They explained the search thus: "It is easy to see that as the dimension of solution set increases, the harder the task becomes, and more time is needed to find the optimal, or at least a near-optimal, configuration. Another difficulty is that it is common for the objective function to have many local optima" (315–316). Thus, the main difference between the enumerative and stochastic search is that the enumerative search can guarantee an optimal solution from the given solution set and more accurate time consumption, however, the stochastic search can search the solution globally with less time but also maybe with less accuracy (Fouskakis and Draper, 2002).

Stochastic search methods offer a robust quality to optimisation processes. The most widely used stochastic search methods in the literature include: genetic algorithms (GA), evolutionary strategies (ES), simulated annealing (SA) and tabu search (TS). The GA and ES are essentially the same (initially the former focused on discrete variables and the latter focused on continuous variables). They emulate nature's evolutionary behaviour, and the search evolves throughout population-based generations. SA is based on the physical process of annealing a material which mimics a thermodynamic evolution process to search minimum energy states. It may accept a solution with positive probability even if the solution is worse than another solution, which allows the algorithm to avoid getting stuck in local maxima (Kirkpatrick *et al.*, 1983). The TS uses a local or neighbourhood search procedure to move iteratively from one potential solution to an improved solution in the neighbourhood of the current solution, until some stopping criterion has been satisfied. The essential idea of the TS is to "forbid" search moves to points already visited in the (usually discrete) search space, at least for the upcoming few steps. It enhances the search performance by using such memory structures. The GA model may be selected to solve an optimisation problem because: (1) it has been successfully applied in many cases in the field of SCM in the literature; and (2) it is population-based and easy to extend to solve multi-objective optimisation problems.

The Committee on the Next Decade of Operations Research (1988) stated that local search (LS), SA, GA and TS are "extremely promising for future treatment of practical applications." Aarts and Korst (1989) studied LS and found that it only accepted moves with higher values of the objective function than the previous move (with poor performance). The SA is a discrete optimisation method that was developed in the early 1980s. It is a stochastic local search technique which approximates the maximum of the objective function over a finite solution set. The GA is a population-based global search method. It was first introduced by Holland (1975), and it became a popular method for solving large optimisation problems with multiple local optima. The TS is a "higher-level" heuristic procedure for solving optimisation problems, designed (possibly in combination with other methods) to escape the trap of local optima (Fouskakis and Draper 2002, 338; Glover, 1977) for solving nonlinear covering.

The LS search could get stuck in a local optimum. The SA may accept a solution with positive probability even if the solution is worse than another solution, which allows the algorithm to avoid getting stuck in local maxima (Kirkpatrick *et al.*, 1983). The TS enhances the performance by using memory structures that describe the visited solutions or user-provided sets of rules. If a potential solution has been previously visited within a certain short-term period or if it has violated a rule, it is marked as "tabu" (forbidden) so that the algorithm does not consider that possibility repeatedly. In this study, based on the literature, it was found that GA has been successfully adopted in many cases in the field of SCM. Meanwhile, Goldberg (1989) and Davis (1991) believed that a number of applications in a range of problems could be solved by using GA.

Current status of logistics and SCM in China

In this section, recent development and issues related to logistics and SCM in China will be discussed.

Overview of development of logistics in China

The statistics show that the discipline of logistics has been increasingly developed in China in the past few decades. In 2000, the proportion of logistics expenses to GDP, including transportation, inventory storage and loss and breakage, was 20% in China. The Chinese logistics industry grew at an annual rate of 15–30% during 2000–2004, which was much faster than the national economic growth of 8–9% annually at the same period (Waters, 2010). Currently, there are generally five main types of logistics companies in China, namely: (1) former subsidiaries of relevant ministries, for example, Sinotrans from the Ministry of Foreign Trade, who have national connections and Guan Xi (a Chinese business culture) advantages; (2) foreign logistics firms or freight forwarders such as DHL; (3) logistics departments of certain large conglomerates that provide logistics services to both their parent companies and some others in the same or similar industries; (4) transportation firms; and (5) private firms. Chinese logistics lacks outsourcing activities with international players, and e-commerce-based distribution activities are dominated by domestic firms (Waters, 2010).

The SCM in Chinese firms

There are numerous issues in SCM in China, referring to infrastructure and technology, quality and business culture and government attitude. Firstly, the infrastructure and distribution system in China is still inefficient in terms of "structural factors, such as inter-provincial and inter-ministerial relationships, the level of relatedness between two industries, inefficient administration procedures and overlaps in the roles and functions of different administrative organisations" (Luk, 1998, 65). Martinsons (2004) reported that Chinese organisations have invested billions of dollars in the application of ERP, and more than 1000 Chinese organisations had implemented ERP by the end of 2001, and about 300 of these used SAP's R/3 package. However, according to Martinsons's research, it is not as easy applying ERP in China compared with the EU and the United States, especially for Chinese state-owned enterprises. It was found that (1) the initial aims of Chinese ERP implementations ineffectively demonstrated tangible benefits; (2) compared with state-owned enterprise managers, private ventures are more actively involved in ERP; (3) private ventures have a cross-functional steering committee; (4) private ventures prefer to hire consultants; (5) ERP could be better used in private ventures; (6) state-owned enterprise had more data maintenance problems after adopting ERP; and (7) private ventures are more satisfied with the results.

Secondly, quality issues have referred to labour quality and production quality. Recruiting and training employees (Zhang and Goffin, 1999), a high job dissatisfaction rate and high labour turnover rate (Jiang *et al.*, 2009), the institutional environment (Yaibuathet *et al.*, 2008) and over-reliance on workers' experience (Chien *et al.*, 2009) have all increased risk in China's SCM. These issues are leading to poor production quality, low productivity, unfilled orders, low operational performance and low customer satisfaction. Total quality management (TQM) practices in China have been discussed, however, production quality research on Chinese goods has addressed maximising profit with loss of quality and customer services' satisfaction risk (Franca *et al.*, 2010), Chinese produced goods' quality and safety for US import risk (Berman and Swani, 2010), the outsourcing quality management risk (Ni *et al.*, 2009) and especially food quality risk (Brown *et al.*, 2002; Wu *et al.*, 2010).

Thirdly, the special Chinese business culture and government attitude, enterprise ownership, cooperation, relationship and trust can sensitively and seriously affect SCM in China. In 2000, Pyke *et al.* (2000) investigated 100 firms with differing enterprise ownership (including state-owned enterprises, collective-owned enterprises and privately held firms) in Shanghai, and they found that although these firms used advanced manufacturing strategies, they were not as advanced as many Western firms and SCM was less effective. For example, they communicated with customers more frequently than with suppliers, and the communications were not very significant. Cai *et al.* (2010) investigated the impacts of Chinese companies' institutional environment, for example, legal protection, government support and Guan Xi (interpersonal relationships), on the development of trust and information integration between buyers and suppliers, and they found that government support and Guan Xi significantly affected trust, which subsequently positively influenced two elements of SC integration, namely, information sharing and collaborative planning. Zhao *et al.* (2011) also considered that Guan Xi could better engage Chinese suppliers and buyers and therefore enhance the SC internal and external integration, and it needs to be understood that there is a very special Chinese business culture. However, although it is hard to identify Guan Xi as an issue, at the least it can be very unfair on other companies, especially foreign ones. As China is seen as a world manufacturer, sourcing in China has benefited lots of foreign firms in terms of low cost, nevertheless, these special business cultures and government attitudes may damage opportunities.

In the past decade, SCM has attracted much attention in many Chinese industrial sectors, for example, agriculture (food) and/or business, manufacturing, energy, automobile, e-business, coastal, pharmaceutical, outscoring, furniture and motorcycle industries. Table 2.3 summarises the literature related to SCM in China using three criteria: industry type, research method and subjects.

In terms of industry and/or business type, the studies on SCM in China cover agriculture (food) (Stringer *et al.*, 2009; Waldron *et al.*, 2010), manufacturing (Pyke *et al.*, 2000; Cai *et al.*, 2010, He and Chen, 2009), energy (Zhu and Sarkis, 2006; Hui and Xiao-ping, 2009; Zhu *et al.*, 2007b), automobiles (Hatani, 2009; Zhu *et al.*, 2007a), e-business (Cai *et al.*, 2010; Lancioni *et al.*, 2003) and outsourcing (Ni *et al.*, 2009). Based on the aforementioned literature, it is clear that the research on SCM in China mainly concerns the food industry, followed by manufacturing, multi-types industry and the energy industry. Little research has considered e-business, outsourcing and the automotive sector. There is no specific research in the areas of our case companies (the aluminium industry for case company A and the chemical industry for case company B).

Table 2.3 The status of China's SCM

		Industry type										**Research method**							**Subjects**								
	Reference	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**
1	Stringer *et al.*, 2009)		*									*															*
2	Waldron *et al.*, 2010		*											*													*
3	Pyke *et al.*, 2000			*				*					*														*
4	He and Chen, 2009			*								*															*
5	(Zhu and Sarkis, 2006				*								*				*									*	
6	Hatani, 2009						*							*	*												*
7	Cai *et al.*, 2010			*		*							*											*			
8	Jiang *et al.*, 2009										*		*						*								
9	Yu *et al.*, 2010										*	*															*
10	Lancioni *et al.*, 2003					*						*													*		
11	Zhu *et al.*, 2007a						*						*													*	
12	Hui and Xiao-ping, 2009				*							*															*
13	Han *et al.*, 2011		*										*								*						
14	Sheu, 2003			*											*					*		*					
15	Yaibuathet *et al.*, 2008							*					*						*								
16	Li *et al.*, 2006			*									*						*								
17	Franca *et al.*, 2010															*					*						
18	Zhu *et al.*, 2007a.			*				*			*		*													*	
19	Humphreys *et al.*, 2001										*			*										*	*		
20	Zhu *et al.*, 2007b				*		*	*					*													*	
21	Xu *et al.*, 2009	*											*			*											*
22	Zhu and Sarkis, 2004			*				*					*													*	
23	Liu *et al.*, 2005										*				*									*	*		
24	Park *et al.*, 2010				*										*											*	*
25	Zhao *et al.*, 2008			*				*					*									*					
26	Qu *et al.*, 2007		*									*													*		
27	Hua *et al.*, 2006									*						*							*				

28	Wang *et al.*, 2007					*										*				*							
29	Su *et al.*, 2008a							*					*														*
30	Ge and Voß, 2009										*	*												*	*		
31	Robb *et al.*, 2008	*											*														*
32	Zhu *et al.*, 2010			*				*				*	*				*									*	
33	Zhu and Cote, 2004		*												*							*				*	
34	Zhu and Geng, 2013			*				*					*													*	
35	Wang *et al.*, 2009		*										*														*
36	Berman and Swani, 2010			*				*				*									*						
37	Su *et al.*, 2008b			*									*										*				
38	Trkman *et al.*, 2010			*				*					*											*			
39	Ni *et al.*, 2009								*							*					*						
40	Ke *et al.*, 2009				*								*										*	*			
41	Zou *et al.*, 2011										*							*		*							
42	Jia *et al.*, 2012		*										*								*						
43	Lu *et al.*, 2008		*														*						*				*
44	Lockström *et al.*, 2010									*					*		*					*					
45	Reyes, 2005										*					*				*							
46	Brown *et al.*, 2002		*									*									*						
47	Yuan and Shi, 2009										*				*											*	
48	Zhang *et al.*, 2008										*			*												*	
49	Zhao *et al.*, 2010			*									*									*					
50	Huang *et al.*, 2009										*		*														*
51	Wu *et al.*, 2010		*												*						*				*		
52	Guo *et al.*, 2000									*					*										*		
53	Geng *et al.*, 2007		*			*						*													*		
54	Xu *et al.*, 2008				*													*							*		
55	Li, 2002										*				*											*	

Source: Authors.

Table 2.4 Research methods and subjects

Industry and/or business type	**Research method**	**Subjects**
A: Furniture	1: Literature review	a: Labour quality
B: Agriculture (food)	2: Survey (statistics)	b: Warehouse, transportation
C: Manufacturing	3: High value chain	c: Producing, products quality
D: Energy (new energy, electricity, renewable energy)	4: Case study	d: Supply chain integration
E: e-business	5: Modelling	e: Cooperation
F: Automobile	6: Interview	f: Information
G: Multiple industry	7: Simulation	g: Technology
H: Outscoring		h: Green supply chain
I: Automotive		i: Others (comprehensive supply chain management)
J: Others with only one article (coastal, pharmaceutical, motorcycle)		

Source: Authors.

In terms of the research methods, both empirical study and modelling research methods have been employed. The empirical studies have mainly included questionnaires, interviews (e.g., Zhu and Sarkis, 2006; Zhu *et al.*, 2010; Lu *et al.*, 2008; Lockström *et al.*, 2010) and statistics (e.g., Pyke *et al.*, 2000; Zhu and Sarkis, 2006; Cai *et al.*, 2010; Jiang *et al.*, 2009; Zhu *et al.*, 2007a; Han *et al.*, 2011; Yaibuathet *et al.*, 2008; Li *et al.*, 2006; Zhu *et al.*, 2010). Also modelling (e.g., Franca *et al.*, 2010; Xu *et al.*, 2009; Hua *et al.*, 2006; Wang *et al.*, 2007; Ni *et al.*, 2009; Reyes, 2005) including mathematical modelling and simulation (e.g., Zou *et al.*, 2011; Xu *et al.*, 2008) and frameworks such as those based on literature reviews (e.g., Stringer *et al.*, 2009; He and Chen, 2009; Jiang *et al.*, 2009; Yu *et al.*, 2010; Humphreys *et al.*, 2001; Qu *et al.*, 2007; Ge and Voß, 2009; Zhu *et al.*, 2010; Berman and Swani, 2010). Case studies (e.g., Hatani, 2009; Sheu, 2003; Liu *et al.*, 2005; Park *et al.*, 2010; Zhu and Cote, 2004; Yuan and Shi, 2009; Lockström *et al.*, 2010; Wu *et al.*, 2010) can be based both on empirical study and modelling.

In terms of the research subjects/contents, the most popular subjects are green SCM (e.g., Hatani, 2009; Zhu *et al.*, 2007a, 2007b; Zhu and Sarkis, 2004; Park *et al.*, 2010; Zhu *et al.*, 2010; Zhu and Cote, 2004; Zhu and Geng, 2013; Yuan and Shi, 2009; Zhang *et al.*, 2008; Li, 2002). information systems (e.g., Cai *et al.*, 2010; Humphreys *et al.*, 2001; Liu *et al.*, 2005; Ge and Voß, 2009; Trkman *et al.*, 2010; Ke *et al.*, 2009), technology both systems and applications (e.g., Lancioni *et al.*, 2003; Humphreys *et al.*, 2001; Liu *et al.*, 2005; Qu *et al.*, 2007; Ge and Voß, 2009; Wu *et al.*, 2010; Huang *et al.*, 2009; Guo *et al.*, 2000; Geng *et al.*, 2007; Xu *et al.*, 2008), quality in production (Han *et al.*, 2011; Franca *et al.*, 2010; Berman and Swani, 2010; Ni *et al.*, 2009, Jia *et al.*, 2012; Brown *et al.*, 2002; Wu *et al.*, 2010) and labour quality (e.g., Jiang *et al.*, 2009; Yaibuathet *et al.*, 2008; Li *et al.*, 2011). Limited research concerns cooperation (e.g., Hua *et al.*, 2006; Su *et al.*, 2008b; Ke *et al.*, 2009; Lu *et al.*, 2008), warehousing and transportation (e.g., Sheu, 2003; Wang *et al.*, 2007; Zou *et al.*, 2011; Reyes, 2005) and SC integration (e.g., Zhao *et al.*, 2008; Zhu and Cote, 2004; Lockström *et al.*, 2010; Zhao *et al.*, 2010).

The majority of SCM studies in China focus on the manufacturing and food industries. This might be explained by the fact that China has been recognised as a world manufacturer in making toys and clothes. Case studies, modelling and simulation research methods have been widely used in Western countries. However, in China the generally adopted research method is statistics analysis and literature reviews. The subjects of SCM research in China could be extended; for example, there is a lack of research on the issues related to information systems, coordination, SCP, SC integration, evaluation of SC models and applications.

The SCM in SMEs in China

The SMEs made up over 99% of all enterprises in China in 2007, and the output value of SMEs accounted for at least 60% of the country's GDP, generating more than 82% of employment opportunities (Liu, 2008). There are a few studies focusing on SCM from a SME perspective; for example, Tan *et al.* (2006) highlighted the underlying factors that contribute to the effective management of a global SC from the perspective of SMEs. They employed a case study of a UK firm, and the "key motives," "enablers" and "inhibitors" of SCM, particularly related to cultural differences, were investigated. Archer *et al.* (2008) identified and measured the perceived importance of barriers in the SME community to the adoption of Internet business procurement and SC solutions through a telephone survey of a sample of 173 Canadian SMEs. As a result, they suggested that it was necessary to educate SME management on the benefits and drawbacks of using e-business solutions.

Inter-organisational information systems that are required to link SC partners can be a serious barrier to online solutions. There is a significant dependency among SC partners in decisions relating to adopting online links. Flexibility, agility and the ability of SMEs can help them to use partial e-business solutions for low volumes of business, but this approach can be very ineffective when transaction volumes are large. However, there is a limited number of studies of SCM in SMEs. For example, Ciliberti *et al.* (2008) studied the practices implemented and difficulties experienced by SMEs transferring socially responsible behaviours to suppliers. They used a multiple case study including five Italian socially responsible SMEs with companies in developing countries, for example, China. They concluded that it is difficult if there is a developing country involved.

The need to know more

Although SCM has been studied for many years, the focus of SCM in SMEs lags behind. In particular, the study of managing the SC in China from a SME perspective is very limited. Secondly, the manufacturing oriented non-grocery SC is different from a retailer oriented grocery SC as the function and uncertainties are different; however, studies focusing on the complex non-grocery SC system are few. Thirdly, although there are some case studies on SCM, there are few from a system simulation perspective as it requires considerable effort and substantial data from the case company. In particular, little has been reported in terms of the impacts of information sharing and coordinated management on SCPs.

We now go on to assess the methodologies which could be used to explore this study of SCM.

3

A Methodology for the Exploration of Supply Chain Management

This chapter discusses research methods. The multiple case study method is reviewed and is followed by an assessment of the appropriateness of a case study approach. The data collection methods in general and the rationale for using interview and observation in this study to collect primary data are addressed. Archived data are outlined and the issues of reliability and validity are considered. Finally, simulation and simulation-based optimisation methods are introduced.

Multiple case study

The case study is an important research method in logistics and SCM, which are relatively new disciplines. For example, Ojala and Hilmola (2003) pointed out that case studies have been increasingly employed in logistics research. Dinwoodie and Xu (2008) reported that there was an increase in research using case studies (both single and multiple) as the research method in logistics from 1996 to 2008. Vafidis (2002) found that multiple case studies were the most widely used approach in logistics. Abrahamsson (2003) reviewed case study areas, including: (1) a retrospective study on logistics restructuring; (2) sales and marketing issues; (3) organisational issues; (4) dynamic capabilities; and (5) logistics platforms. Abrahamsson *et al.* (2002) classified three different types of logistics areas suitable for case studies: optimisation of activities, logistics structure and dynamic capabilities.

Based on the research gaps identified in the last chapter, the multiple case study method has been employed. This method provides a better understanding of the detailed practical operations in Chinese medium-sized manufacturer SCs. They identify the key challenging issues in the case companies, develop appropriate strategies and generate the results in a wider context.

The case study approach employed in this project included the following steps. Firstly, the primary data was collected from the selected case companies. Secondly, based on this data, the case companies' SC was illustrated and constructed through the SC process mapping approach. Thirdly, the issues within the case SCs were identified and analysed. Fourthly, the information-sharing strategies and coordinated management strategies were developed to improve the SCP using techniques such as simulation and optimisation. Managerial insights were generated.

Interviews

Both individual and group interviews were conducted with both companies' senior managers who were in charge of procurement, transaction, warehousing, production, finance and marketing. Group interviews can be useful in identifying key themes (Zikmund, 2000). The group interview may also motivate participants' contributions because the interaction and effective communication enriches the proposals by the group. On the other hand, a group interview may inhibit some contributions because of the lack of trust between group members (Kahn and Cannell, 1965).

The group interviews were first combined with individual interviews. The former were used to develop an overall SC map in a broad context and identify which pieces of data could be collected from which department in the case companies. The latter were used to collect in-depth data and to modify and refine the primary data.

The case companies were contacted in 2009. Before the interviews, the semi-structured interview questions were sent to case company A in late 2009 and to case company B in early 2010. The semi-structured interview questions consisted of three parts including 63 questions. The first part covered general information on the company, for example, background, organisational structure. The second part was about the production process, SC members, characteristics of the SC and SCM issues. The third part included detailed questions about management policies (e.g., raw material ordering and finished goods production strategies, sales plans), finished goods inventory data, operational costs in detail and customer services. The face-to face interviews were conducted twice, in 2010 and 2011, respectively. In between, there were a number of email contacts and telephone interviews. Five people were interviewed in case company A, and eight people in case company B including the directors and senior managers, who were from different departments.

The data collection procedure is described in more detail later. Firstly, a group of managers was asked to complete a pipeline map about the SC showing the inventory information and warehouse information such as safety stock level and stock replenishment. Secondly, interview questions, related to material flows, information flows and financial flow in the case SCs, were asked. This included lead time, materials' categories, inventory level, how the inventory was managed, suppliers, how suppliers were selected, partnership management, internal and external communication methods, ordering decisions and customer services. Most questions were open questions that helped to map the SC in a broad context and clarified the links between SC parties. Thirdly, a group interview was employed to discuss characteristics such as customer order uncertainty, production quality uncertainty, and transportation uncertainty in the SC and the management issues for the case companies. Finally, based on the collected data, the case companies' SCs were elaborated. The models of the SCs were then confirmed by the corresponding companies' managers to ensure their appropriateness and refined if necessary.

Observation

Observation provides a systematic viewing of people's actions and recording, analysing and interpreting their behaviour (Gray, 2009). Observers can either participate in the event (as participant observers) or simply observe the event or situation without participating in it (non-participant observers). Structured observation means that the observer will not try to observe everything but will observe what has been decided in advance to watch. When using this method, observers try not to influence the environment they observe (Saunders *et al.*, 2003).

In this study, non-participant structured observation was employed to gain quantitative data such as the production processes of the products, the time-phased labour action, the resource constraints and the layout of production facilities and manufacturing workshops. As this project was based on industrial case studies, observation provided a deeper understanding of the backgrounds to the industries, the manufacturers' operations, management strategies and the SC systems.

Archived data

For both case companies, much historical data is held in archives such as the time series of finished goods inventory level, main raw material inventory level and customer orders in the period 2009–2010. The companies' SCM issues were discussed in the group interview. Case company A mainly serves the Chinese domestic marketplace. For case company B, the data related to their international SC process, and daily based international customer orders from 2009 to 2010 were collected from their ERP system.

Validity and reliability

Validity and reliability are top criteria concerning the quality of data collection. Validity refers to the essential truthfulness of a piece of data, and reliability refers to the accuracy of the collected data. In the study, the qualitative data about SC processes/activities and SC member relationships were first collected through group interviews from senior managers and then refined and confirmed by top managers in individual interviews. The participation of multiple senior managers and the combinations of group interviews and individual interviews ensured that the collected qualitative data were trustworthy and reliable. Additionally, the quantitative data related to production operations, resource capacities, inventory levels, lead times and customer orders were collected through non-participant observations and companies' archived data (directly output from the case company's ERP system), which were regarded as actually measuring and reflecting the specific phenomena of the case study SCs.

Simulation

Simulation is "the imitation of the operation of a real-world process or system over time" (Banks *et al.*, 2001, 1). It can refer to using a computer to evaluate a model numerically, and data gathered in order to estimate the desired true characteristics of the model. Computer simulation "is an attempt to model a real-life or hypothetical situation on a computer so that it can be studied to see how the system works. By changing variables in the simulation, predictions may be made about the behavior of the system. It is a tool to virtually investigate the behavior of the system under study" (Banks *et al.* 2001, 1–2). According to Thomas (1998), computer simulation offers a third symbol system and was used to facilitate the generation of predictions from the theory-as-program. He explained that computer simulation, as the third symbol system, offered a substantial advantage over human systems in economics, social science (computational sociology) and engineering.

Simulation has been widely used in many contexts, for example, simulation of technology for performance optimisation, safety engineering, testing, training, education and video games. Simulation is used with the scientific modelling of natural systems or human systems to gain insight into their functioning (Smith, 1999). Simulation can be used to show the eventual real effects of alternative conditions and courses of action. Simulation is also used when the real system cannot be engaged because it may not be accessible, it may be dangerous or unacceptable to engage, it is being designed but not built or it may simply not exist (Sokolowski and Banks, 2009, 6). Simulation also allows time to be compressed or expanded. Banks *et al.* (2001) suggested the following list of use for computer simulation: manufacturing systems; public systems: health care, military, natural resources; transportation systems; construction systems; restaurant and entertainment systems; business process reengineering/management; food processing; and computer system performance.

Simulation software

According to Robinson (2004, 40–43), there are three main types of software, namely: spreadsheets, programming languages and specialist software. He believed that programming languages provided the greatest range of applications and modelling flexibility. Models developed in programming languages could run faster than equivalent models in the other software. Meanwhile, specialist simulation software tended to win in terms of speed of model build and ease of use. Spreadsheets were probably better than programming languages in respect of speed of model build and ease of use (at least for smaller applications), but they were not as quick or straightforward to use as the specialist software. The choice of software depended upon the nature of the study, particularly its level of complexity. For very simple applications, a spreadsheet may suffice and was probably the best option because in most cases the software and skills were already available within an organisation. Most applications, however, were more complex and it soon became necessary to adopt more powerful software. Specialist (general purpose) simulation packages were able to model a very wide range of applications (their capabilities increased over the years) and should suffice unless the model was highly complex. In this case a programming language was probably required.

The principle of simulation

Groumpos and Merkuryev (2002, 158) suggested that a simulation study consisted of:

1. Problem formulation
2. Training project participants
3. Setting objectives and overall project plan
4. Model conceptualisation
5. Data preparing
6. Checking model concept and macro data
7. Model translation
8. Verification
9. Testing model with macro data
10. Validation
11. Strategy planning of simulation experiments
12. Tactical planning of simulation experiments
13. Running and analysis of simulation experiments
14. More experiments
15. New experiments
16. Specifying simulation goal
17. Correct algorithm
18. Model changing

19. Analysis and interpretation of simulation results
20. Presenting simulation results
21. Implementation

When undertaking a simulation study, in step 1 the problem to be solved should be identified. In step 2, everybody should understand their role in the whole team and realise what other people are doing as well. In step 3, objectives of the study should be specified, with the aim of solving the problem, for example, resources availability, methodology used, parameters to be varied and alternatives to be tested, calendar planning, and so on. Step 4 constitutes the specifying operation algorithm of the simulated system and development of its conceptual model (distinguishing the simulated system from its environment, deciding about the level of details, identifying main elements and relations, specifying parameters and variables). In step 5, if the input data differs from what is present in reality, statistical considerations are taken into account, when describing random factors, for example, random variables. In step 6, the conceptual model and descriptions of input data (types of probability distributions, input variables) are discussed. In step 7, the conceptual model in the form of a corresponding software program is implemented. In step 8, whether or not the developed program indeed realises the operational algorithm of the simulated system is checked. In step 9, the sensitivity of simulation results is checked towards changes of parameters of probability distributions of model random input variables. In step 10, validation is the second stage where the developed model is checked for adequate presenting of the modelled system. In step 11, experiments are planned with the simulation model. Step 12 includes realisation of each experiment (based on experiment plans). Step 13 includes running and analysing simulation experiments. In step 14, it is discussed if there will be more experiments. If necessary, additional experiments are performed. In step 15, it is discussed if there will be new experiments. In step 16, it is questioned if during the simulation study some new aspects come to consideration that ask for analysing other aspects of the modelled system behaviour. In such a situation a new strategic plan of simulation experiments could be developed. Step 18 involves analysis and interpretation of simulation results in order to make corresponding decisions (e.g., deciding about the best values of parameters of the modelled system, or choosing the best control algorithm). In step 19, presenting simulation results, and in step 20, implementation of results of the simulation study. Steps 16–18 are part of the feedback process.

The types of simulation

There are many different types of computer simulation. The common feature is generating a sample of representative scenarios for a model in which a complete enumeration of all possible states can be prohibitive or impossible (Sokolowski and Banks, 2009). The computer simulation can be classified according to different criteria: (1) stochastic or deterministic; (2) steady-state or dynamic; (3) continuous or discrete; and (4) objective oriented programming (OOP) or process oriented simulation. Stochastic algorithms and methods were initially developed to analyse chemical reactions involving large numbers of species with complex reaction kinetics (Bradley and Gilmore, 2006, 10). Deterministic simulations contain no random variables and no degree of randomness and consist mostly of equations and are usually designed to capture some underlying mechanism or natural process. Rather than a stochastic model, the deterministic model is viewed as a useful approximation of reality because it is easier to build and interpret. However, such models can be extremely complicated with large numbers of inputs and outputs (Poole and Raftery, 2000). Determining whether to use stochastic or deterministic processes concerns the role of randomness in the model. If a system displays no random behaviour, then it is modelled by a deterministic model, that is, one without probabilistic components. However, if the behaviour of the system is at least partly random (which is the case of many real-world systems), a stochastic model is required (Law and Kelton, 2000).

Steady-state and dynamic simulation can be seen as a process oriented simulation. Steady-state models perform a mass and energy balance of a stationary process in an equilibrium state and ignore any changes. Dynamic simulation is an extension of steady-state process simulation whereby time-dependence can be built into the models by derivative terms (Rhodes, 1996). Thanks to the dynamic simulation, the time-dependent description, prediction and control of real processes in real time has become possible. However, dynamic simulations require increased calculation time and are mathematically more complex than a steady-state simulation. Determining the choice of steady-state or dynamic focusses upon the role of time in the model.

A steady-state simulation model represents the system at a particular point in time, thereby assuming that the influence of time in the behaviour of the system can be neglected. A dynamic simulation model, on the other hand, represents the system as it evolves over time (Law and Kelton, 2000).

Continuous simulation is concerned with modelling a set of equations representing a system, over time. This system may consist of algebraic systems, game theoretic models, statistical models or differential equations set up in such a way as to change continuously to represent the ebb and flow of parameters associated with the system state (McHaney, 2012). A discrete event simulation (DES) manages events in time, which is characterised by the passage of blocks of time during which nothing happens, punctuated by events which change the state of the system (McHaney, 2012). Determining continuous or discrete concerns the way in which changes in the state of the system are addressed by the model. In a discrete-event simulation model, the state variables that describe the state of the system change instantaneously at precise points in time. In a continuous model, on the other hand, state variables change continuously with respect to time. These models usually contain differential equations that define the rate of change of the state variables with time (Law and Kelton, 2000).

OOP is a suitable technique for representation of concepts and so is convenient for description of (computer) simulation models, as the description can be near to that of simulated systems. The description of behaviour of such elements often needs object oriented representation of concepts that are applied in the control process (Kindler and Krivý, 2011, 313).

Additionally, there is process simulation: steady-state flow sheet simulators and dynamic flow sheet simulators. Steady-state flow sheet simulators have been widely used in chemical process engineering since the 1960s. Steady-state simulators describe the process as a set of modules connected by flows of material and energy between them. The modules correspond to mass and energy balances together with physical and thermodynamic data necessary for calculations. The calculations may be performed using one of two basic techniques. The sequential approach computes modules one by one, in a direction that generally follows that of the physical flows in the system (Leiviskä, 1996).

In this study, the case company's SC will be modelled and simulated. The simulation method is a combination of dynamic, process oriented and stochastic model because the SC process is complicated with lots of uncertainties.

The advantages and disadvantages of using simulation

The advantages of using simulation are explained from three perspectives. Firstly, simulation versus experimentation with the real system. Compared with experiments, developing and using a simulation model can reduce the cost and time and be easier to control. Also, the simulation method can assist decision making when the real system does not exist. Secondly, simulation can be used in preference to these other methods in order to improve modelling variability, transparency and restrict assumptions. Thirdly, from the management perspective, simulation can foster creativity, create knowledge and understanding, improve visualisation and communication and help consensus building. However, the disadvantages of simulation include expensive software, it is time consuming, data hungry and requires expertise and may cause overconfidence in the computer's results (Robinson, 2004). The issue of using the simulation method also has shortcomings (Law and Kelton 2000):

1. The development of simulation models is generally quite complex, time consuming and expensive
2. Model building requires specialist training
3. Each run of the model is lengthy and produces only one observed value for each variable, which forces the modeller to run the model several times to obtain confidence intervals (warm-up period) for those values in order to be in the steady state
4. Simulation results can be difficult to interpret because they are usually generated in large amounts and because it can be hard to distinguish whether an observation is the result of system interrelationships or of randomness

There are many issues to consider in generic simulation modelling, for example, stochastic, resolution, time horizon, steady state and warm-up period. These issues are often related to the model accuracy and the simulation running time. For example, modelling stochastic systems requires a large number of experiments or samples. As a result, it consumes much computational time in order to improve the model accuracy. Setting the resolution unit (such as month, week, day) to a smaller unit will not only increase the model accuracy, but also the running time. Longer simulation horizon time would ensure the system reaches steady state (however, the real-world system may not be steady state) and improves the model accuracy. However at the initial stage of a simulation, where there is nothing in the system, a warm-up period is often required to allow the system to approach to a steady state first before collecting the results.

Qualification, verification and validation of models

Qualification refers to the development of the conceptual model. Qualification means that the model needs to be interpreted with a sufficient confidence level. Knowledge incorporated into the model must be re-used without loss or bad interpretation by actors coming from different domains and involved in other decision processes in the enterprise (Chapurlat and Braesch, 2008, 715). Verification checks that the code does what was intended and that the model represents reality. The verification and validation (V&V) definitions used in this report are adopted from the 1998 American Institute of Aeronautics and Astronautics (AIAA) Guide (2): "Verification is the process of determining that a model implementation accurately represents the developer's conceptual description of the model and the solution to the model. Validation is the process of determining the degree to which a model is an accurate representation of the real-world from the perspective of the intended uses of the model". Although V&V are processes that collect evidence of a model's correctness or accuracy for specific scenarios, V&V cannot prove that a model is correct and accurate for all possible conditions and applications. It can provide evidence that a model is sufficiently accurate. Therefore, the V&V process is completed when sufficiency is reached.

The differences between V&V have been explained. Verification is focused on identifying and removing errors in the model by comparing numerical solutions to analytical or highly accurate benchmark solutions. However, validation is concerned with quantifying the accuracy of the model by comparing numerical solutions to experimental data. Verification deals with the mathematics associated with the model, whereas validation deals with the physics associated with the model (Roach, 1998). Mathematical errors can eliminate the impression of correctness (by giving the right answer for the wrong reason); verification should be performed to a sufficient level before the validation activity begins. Schwer (2007) explained that verification was the domain of mathematics and validation was the domain of physics.

In the study of simulation, Hicks and Earl (2001) explained the importance of validation to simulation models. They supported the theory of Schlesinger (1980) and suggested that the components were: (1) analysis generated a conceptual model; (2) model qualification determined the adequacy of the conceptual model; (3) programming the model; (4) model verification confirmed that the computerised model could represent the conceptual model within specified limits of accuracy using carefully chosen test cases; and (5) in the process of validation, tested the input-output transformation of the simulation by statistical analysis.

In this study, the V&V process has been represented by close cooperation among models and experiments until the experimental outcomes are obtained. Mathematically, the boundary condition of decision parameters is set up in accordance with the interview data from the case companies. In addition, although the study involves both numerical and physical parameters that have ranges and uncertainties, these boundaries of the ranges and parameters of the uncertainties have been confirmed from the interviews. There are three methods employed to improve the V&V process, namely:

1. writing the program in modules and sub-programs facilitates program debugging. It is rare that the first attempt at coding works in computer programming even if it is the simplest patches of code. Therefore, it would be difficult to write the whole program and only then try to debug it because the possible sources of error would be extremely diverse;
2. running the model under a variety of settings of input parameters and checking that the model output is reasonable. There are many possible interactions in the state of the modules under different uncertain environments or different decision strategies. The model is thereby tested with "extreme" values, that is, very short period times (clock equals to 1 or 2), setting all uncertain

parameters equal to 1, and using the collected interview data to test the result and compare with the companies' results;

3. tracing the model during its execution means following the state of the simulated system, for example, values of variables, statistical counters and so on, throughout the simulation. Additionally, using the built-in tracking system to identify the bugs in the system.

The use of simulation

Simulation method as an alternative approach has been used in modelling logistics and SC problems in many cases when SC systems are too complicated for analytical methods. Meanwhile, a simulation model is significant to evaluate dynamic decision rules in SC processes (Min and Zhou, 2002) because simulation can quantify benefits and the impact of issues (Terzi and Cavalieri, 2004). In the literature, simulation has been employed in many SCM studies. Towill *et al.* (1992) reviewed the dynamic operation of SCs and reached some simple conclusions for reducing demand amplification, which consequently attenuates swings in both production rates and stock levels. The results were based on one particular SC, for which the use of systems simplification techniques had generated valuable insight into SC design. Swaminathan *et al.* (1998) developed an SC modelling framework which was composed of software components that represented types of SC agents (e.g., retailers, manufacturers, transporters), their constituent control elements (e.g., inventory policy) and their interaction protocols (e.g., message types). The model provided a reusable base of domain-specific primitives that enabled rapid development of customised decision support tools. Min and Zhou (2002) measured the bullwhip effects in dynamic situations by simulation. Fleisc and Tellkamp (2005) examined the relationship between inventory inaccuracy and performance in a retail SC by simulating a three echelon SC with one product in which end-customer demand was exchanged between the echelons.

Simulation in SCM

It has been recognised that the simulation method has been used in modeling logistics and SC problems in many cases, for example, measuring the bullwhip effects in dynamic situations (Min and

Zhou, 2002). Especially, when SC systems are too complicated for analytical methods, simulation is a good alternative. Meanwhile, a simulation model is significant to evaluate dynamic decision rules in SC processes (Min and Zhou, 2002) because simulation can quantify benefits and issues (Terzi and Cavalieri, 2004). In the literature, simulation has been employed in lots of SCM studies. Towill *et al.* (1992) reviewed the dynamic operation of SCs and reached some simple conclusions for reducing demand amplification, which consequently attenuates swings in both production rates and stock levels. The results were based on one particular SC, for which the use of systems simplification techniques had generated valuable insight into SC design. Swaminathan *et al.* (1998) developed a SC modelling framework composed from software components that represented types of SC agents (e.g., retailers, manufacturers, transporters), their constituent control elements (e.g., inventory policy) and their interaction protocols (e.g., message types). The model provided a reusable base of domain-specific primitives that enabled rapid development of customised decision support tools. Fleisc and Tellkamp (2005) examined the relationship between inventory inaccuracy and performance in a retail SC by simulating a three echelon SC with one product in which end-customer demand is exchanged between the echelons. For example, Banerjee *et al.* (2001) showed that partial shipments could be a desirable way for improving eventual customer service at the retail level in a SC system by simulation. Lee *et al.* (2002) presented a SC simulation model that combined discrete-event simulation and continuous simulation. Pierreval *et al.* (2007) undertook a continuous simulation system for the automotive industry SC. Abdulmalek and Rajgopal (2007) analysed the benefits of analysing manufacturing and value streams by simulation. Zhang and Zhang (2007) studied sharing demand information in a SC by simulation. In this study, the SC system was simulated by Matlab.

Optimisation methods

As the optimisation problem in SCs often involves multiple objectives, the rest of this section will briefly review the traditional multi-objective optimisation methods and genetic algorithm optimisation (which can be applied to multi-objective problems easily).

Traditional multi-objective optimisation methods

There are many traditional multi-objective optimisation methods in the literature such as the weighted sum method, weight matrix method, value function method and goal programming and interactive method. Weighted sum optimisation is one of the traditional optimisation methods, which usually seeks Pareto optimal solutions one by one by systematically changing the weights among the objective functions. However, this method often produces poorly distributed solutions along a Pareto front, and it cannot find Pareto optimal solutions in non-convex regions (Kim and de Weck, 2005). They also developed a weighted sum method focusing on unexplored regions by changing the weights adaptively rather than by using *a priori* weight selections and by specifying additional inequality constraints. More recently, Marler and Arora (2010) investigated the fundamental significance of the weights in terms of preferences, the Pareto optimal set and objective-function values, and then they determined the factors that dictated which solution points result from a particular set of weights. They also identified the fundamental deficiencies of using this approach. The weighted matrix method gives more optimisations in the matrix set of weights, but it is a similar idea to the weighted sum method. The value function iteration algorithm (VFI) is used to solve the value function in the neoclassical growth model in economic studies in general (e.g., Aruoba *et al.*, 2006). Ringuest and Gulledge (1983) focused on the integration of a number of objectives or goals into a single objective function to be optimised in decision making and discussed a trade-off between realism and tractability. They developed an efficient experimental design which was used to assess directly a quadratic approximation of the multi-attribute value functions. As a result, comparing with the value function method and goal programming, they both got good results. Zionts and Wallenius (1976) presented a man-machine interactive mathematical programming method (a type of goal programming and interactive method) for solving the multiple criteria problem involving a single decision maker. It is assumed that all decision-relevant criteria or objective functions are concave functions to be maximised and that the constraint set is convex. Although traditional optimisation can efficiently solve some problems, it is hard to find a global optimisation result especially in a complex system.

Genetic algorithm optimisation

Most traditional mathematical optimisation methods are only suitable for local optimisation and therefore will not generally find the global solution (Jenkinson and Smith, 2001). The interest in using GAs to solve production and operations management (POM) problems has grown rapidly recently (Aytug *et al.*, 2003). Genetic algorithm as one of the evolutionary algorithms is different from classic multi-objective algorithms (e.g., weighted sum method, weight matrix method, value function method, goal programming and interactive method). It has been well documented that GA could be better for solving multi-objective problems in a complex world in terms of non-domination set, which finds a set of solutions that could be closer to a Pareto front (Deb, 2009).

Compared with classic algorithms, one of the main differences is that the MOGA can provide a set of non-dominated solutions instead of a rather limited number of solutions (usually only one for classic algorithms). The non-dominated solution is a feasible solution where another feasible solution that is better than the current one does not exist in some objective function without worsening another objective function (Deb, 2009). Therefore, even if a user does not know the weights between different objective functions in advance, the solution results are still significant. The user can choose a feasible solution from the eventually non-dominated solution set that is closer to the Pareto front (Kumar and Rockett, 2002). Secondly, using a GA that could look for a feasible solution is better for non-convex functions and discrete solutions (Mitchell, 1998). However, the disadvantages of using GA when undertaking global optimisation include: (1) sometimes, it requires a long computational time to search for good solutions; (2) the user has to pick up the most adoptable solution from a number of solutions, which may be subjective and require effort. More recently, the development of hardware in computer science has contributed to reducing GA's searching time. Thus, GA could be a useful tool for multiple objective global optimisation (Sivanandam and Deepa, 2007).

In terms of dealing with multi-objective problems, many different types of GA have been proposed, for example, vector-optimised evolution strategy, weight-based GA, niched-Pareto GA, predator-prey evolution strategy, Rudolph's elitist multi-objective evolutionary algorithm and distance-based Pareto AG. However, there is probably no single and consistently best GA program because the solution's location and Pareto-front is often problem dependent (Deb, 2009).

Aytug *et al.* (2003) reviewed the use of genetic algorithms to solve operations problems. Genetic algorithm has eight basic components: genetic representation, initial population, evaluation function, reproduction selection scheme, genetic operators, generational selection scheme, stopping criteria and GA parameter settings. The eight components are explained further (Aytug *et al.*, 2003, 3980–3982):

1. The representation of GA includes binary code GA, decimal code GA and real parameter GA
2. Generally, the initial populations are generated randomly. However, if the problems are with small feasible regions, initialisation can incorporate problem-specific knowledge to increase the likelihood of having feasible individuals and to generate some good solutions in the initial population
3. Each individual population represents a potential solution to a problem. The evaluation function that is a monotonic function of the problem objective function assigns a real number as a measure of fitness to each solution
4. Two popular selection methods are the roulette wheel and the tournament (Aytug *et al.*, 2003; Heppenstall *et al.*, 2011), which gives individuals a chance of selection equal to their fitness relative to the population. In the genetic operators component, for each generation, selected chromosomes are exposed to genetic operations: crossover and mutation. Crossover enables the GA to exploit the current neighbourhood and is expected to move the GA to a local optimum. Crossover exchanges genetic material between two or more parents. There are two types of methods. A one-point crossover exchanges all genes to the left of the cut-point that is usually randomly determined, whereas a two-point crossover exchanges genes between two cut-points. Mutation can make a movement of GA to a different neighbourhood of searching space. It slightly changes an individual and can be achieved by randomly changing gene, swapping the values between two genes or randomly inserting the value of one gene into another location (Aytug *et al.*, 2003, 3980)
5. Replacement strategies specify how the next generation is to be created (commonly using the child replacing the parents).

Nevertheless, there are many variations to this rule. The elitist strategy always carries the best individual to the new generation (Aytug *et al.*, 2003). A tournament strategy is based on a tournament scheme, where the winner of a contest between two or more individuals is used to create the next generation. Another scheme uses each child as a starting point for a local search algorithm and accepts the resulting and improved solutions as new children

6. Setting a fixed number of generations is the most common stop criterion. However, time-independent criterion such as population diversity or entropy which crosses a specified threshold and to stop execution when the average or best population fitness has not increased in the last *t* (period) generations can be used
7. In the selection of GA components, this includes the setting of values for population size, crossover and mutation rates and stopping criteria. Although there does not appear to be a definitive process for choosing these parameters from numerous GA articles, in practice, it is best to use parameters based on pilot runs or ad-hoc selection.

Simulation-based optimisation

Simulation-based optimisation has been widely studied along with the development of technology. There are many studies evidencing the advantages of using simulation-based optimisation. Carson and Maria (1997) reviewed the simulation-based optimisation methods and applications and identified that the objective of simulation-based optimisation was to minimise the resources spent while maximising the information obtained in a simulation experiment. They also believed that a simulation experiment could be defined as a test or a series of tests in which meaningful changes were made to the input variables of a simulation model so that the reasons for changes in the output variable(s) could be observed and identified. The process of finding the best input variable values from among all possibilities without explicitly evaluating each possibility was simulation optimisation. Rubinstein (1997) discussed the optimisation of complex computer simulation models involving rare events (e.g., computer-communication networks, flexible manufacturing systems, project evaluation and review techniques [PERT] and flow networks). Gosavi (2003) discussed parametric optimisation techniques and reinforcement learning and introduced the development of simulation-based optimisation. He believed that analysing random systems using computers, scientists and engineers was the means to optimise systems using simulation models. Recently this method was successfully adopted in practice with optimisation techniques, which gave simulation added dimensions and power that it did not have in the recent past. Bhatnagar (2005) employed simulation optimisation on four adaptive three-timescale stochastic approximation algorithms and provided an example for randomised simulation-based optimisation algorithms.

In this research, due to the complexity of the SC system, the simulation-based optimisation method is employed to deal with decision making issues. The SC system and the GA optimisation programs are described in Chapter 7. In the next chapter, data collection and the background to the case companies are introduced in accordance with the designed research method.

4

The Case Company Supply Chains

In this chapter, the background to the two case companies and the reasons for their choice are explained. The details of data collection from both companies are described, and the case companies' SCs are mapped and compared. Finally, the SCM issues in the case companies are identified.

Case company background

Fourteen SMEs in China were contacted. The research involved the collection of primary data and required a considerable effort from the case companies, whilst companies were often very sensitive to data confidentiality and had limited human resources and relevant technologies to support data collection. Consequently, the choice was limited. However, two agreed to give their full support to the data collection. These companies are reasonably representative because their SCs include multiple functions and parties (e.g., many suppliers, manufacturing, private warehouse, transport companies, and many customers) in different markets. More importantly, the SC structure in the two case companies is similar in terms of information and material flows and their associated characteristics, for example, multiple uncertainties, although the scale of some uncertainties may be different. Additionally, these two manufacturers are located in the north and south of China, respectively, which represent alternative local economic and societal influences. The two companies are in different industries, and therefore, the investigation of their differences and similarities can contribute to the process of model generalisation.

Case company A

Company A was founded in 2000, and its headquarters are located in Shandong province in Northern China. In 2009, the company had about 900 employees. The turnover was just over £10 million. The fixed assets of the company were valued at £1 billion. The company specialised in manufacturing aluminium pigments, mainly focusing on four types of finished goods, for example, aluminium pig A199.90, A199.85, A199.70A and A199.70. Each of these required four main raw materials, which were procured from different suppliers. The company sold the products across the whole of mainland China. The associated SCs were termed domestic SCs.

Case company B

Case company B was founded in 2003, and its headquarters are located in Jiangxi province in Southern China. It was a Sino-foreign joint venture specialising in the manufacturing of fine chemicals, pharmaceutical intermediate, pesticide intermediate and dye intermediate. It had about 150 employees with annual sales of £10 million. The SC chosen as a case study was one of the company's production SCs (requiring three main raw materials), the finished goods supply for many other chemical companies. Case company B's SC was more complicated because of the special requirements of the raw materials' storage and transportation. This case company also had an international SC, which interacted with its domestic SC.

Selection reasons

There are three main reasons for selecting the two case companies. The first is their background. The two case companies are Chinese SME manufacturers, which fit the requirements of the research objective to study the SME manufacturing SC in China. Both case companies produce multiple types of finished goods and require multiple types of raw material. One type of finished goods SC has been selected from each company. Within their SCs there are a number of suppliers, transportation companies, banks and warehouses involved. Case company A is more focused on the domestic market, however, case company B focuses on both the domestic and international market. Therefore, the interests of the two case companies are different and their management strategies are different. Studying both companies helps to understand the differences and similarities that contribute to model generalisation. Secondly, the two case companies are in different industries and locations. Case company A is in the aluminium industry which is labour intensive and located in the north of China; case company B is in the chemical industry which is high-technology and located in the south of China. Thus, the two case companies are regulated by different governmental policy regimes (local and national) and provide an interesting comparison. Thirdly, the two case companies were supportive for data collection.

Data collection

For both companies, there are three parts to data collection. Part one: general information of the case companies (e.g., background, organisational structure of the company); part two: production process, SC members, SCM issues; part three: detailed questions related to management strategies (e.g., ordering and productions strategies) and raw material, finished goods inventory data, costs in detail and customer services. Due to the data confidentiality requirement, costing data is excluded. In order to improve the quality of the data, group, individual interview and non-participant observation method have been employed during data collection. The quantitative data are collected from the case companies' ERP system (Kingdee K/3). Afterwards, the companies confirmed the information given regarding their SC.

The data was collected through its SCM application. The cost data was collected by the cost application. The case companies' issues and SCs were investigated by interviews and manufacturing management application.

The interviews involved 63 questions, which were based on an understanding of the general information of the case company and the SC process mapping requirements, for example, the information flows, material flows, financial flows, the SC members, coordinated management, SCP and SC uncertainty. Meanwhile, in order to collect the cost related information, the companies were asked to complete Table 4.1.

Summary for case company A

For case company A, 85% of total sales are regular orders from a long-term relationship customer. About 15% of total sales are from new customers. The case company's maximum production capacity is

Table 4.1 Cost information

Item	**Inventory cost**	**Long-term supplier's cost**	**Short-term supplier's cost**
Raw material 1			
Raw material 2			
Raw material 3			
Other raw materials			
Finished goods			
Water/electricity/gas/salary			
Package and checking quality			
Administration and depreciation fee			
Transportation for raw material/unit			
Transportation for domestic market finished goods/unit			
Transportation for international market finished goods/unit			
Tax			
Total cost			
Selling price			

Source: Authors.

370–375 tons/month. It normally keeps at least 1,000 tons as finished goods safety stock for satisfying new and emerging orders, but the inventory level fluctuates normally around 4,000–5,000 tons, with a maximum up to 8,000 tons. If there is a new customer order, the company fulfils the order by using finished goods on-hand inventory (if the order is less than 1,000 tons). Then the company adjusts the production plan and produces more up to the maximum capacity to fulfil long-term customer orders, and then the rest of finished goods are stored as on-hand inventory. If the finished goods inventory exceeds 8000 tons, the company will pause production.

For each main raw material, there are at least two cooperating suppliers. If any raw material is in backorder, the supplier arranges delivery within 3 to 20 days, which depends on the type of raw material. Inventories of raw material 1 are held for 4 weeks (at least 20,000 tons); inventories of raw material 2 are held for 3 weeks (4,000 tons); and inventories of raw material 3 are held for less than a week (around 30 tons) because of the consumption rates and warehouse capacity. According to the interviews, the biggest issue within the case company is inventory management with demand uncertainty, which has had a big influence on order cycle time. The delivery cycle time is around two weeks to the long-term customer. The quantity depends on the customer requirement and truck capacity (normally 35 tons/truck).

Summary for case company B

For case company B, 80% of total sales are a regular order from long-term relationship customers. Of total finished goods, 20% were sold to new customers. The case company's maximum production capacity is 175 tons/month. It normally keeps 200 tons as finished goods inventory for satisfying new and emerging orders. If there is a new customer order, the company fulfils the order by using on-hand inventory (from 200 tons if the order is <=200). Then the company adjusts the production plan and produces more until maximum productivity to fulfil long-term customer orders, and the rest of the finished goods will be placed in the on-hand inventory. If the finished goods inventory is more than 200 tons, the case company pauses production.

For each main raw material, there are at least two cooperative suppliers, and if any raw material is in back order, the suppliers arrange delivery within three–five days. Raw material 1 is only held for two weeks' consumption, raw material 2 for one week and raw material 3 for two weeks because of their characteristics and warehouse capacity.

According to the interviews, the biggest issue within case company B is manufacturing planning and inventory management for domestic and international markets with various uncertainties.

The delivery cycle time is around two weeks to the long-term customer; the quantity depends on the customer requirement and truck capacity because of the finished goods characteristics that require special trucks, normally 35 tons. The company would not arrange delivery if the quantity was below 30 tons.

Case company SC process mapping

The use of SC process mapping has been reviewed in Chapter 2. SC process mapping can be defined thus: "The procedure [whereby] the process mapping technique is applied to supply chain systems in order to make complex systems visible and facilitate identifying the supply chain problems such as poor coordination of effort, incompatible information systems and longer cycle time" (Fawcett *et al.*, 2007). In this study, step-by-step and value stream mapping are used for mapping the case SC. Through interviews and the step-by-step approach, the processes (information and material flows) are followed by answering the three questions: (1) How do the case companies make raw material orders? (2) How do the case companies manufacture finished goods (from taking raw materials to save the finished goods to inventory or satisfying customer order)? And (3) how do the case companies satisfy customer orders?

Mapping case company A

Figure 4.1 shows the information flows and material flows among suppliers, manufacturers, warehouses and customers in the SC. The information flows mainly include six processes associated with order processing among customers, manufacturers and suppliers and also the production planning activities (as shown by dotted lines in Figure 4.1):

1. customer places order to manufacturer;
2. manufacturer checks raw materials inventory.

If raw materials are available:

1. Manufacturer performs production planning
2. Manufacturer confirms order to customer

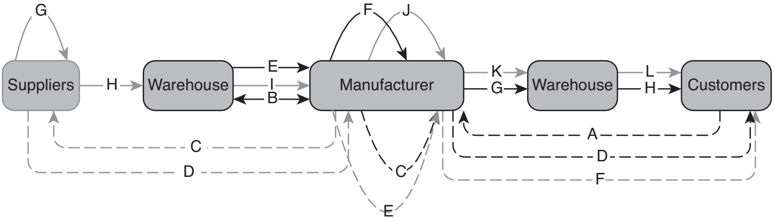


Figure 4.1 Supply chain map in case company A SC

Material flow when raw materials are not available.

Information flow when raw materials are not available.

Material flow when raw materials are available. Information flow when raw materials are available.

If raw materials are not available:

1. Manufacturer places order to supplier
2. Supplier confirms order to manufacturer
3. Manufacturer performs production planning
4. Manufacturer confirms order to customer
5. Supplier produces raw materials
6. Transports raw materials from supplier to manufacturer's raw materials warehouse

Finished goods production:

1. Store and transport raw materials from warehouse to production units
2. Manufacturer produces finished goods
3. Manufacturer operates production planning
4. Manufacturer confirms order to customer

Mapping case company B

Domestic SC

Case company B has two markets; the DSC is identified as how case company B satisfies domestic market orders.

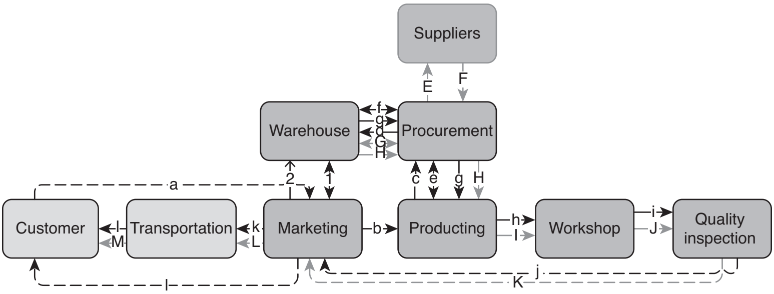


Figure 4.2 Domestic supply chain map in case company B SCs

Material flow when raw materials are not available.

Information flow when raw materials are not available.

Material flow when raw materials are available.

Information flow when raw materials are available.

1. Customer makes order to marketing department
2. Marketing department sends order information to production department
3. Production department calculates raw materials quantity and sends order to procurement department
4. Procurement department checks raw materials with warehouse

If raw materials are enough:

1. Procurement department discusses production plan with production department
2. Procurement department prepares the raw materials with warehouse
3. Procurement department delivers raw materials from warehouse to production department

If any main raw materials are not available:

1. Procurement department contacts supplier to order raw materials
1. Supplier delivers raw materials
2. Procurement department prepares the raw materials with warehouse
3. Procurement department delivers raw materials from warehouse to production department

Producing finished goods:

1. Production department adjusts production plan and arranges raw materials in workshop
2. Workshop produces
3. Quality inspection and contact with marketing department

Finished goods satisfying customer order:

1. Marketing department contacts transportation company and customer to arrange finished goods delivery
2. Transportation company delivers finished goods to customer depending on the location and different transportation companies

Update finished goods inventory level:

1. Marketing department checks finished goods inventory
2. Delivery of finished goods to warehouse, if exceeding current customer demand

International supply chain

The ISC explains how case company B satisfies international market orders. There are a total of 18 tiers in the ISC including supplier, manufacturer, raw materials warehouse, raw materials transportation company, finished goods warehouse, finished goods transportation company, domestic customer, domestic bank, international bank, international customer, package supplier, CIQ (China Entry-Exit Inspection and Quarantine), insurance company, finished goods internal transportation agent, internal port, shipping company, customs and customer port. The SC processes are shown in Figure 4.3.

In terms of the finished goods production, transportation and satisfying customer demand (international market):

1. International customer places the order to manufacturer
2. Manufacturer receives the order with internal checking

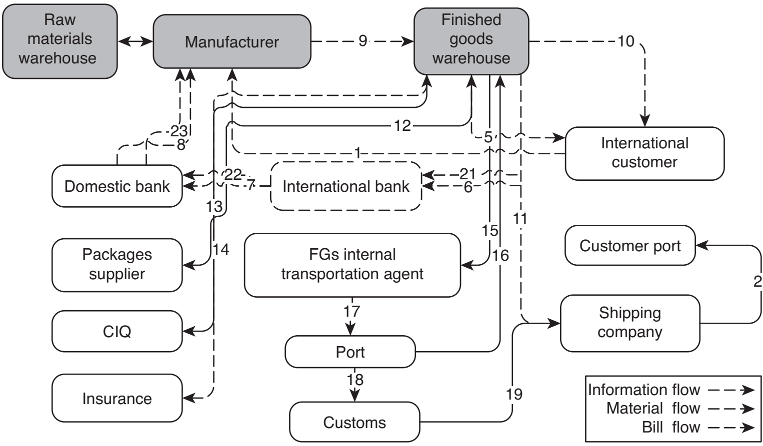


Figure 4.3 International supply chain map in case company B

3. Manufacturer shares the customer order information with finished goods warehouse
4. Finished goods warehouse reports inventory information to manufacturer
5. Finished goods warehouse contacts international customer to share finished goods quality, quantity information
6. International customer issues deposit payment (credit) (30–70%) with the customer's bank. The company accepts credit letter (L/T) and telegraphic transfer (T/T)
7. The company's bank asks the credit and currency (usually in USD or RMB) from the customer's bank (international bank)
8. The company's bank informs the deposit payment to manufacturer
9. Manufacturer informs finished goods warehouse to prepare the order for delivery
10. Finished goods warehouse informs international customer of expected delivery information
11. Finished goods warehouse contacts shipping company to book container lots
12. Finished goods warehouse contacts packages supply company to package finished goods in the light of shipping requirements
13. CIQ checks finished goods and issues export certification
14. Finished goods warehouse arranges insurance of the finished goods
15. Finished goods warehouse contacts finished goods transportation company to arrange delivery
16. Finished goods internal transportation agent picks up finished goods from finished goods warehouse
17. Finished goods internal transportation agent ships finished goods to port of origin
18. Finished goods passes through China Customs
19. Finished goods are loaded onto ship
20. Shipping company ships finished goods to international customer's port
21. International customer makes final payment (L/T, T/T)
22. The company's bank asks for credit and currency from the customer's bank
23. The company's bank informs of payment to the manufacturer

Comparing case company SCs

There are many similarities and differences in both case companies' SCs. Both SCs' members from a domestic aspect are functionally similar. This includes, for example, suppliers, raw material transportation company, manufacturer, finished goods transportation company, warehouses and customers (the flows from raw material procurement until the finished goods satisfy the customer order). Thus the types of uncertainties within the information and material flows that link the aforementioned members are similar. For example, they both face customer order uncertainty issues. The reason for inventory related uncertainties are represented by (1) shortages of raw materials for production; and (2) shortages of finished goods inventory for satisfying customer demand.

However, the main difference between the case SCs is in the degree of these uncertainties; they are different because of the background, operation, relationship with supplier and customers and strategy differences. For example, for case company A there are only domestic orders, but case company B has both domestic and international customers. Thus, the uncertainty of customer order information quantity is different, whereby case company A's customer order uncertainty is smaller than case company B's because of communication difficulties for international customers (e.g., culture, language, etc.). The finished goods delivery uncertainties for case company A are smaller than for case company B as international shipping is more complicated. So modelling the SC has to consider the similarity of uncertainties and flows in general and differences of uncertainty in degree.

Supply chain management issues for case companies

Two main SC issues were identified through the discussions with the case companies. The first is raw material ordering with regard to finished goods production planning in the presence of multiple types of uncertainties. For both companies, there are lots of uncertainties in their SC, for example, raw material delivery lead time is subject to not only the inventory availability at the suppliers, but also the traffic conditions on the way from the suppliers to the raw material warehouse.

The second issue was identified from case company B. Because of the limited production capacity, the company has to design an appropriate plan to serve both domestic and international markets. On the one hand, the company has to consider the constraints imposed by government policy (e.g., the minimum percentage of exporting to a foreign market) and the company's long-term strategy (e.g., maintaining international customer relationships). On the other hand, the company has to consider short-term or medium-term profitability because in the current economic situation the profit from the international market is significantly lower than that from sales in the domestic market.

These two issues are considered in the following chapters. First of all, a generalised SC model from the discussed case studies will be developed in the next chapter. Then in later chapters, a set of SCM strategies, based on information sharing and coordinated management mechanisms with the aim to improve and optimise the SCP, will be presented and evaluated.

5

A Generalised Domestic and International Supply Chain Model

In this chapter, based upon two case studies, a generalised model will be developed including both the DSC and ISC, and then the multiple uncertainties will be categorised and explained. Finally the SCP will be presented in the DSC and ISC.

Model description and assumption

The supply chain management model is generalised from two case studies representing Chinese medium-sized manufacturers. It includes two interacting SCs, a DSC and an ISC, to serve domestic and international markets, respectively. Thus, the context of the generalised model can be described as follows:

1. The model includes 17 channel members, including supplier, customer, banks, transportation company and port. Although the SCs are different in different companies, the 17 channel members selected for the generalised model cover the main functional activities and keep the model simple.
2. The model focuses on a manufacturer oriented (non-grocery) SC, and thus the issues, uncertainties and SCP improvement strategies do not accommodate a retailer oriented SC.
3. The model is based on Chinese SMEs. There are some similarities between Chinese SMEs and Western SMEs; however the size and operational activities may be different.
4. The model is categorised and consolidated into four sub-models in order to improve the V & V of the SC simulation program.

We make the following assumptions in our supply chain management model:

1. The definition of a period is a day.
2. Regarding the interviews, the time uncertainty variables follow uniform distributions U(0, 7) and U(0, 3).
3. Regarding the interviews, the quantity uncertainty variables follow uniform distributions U(0, 0.3) and U(0, 0.1).
4. The customer demand data is generated from periodic customer orders using a polynomial regression function based on the case company historical data with a random variable added that follows the uniform distribution to represent the uncertainty.
5. The reworking of finished goods requires extra raw materials.
6. The safety-stock level is set to between 20% and 30%.

The model and the data

There are two types of data: (1) the open questions (listed in the questionnaire and case companies' SC mapping in Chapter 4) contribute to the model processes mapping in Figure 5.1; (2) the archived data from the ERP system contribute to assessing the value of the related variables considered in Chapter 6, for example, static input variables, expected customer order and cost coefficient, and so on. In addition, the decision variables under the companies' original strategy use the archived data. Moreover, the range and distribution of uncertainties (time and quantity uncertainties) are based on data from the interviews.

In the SC simulation program, the archived data, including, for example, raw material procurement and finished goods production, are put in using a matrix in order to compare with the performance of designed improvement strategies. The customer order data has been generalised by polynomial regression. The decision parameters are used as vectors. In the SOGA and MOGA programs, the population are metric data and each decision is represented by vectors.

Model processes

The developed manufacturing SC model is shown in Figure 5.1, which includes the following three processes:

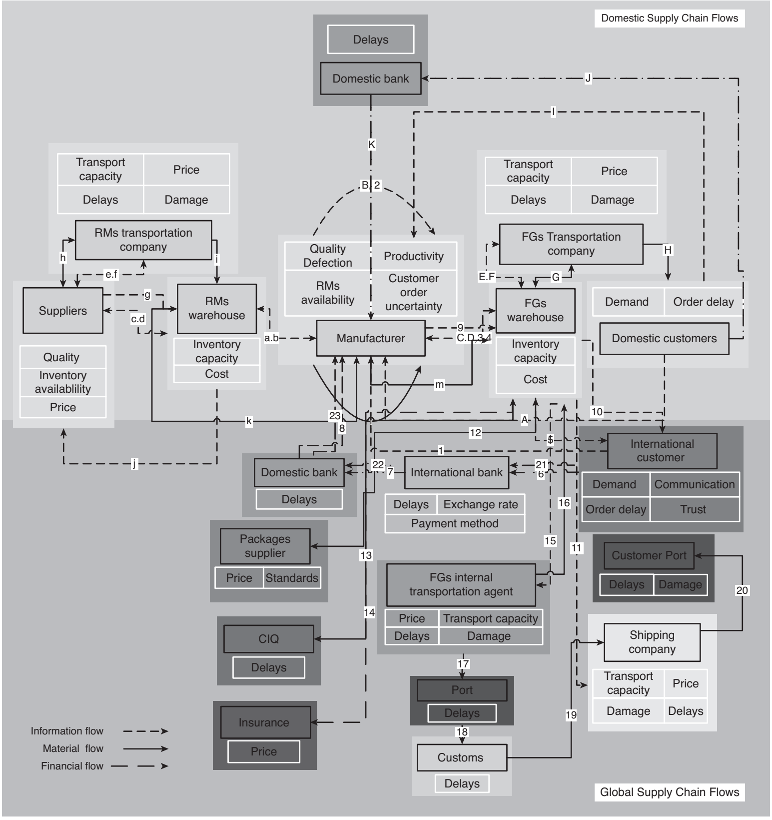


Figure 5.1 A generalised domestic and international supply chain model with information, material and financial flows

1. Raw material procurement and raw material shipping to raw material warehouse process
2. Finished goods production, satisfying customer demand and finished goods shipping to domestic customer
3. Finished goods production, satisfying customer demand and finished goods shipping to international customer

In terms of raw material procurement and transportation, the associated activities sequenced by their order of occurrence include:

1. Manufacturer shares the production plan with the raw material warehouse
2. Raw material warehouse reports the raw material on-hand inventory information to manufacturer
3. Raw material warehouse places order to supplier
4. Supplier gives feedback incorporating inventory availability to raw material warehouse
5. Supplier contacts raw material transportation company to arrange the delivery
6. Transportation company confirms the delivery requirements with supplier
7. Supplier provides delivery information to raw material warehouse
8. Raw material transportation company picks up raw material from supplier
9. Raw material transportation company ships raw material to raw material warehouse
10. Raw material warehouse gives feedback to supplier and makes the payment
11. Raw material warehouse updates inventory and delivers raw material to manufacturer's workshop
12. Manufacturer produces finished goods
13. Manufacturer delivers finished goods to finished goods warehouse

In terms of the finished goods production, transportation and satisfying customer demand (domestic market), the associated activities according to their sequence of occurrence include:

1. Domestic customer places the order to manufacturer
2. Manufacturer receives the order with internal checking
3. Manufacturer shares the customer order information with finished goods warehouse
4. Finished goods warehouse reports inventory information to manufacturer
5. Finished goods warehouse contacts finished goods transportation company to arrange delivery
6. Transportation company confirms the delivery requirements with finished goods warehouse

7. Transportation company picks up finished goods from finished goods warehouse
8. Transportation company ships finished goods to customer
9. Customer makes payment to manufacturer
10. Customer gives feedback to manufacturer's bank
11. Manufacturer receives the payment

In terms of the finished goods production, transportation and satisfying customer demand (international market), the associated activities according to their sequence of occurrence include:

1. International customer places the order to manufacturer
2. Manufacturer receives the order with internal checking
3. Manufacturer shares the customer order information with finished goods warehouse
4. Finished goods warehouse reports inventory information to manufacturer
5. Finished goods warehouse contacts international customer to share finished goods' quality and quantity information
6. International customer issues deposit payment (credit) (30–70%) with the customer's bank. The company accepts credit letter (L/T) and telegraphic transfer (T/T)
7. The company's bank requests the credit and currency (usually in USD or RMB) from the customer's bank (international bank)
8. The company's bank confirms the deposit payment to manufacturer
9. Manufacturer informs finished goods warehouse to prepare the order for delivery
10. Finished goods warehouse informs international customer of expected delivery information
11. Finished goods warehouse contacts shipping company to book container lots
12. Finished goods warehouse contacts packages supply company to package finished goods keeping in mind the shipping requirements
13. China Entry-Exit Inspection and Quarantine (CIQ) checks finished goods and issues export certification
14. Finished goods warehouse arranges insurance of the finished goods

15. Finished goods warehouse contacts finished goods transportation company to arrange delivery
16. Finished goods Internal Transportation Agent picks up finished goods from finished goods warehouse
17. Finished goods Internal Transportation Agent ships finished goods to port of origin
18. Finished goods pass through Chinese customs
19. Finished goods are loaded onto ship
20. Shipping company ships finished goods to international customer's port
21. International customer makes final payment (L/T, T/T)
22. The company's bank requests the credit and currency from the customer's bank
23. The company's bank confirms the payment to the manufacturer

Figure 5.1 shows a generalised domestic and international supply chain model with information, material and financial flows. In this figure, each box with a black border represents supply chain members, and the uncertainty reasons (taken from interview data) are represented by the boxes with white borders. There are three types of flows: information (line with square dot), material (solid line) and financial (long dash line) in the model. All information flow related uncertainties are represented by time uncertainties. All material flow related uncertainties are represented by quantity uncertainties. The financial flow related uncertainties are considered in the first objective function (cost). The activities in the early description can be categorised and consolidated into four sub-models that are represented in the SC simulation program.

The flows contribute to the structure of the SC simulation program. In the program, the SC follows the flows shown in the model process. Meanwhile, the relationships among the members in Figure 5.1 influence the types and value of uncertainties in the SC simulation program. For example, in the (Sub-model I) domestic SC the manufacturer and the domestic customer relationship is influenced. In this study, the influences cause uncertainties – for example, customer and company's contract period, customer order information lead time, customer order information delay lead time and order accuracy. In the international SC, the international customer has similar influences. However, the uncertainties between the manufacturer and the international customer are bigger than with the domestic customers because of business culture differences and communication issues. Additionally, the relationship between the supplier's raw material warehouse and the manufacturer makes for uncertainties on production lead time, remanufacturing lead time and defective production rate (Sub-model II). The relationship among supplier, raw material transportation company and raw material warehouse influences the uncertainties in Table 5.1 (Sub-model III). In the domestic SC, the relationships among the manufacturer, finished goods warehouse, finished goods transportation company and domestic customer make for uncertainties in Table 5.1 (Sub-model IV [DSC]). The international SC is more complicated and the uncertainties shown in Table 5.1 Sub-model IV (ISC) are made by the relationships among the manufacturer, finished goods warehouse, finished goods internal transportation agent, package supplier, CIQ, insurance company, manufacture-side seaport, customs, shipping company and customer-side seaport.

These activities can be categorised and consolidated into four sub-models that are represented in the SC simulation program in accordance with their rank, namely:

Sub-model I: The customer order model includes the customer placing order activities within both the DSC and ISC, which link the domestic customer in the DSC with manufacturer and the international customer with manufacturer in the ISC. In the sub-model, the processes A, B and C show the domestic customer order and the processes 1, 2 and 3 show the international customer order. In this sub-model, the domestic and international customer orders are produced.

Sub-model II: The manufacturing (production) model represents how the manufacturer manages raw material flow from the raw material warehouses, produces the finished goods and satisfies the orders from the finished goods warehouses. It is represented by the processes a, k, l and m. In this sub-model, the manufacturer's production plan is to be made.

Sub-model III: The raw material procurement with transportation model represents how the raw material warehouses make the raw material procurement decision with the consideration of the manufacturer's production plan, which includes the processes b–j. In this sub-model, the raw material procurement plan is to be determined.

Table 5.1 Classifications of uncertainties in the four sub-models

			Uncertain types		
			Time uncertainty		
Model	**SC**	**Types of flow**	**Lead time**	**Delay**	**Quantity**
Sub-model I	DSC	Demand	Customer contracted delivery date		Customer demand
		Information flow	Customer order information lead time	Information delay lead time of inaccurate order	Inaccurate order quantity
	ISC	Demand	Customer contracted delivery date		Customer demand forecasting Customer demand
		Information flow	Customer order information lead time	Information delay lead time of inaccurate order	Inaccurate order quantity
Sub-model II	DSC and ISC	Material flow	Production lead time	Remanufacturing lead time	Defective production
Sub-model III	DSC and ISC	Information flow	Raw material order information lead time/ booking transportation lead time	Raw material order information delay lead time/transportation arrangement delay lead time	
		Material flow	Raw material availability/raw material transportation lead time	Raw material delay transportation lead time	A fraction of raw material transportation delay
Sub-model IV	DSC	Information flow	Arranging FG transportation lead time	Finished goods Transportation arrangement delay lead time	
		Material flow	Finished goods domestic market sales availability/ finished goods transportation lead time	Finished goods delay transportation lead time	A fraction of finished goods transportation delay
	ISC	Information flow	Arranging internal finished goods transportation lead time/arranging external finished goods transportation lead time	Finished goods internal transportation arrangement delay lead time/finished goods external transportation arrangement delay lead time	
		Material flow	Finished goods International market sales availability/finished goods internal transportation lead time/finished goods international shipping availability/finished goods external transportation lead time	Finished goods internal transportation delay lead time/finished goods external transportation delay lead time	A fraction of finished goods internal transportation delay/a fraction of finished goods external transportation delay

Source: Authors.

Sub-model IV: The finished goods satisfying customer order with transportation model represents how the finished goods warehouse satisfies customer orders with the cooperation of transportation. In the DSC, it is simply that there are processes D–I. However, the ISC is more complicated and includes processes 4–23. In this sub-model, the domestic and international customer orders are satisfied, respectively; therefore the objective functions (cost and customer services level) can be calculated. Based on the aforementioned processes-based sub-models, the SC simulation program has been developed consisting of the four sub-models. There are two types of uncertainty data – the time and quantity data. The time uncertainties are represented by varying the required number of periods in the program. The quantity uncertainties are represented by the related parameters varying within certain percentages. The detail will be explained in later sections and in Chapter 6. The domestic and international customer order information is produced in Sub-model I, and afterwards, the manufacturer production decision (the planned production quantity for finished goods) will be made in Sub-model II. However, there are different strategies to be adopted depending on what information the manufacturer employs because the raw material and finished goods inventory and received customer order information are available in the SC simulation system. In practice, the use that the case companies make of different information-making production plans could influence the SCP significantly. Thus, in the experimental design, many types of strategies are employed, which are based on utilisation of different pieces of information. At the end of this sub-model, the finished goods state variables will be updated. Then, the raw material procurement decision is made in Sub-model III (the planned order quantity for raw material). At the end of Sub-model III, the raw material state variable will be updated. Finally, Sub-model IV determines how the customer orders are satisfied, which is based on the decisions of international sale strategies and the finished goods inventory level.

The main decisions in the SC are placing raw material orders with suppliers and determining the production quantity for the manufacturer in order to meet customer demands efficiently and effectively. However, there are many uncertainties and constraints in the aforementioned processes in the light of the interviews, which makes decision making complicated and difficult. Those uncertainties and constraints will be discussed in later sections.

Although the model in Figure 5.1 is generalised, it is based on the operations of two Chinese manufacturers, and its specifics to China can be explained from the following four aspects. Firstly, the relationship between the company and the international customer is harder to manage and it is easier to cause delays (in process 1, 2, 3 and 5). This may be due to different cultures, technological systems, decision-making processes and even different time zones. Secondly, in process 13, there is CIQ. The export company has to make an appointment with CIQ in advance. The CIQ checks the finished goods and then issues certification that allows the company to export the finished goods. Usually, it takes at least a week to issue export certification. Thirdly, in process 18, the Chinese customs checks the finished goods randomly. In some ports, such as Guanzhou in China, the customs do not go to the port warehouse to check goods; instead, the goods are transported from the port warehouse to a special place where they await checking. Therefore, it increases the waiting time and unreliability. Finally, process 14 is different in China because the major Chinese insurance companies are state-owned companies that are not very internationalised. Their operation processes are different from EU insurance companies. This is because, at present, the Chinese government does not allow foreign companies to undertake this business.

In the remainder of this chapter, the key characteristics of the SCs in the model will be discussed from three aspects: uncertainties, constraints and cost elements, in association with the relevant flows and activities.

Uncertainties in the model

In this section, based on the information from the interviews, the uncertainties in each sub-model in relation to the special context for China are discussed and then classified into different categories.

Uncertainty in Sub-model I

According to the interviews, there are many common types of uncertainties that exist in both cases in Sub-model I, such as customer contracted delivery date, customer demand, customer order information lead time, inaccurate order quantity and information delay lead time of inaccurate orders in both DSC and ISC. However, the degrees of these uncertainties are quite different. For example, for case company B, the upper bound of customer order information lead time in DSC is around 7 days; whereas in the ISC, it is up to 30 days, which may be due to the nature of international business, including communication issues, business culture, different standards, international contracting and negotiation. Compared with the DSC, the ISC in Sub-model I is more complicated. According to the data from the interviews, the differences in business culture, time zone, language and production quality standards are regarded as the key causes. Case company B pointed out that customer demand forecasting uncertainty in ISC, together with the coupled relationship between domestic market and international market, and the limited production capacity, greatly influences the SCP.

Uncertainty in Sub-model II

The uncertainties associated with material flows in the SC are the focus in Sub-model II. The boundaries (lower and upper) of production lead times in China are influenced by labour working time. Both case companies operate 24 hours per day and up to 340 days per year. Moreover, both companies' information systems use different versions of ERP systems, and this causes integration issues that may not be compatible with the company's existing production control system, nor with SC partners' information system. Both companies employ Kingdee's k/3 as their ERP system, as Kingdee (2012) has occupied the biggest market share in China during the past six years for domestic ERP technology. Kingdee provides cheaper packages with similar functions to other ERP packages (e.g., provided by SAP). However, for case company B especially, integrating their manufacturing control system with their ERP system is a major issue. It leads to production uncertainty. Additionally, the labour quality is generally lower in China than in the Western, developed countries, which influences the defective production uncertainty. Therefore, the degree of uncertainty in terms of defective production rate could be significantly higher. The defective goods will be remanufactured, where the remanufacturing lead time is subject to production plan, production capacity and relevant raw material availability. Remanufacturing lead time uncertainty depends on the production plan and relevant constraints. These types of uncertainties may occur in both companies. There is also a small probability that a part of the finished goods external transportation processes may be delayed because of the unavailability of finished goods and communication problems with the transportation company.

Uncertainty in Sub-model III

The raw material order information lead time depends on the characteristics of the raw material, the supplier relationship and the SC integration level. For both case companies, the main raw material order is placed by a traditional method such as email or telephone with closely related suppliers. Integrated systems are rarely implemented in Chinese SMEs. According to the interviews, there are three main reasons for this, namely, cost, employee quality and business culture. The typical Chinese business culture, characterised by industry-oriented professional communities' organisations, helps companies build up informal relationships. Thus, even without the implementation of an integrated information system, both case companies' raw material procurement managers would not face big challenges to place orders to their suppliers. The delays are mainly caused by road traffic jams rather than by raw material inventory unavailability. For case company B, due to the special requirements of raw material transportation (chemicals), the uncertainties of lead time and delay lead time are higher than in company A.

Uncertainty in Sub-model IV

The uncertainties of the DSC in this model related to transportation are similar to Sub-model III. The finished goods availability depends on the finished goods inventory, production plan, and international sales plan. The uncertainties of ISC in this sub-model are complicated. Here the transportation processes are divided into two parts, internal transportation and external transportation. Internal transportation includes information flows and material flows relating to internal delivery (from finished goods warehouse to manufacturer's seaport), and external transportation includes information flows and material flows relating to international shipping (from manufacturer's origin seaport to international customer's destination seaport). According to the data from the interviews, internal transportation in the ISC (which includes arranging internal finished goods transportation lead time; finished goods availability for satisfying international orders; finished goods internal transportation lead time; delays on a fraction of finished goods internal transportation; finished goods internal transportation delay lead time) is subject to more uncertainties than internal transportation in the DSC. This is due to the fact that government policy (e.g., export certification issue, customs), packaging standards and communication issues with international customers often demand extra efforts for internal transportation in the ISC. The uncertainties of finished goods external transportation lead time in the ISC depend on the shipping destination and other factors. For example, it would normally take 40 days (subject to the unpredictable events on the shipping route) from China to Brazil. Finished goods external transportation delay lead time depends on shipping lines' operations (e.g., schedule, frequency) and port operations (e.g., traffic, handling).

Based on this discussion, we may classify these uncertainties into three categories according to their sources: (1) information flow uncertainty; (2) material flow uncertainty; and (3) customer demand uncertainty. On the other hand, according to the nature of uncertainty and the convenience of mathematical modelling, they can also be classified into three types: lead time, quantity and delay. Table 5.1 summarises the classifications of those uncertainties within four sub-models.

Explanation of time uncertainty (lead time and delay) and quantity uncertainty in the model

The values of the uncertainties follow uniform distributions and were suggested by the interviews. The time uncertainties in Table 5.1 include lead time uncertainty and delay uncertainty which are related to the period variable t, in other words, the values of this type of uncertainty have to be an integer number. The time uncertainties variables are listed in Chapter 6. The lead time uncertainty represents the stochastic lead time in the flows between two channel members. The delay uncertainty indicates the lead time for those delayed goods or orders to be re-processed. Quantity uncertainty represents the incompleteness of materials, products and orders. For example, part of raw materials, finished goods and order information may be delayed due to unpredictable factors. The value of this type of uncertainty has to be a percentage. The quantity uncertainty variables are also listed in Chapter 6.

There are three main reasons to select these two types of uncertainties. Firstly, according to the investigation, these two types of uncertainties exist in most flows (information, material and financial flows) in both a DSC and an ISC. Secondly, some common uncertainties are considered. For example, machine breakdown is a common type of uncertainty, and it is represented by longer and more unreliable manufacturing lead times. Thirdly, our classification offers a great flexibility of the model by parameterising those uncertainties. That means the model can be used to model a wider spectrum of scenarios with uncertainties by appropriately setting up the input parameters.

To illustrate the relationship between the two types of uncertainties (time and quantity uncertainties), the raw material transportation from suppliers to the raw material warehouse in Sub-model III has been taken as an example (Figure 5.2). The manufacturer makes a raw material procurement plan (decision parameters of raw material procurement $u_i(t)$) regarding the type and amount of raw material to be ordered from suppliers. There is a

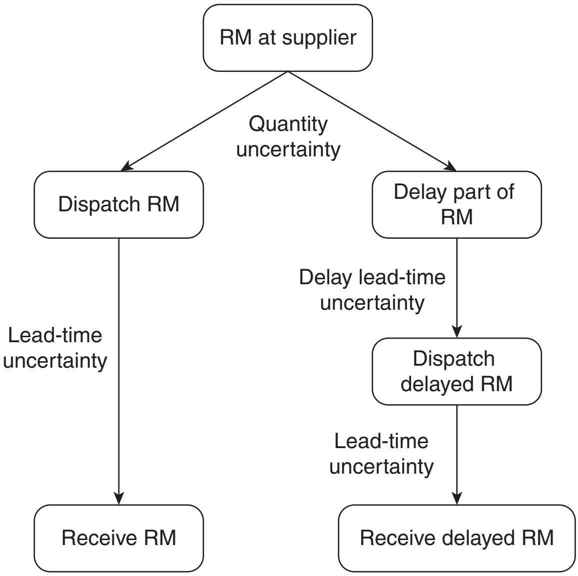


Figure 5.2 The relationship among lead time, quantity and delay uncertainties

Source: Authors.

quantity uncertainty related to whether suppliers can fulfil and dispatch the order on time ($\xi_i(t)$ in Chapter 6). In other words, the purchase order is divided into two parts: (1) the on-time dispatched part of the order (as shown on the left side of Figure 5.2); (2) the delayed part of the order (as shown on the right side of Figure 5.2). For the on-time dispatched part, there is a lead-time uncertainty during transportation at the period ($l_i(t)$). This part of the order will reach the raw material warehouse after the uncertain lead time. For the delayed part of the order, it is more complicated. Firstly, the fraction of the purchase order that is delayed depends on the quantity uncertainty ($1-\xi_i(t)$). Secondly, there is a delay lead time ($l_i^d(t)$) that represents how long it is delayed. Thirdly, from the dispatch of the delayed part of raw material to the time that the warehouse receives it, there is a lead-time uncertainty at this period ($l_i(t)$). The lead-time uncertainty on the right side may be different from that on the left side in Figure 5.2.

Constraints in the model

Various constraints exist in both case companies, including inventory capacity, transportation capacity and production capacity. For example, the interviews show that labour quality and operation management could influence the production capacity and productivity in China. Based on the data from the case studies, the constraints are classified into three groups corresponding to three SC processes, namely, DSC, ISC, and production and raw material procurement (Table 5.2). These constraints are designed as input parameters in the model so that they can be easily changed according to the company's data.

Table 5.2 Classification of constraints in the model

Domestic SC	**International SC**	**Production and raw material procurement**
Finished goods inventory capacity; finished goods transportation capacity	Finished goods inventory capacity; finished goods internal transportation capacity; finished goods external transportation capacity	Production capacity; raw material inventory capacity; raw material transportation capacity

Source: Authors.

Supply chain performance

The SCP in this study has been identified from two aspects, namely: SC total cost and customer services level. In this section, based upon the data from case studies and other research, the SC cost and customer services level in DSC and ISC are considered.

Total cost

There is a wide range of cost components incurred in the case SCs, which are classified into three categories, that is, domestic SC cost (based on cases A and B), international SC cost (based on case B) and production and raw material procurement cost (based on cases A and B).

Domestic SC cost

In DSC, five types of cost have been taken into account. The finished goods domestic market transportation fee has increased greatly in China, as confirmed in the interviews. There are two reasons that have directly generated an increase in this type of cost, which are increased gas price and the inflation rate in China. The average growth rate in costs for the two cases is around 15% in 2010 compared with 2009. Another reason leading to a higher domestic transportation fee is the lack of standardised commission fee in different cities in China. A commission fee is charged differently based on local government policy. Consequently, in some cities, the commission fee is extremely high. The delay penalty cost (customer order and shipping) has been considered because those delays negatively influence a manufacturer's integrated raw material ordering and production plans. For example, the infrastructure plan and the capacity of roads lead to much traffic congestion on Chinese highways, which causes many transportation delays of finished goods and raw materials. Domestic banking fees and payment delay penalty costs are cheaper than in the ISC. In China, the business account payment transaction fee (usually £5 for one payment) is much cheaper than the international payment. The lead time in domestic payment usually takes one working day depending on the systems of different banks.

International SC cost

There are more types of cost to consider in the ISC. The internal transportation fee is similar to the transportation fee in the DSC. The external transportation fee is more standardised, but it increased in 2010 (from the interviews) in terms of the international shipping fee. The currency exchange rate increased the cost of international shipping greatly in 2010. For case B, the exchange rate increased around 8% in 2010. According to the interviews, the company is willing to reduce exports; however, in order to keep its target international market share and meet the local government requirement, although the cost for exporting is higher than sales in the domestic market, case company B still accepts at least 10% international orders. Thus, there is a penalty cost based on the situation of the company not satisfying the international target percentage (the target percentage could be setup by using the input parameter). For example, for case B, the target percentage is 10%, and therefore the penalty cost is equal to a large number or infinity, or equal to 0 otherwise. The international banking commission fee and payment delay penalty cost is much more expensive and complicated. For example, the fee for issuing a credit letter is around 0.2% for HSBC Bank, and the company is charged again when they cash a credit letter or cheque. The payment lead time is longer because of international trade issues, for example, an international bank transaction usually takes three–five working days. For a domestic bank (manufacturer's bank in China), the opening time of a large branch is usually from 8 am to 5 pm, including Sunday. However, an international bank (customer side) is usually open only from Monday to Friday. Additionally, different national holidays influence companies receiving payments as well. Because of this, the company has had trouble in the past five years.

Production and raw material cost

Production fees in the model include labour cost, raw material cost, tax and machine depreciation. In China, labour cost increased in 2010 by around 12% in case company A and 14% in case company B. However, the setup fee and finished goods inventory holding cost was stable in 2010 for both companies. The reason for a stable finished goods inventory holding fee was that the location of finished goods warehouses was normally far from the city centre, and those warehouses were company owned. In 2010, the average raw material cost increased around 10% for the case companies in Q3 compared with Q2, and it was increasingly high. Therefore, the production fee kept rising in China. Raw material transportation cost was similar to finished goods transportation in the DSC. However, the payment method for raw materials was flexible in China. Case company A usually made payments to suppliers on a monthly basis. Case company B usually made payment to suppliers every two–three months. However, the Chinese business culture ensures that all payments have to be made before Chinese Spring Festival, which is usually in February.

Based on this discussion, Table 5.3 gives the classification of the cost elements in the model. There are more cost elements in the ISC compared with the DSC. In order to increase the flexibility, all cost

Table 5.3 Classification of cost elements in the model

Domestic SC	**International SC**	**Production and raw material procurement**
Domestic customer order delay penalty cost Finished goods in domestic market transportation cost Finished goods backorder cost Finished goods shipping delay and inaccurate quantity penalty cost Domestic banking fee and payment delay penalty cost	International customer order delay and inaccurate penalty cost Finished goods internal transportation (from finished goods warehouse to manufacturer's seaport) delay and inaccurate penalty cost Finished goods internal transportation cost Finished goods external transportation (from manufacturer's seaport to customer's seaport) delay and inaccurate penalty cost Finished goods external transportation cost Finished goods international backorder cost Banking fee and payment delay penalty cost Lose international market share penalty cost	Production fee Setup cost Defective quality penalty cost Finished goods inventory holding cost Raw material inventory holding cost Raw material transportation cost Raw material transportation delay penalty cost

Source: Authors.

parameters are set as input variables so that a company can input those data according to their own price (cost) structure and context.

Customer service levels

The customer services level has been defined as the percentage that the company satisfies domestic customer orders and the target percentage of international orders within the contracted deadlines. In other words, it can be recognised as the fulfilment rate. However, the contracted period is stochastic, which depends on every single contract. In the system, it has been set up as a stochastic parameter. According to the interviews, the general contracted periods are two weeks for case company B. From the time the company receives the order from the customer, the finished goods have to be delivered to their warehouse within two weeks. We do not take into consideration how many deliveries there are. This study only considers if the customer received the right delivery at the end of the contract.

Chapter 6 goes on to look at the specific issues in mathematical modelling of the SC.

6

Mathematical Modelling for the Supply Chain System

In this chapter, the DSC and ISC will be represented by mathematical modelling, with the uncertainties noted in Chapter 5. There are four sub-models including a customer order model, a production model, a raw material ordering and transportation model and a finished goods satisfying customer demand and transportation model.

The customer order model consists of domestic customer demand and international customer demand sections. How the international and domestic customer orders are generated will be presented. The production model explains how the manufacturer uses raw materials to produce finished goods within constraints. The raw material ordering and transportation model describes how the manufacturer places orders for main types of raw materials and how the raw material inventory in the warehouse is updated. The finished goods satisfying customer demand and transportation model includes how the finished goods satisfy customer demand and how the goods are shipped from the finished goods warehouse to the domestic and international customer.

After formulating four sub-models, the SCP including the SC total cost and CSL will be defined mathematically. Finally, parameterised and non-parameterised strategies that will be used to manage the SCM issues are introduced.

Notation

In this section, the notation in the models is introduced, classified into several categories including static input variables, decision variables, state variables, time uncertainty related variables, quantity uncertainty related variables, dynamic input or derived variables, cost coefficients and performances indicators.

Static input variables

T: the number of planned time periods;
T_d: the maximum number of periods placing domestic customer orders in advance;
T_i: the maximum number of periods placing international customer orders in advance;
I: the number of different types of raw materials;
S_i: the maximum inventory capacity for raw material i;
S_o: the maximum inventory capacity for finished goods;
U_o: the maximum production capacity in one period;
r_i: the amount of raw material i required to produce one unit of finished goods.

Decision variables

$u_i(t)$: the planned order quantity for raw material i at period t;
$u_o(t)$: the planned production quantity for finished goods at period t;
$uI(t)$: the percentage of produced finished goods that is planned to sell to the international market at period t.

State variables

$x_o^D(t)$: the on-hand domestic inventory level of domestic finished goods (before status updated) at the beginning of period t;
$x_o^I(t)$: the on-hand international inventory level of domestic finished goods (before status updated) at the beginning of period t;
$x_i(t)$: the on-hand inventory level of raw material i (before status updated) at the beginning of period t.

Time uncertainty related variables

$l_c(t)$: the domestic SC information lead time for a customer placing an order from customer to manufacturer at period t;
$l_{ci}(t)$: the international SC information lead time for a customer placing an order from customer to manufacturer at period t;
$l_c^d(t)$: the domestic SC lead time of delayed customer order information from customer to manufacturer at period t;
$l_{ci}^d(t)$: the international SC lead time of delayed customer order information from customer to manufacturer at period t;

$l_i^p(t)$: the (information) lead time of placing a raw material *i* order from manufacturer to supplier at period *t*;

$l_i^s(t)$: the (physical) lead time of shipping raw material *i* from supplier to raw material warehouse at period *t*;

$l_i(t)$: the total lead time of procurement of raw material *i* from the time of placing the order from manufacturer to supplier until the time of physically receiving the raw material at period *t*;

$l_i^d(t)$: the lead time for delayed shipments of raw material *i* from supplier, raw material transportation, to raw material warehouse at period *t*;

$l_\mathrm{o}(t)$: the lead time of manufacturer producing the finished goods at period *t*;

$l_o^d(t)$: the lead time of defective products to be reworked at period *t*;

$l_o^s(t)$: the (physical) lead time of shipping the finished goods from finished goods warehouse to finished goods transportation company and then finally to arrive to customer;

$l_o^p(t)$: the (information) lead time of shipping the finished goods from finished goods warehouse to finished goods transportation company and then finally to arrive to customer;

$l_s(t)$: the total lead time of shipping the finished goods from finished goods warehouse to finished goods transportation company and then finally to arrive to domestic customer at period *t*;

$l_s^d(t)$: the lead time of shipping delayed finished goods from finished goods warehouse to finished goods transportation company and then finally to arrive to domestic customer at period *t*;

$l_{si}(t)$: the total lead time of shipping the finished goods from finished goods warehouse to finished goods transportation company and then finally to arrive at manufacturer side of seaport at period *t*;

$l_{si}^d(t)$: the lead time of shipping delayed finished goods from finished goods warehouse to finished goods transportation company and then finally to arrive at manufacturer side of seaport at period *t*;

$l_{sI}(t)$: the total lead time of shipping the finished goods from manufacturer side of seaport to customer's seaport at period *t*;

$l_{sI}^d(t)$: the lead time of shipping delayed finished goods from manufacturer side of seaport to customer's seaport at period *t*;

$s_l(t)$: the domestic SC contracted lead time of satisfying the customer order at period *t*;

$s_{li}(t)$: the international SC contracted lead time of satisfying the customer order at period t.

Quantity uncertainty related variables

$\xi_d(t)$: the random variable representing the fraction (ratio) of domestic customer orders received/processed by manufacturer on time at period t;
$\xi_{di}(t)$: the random variable representing the fraction (ratio) of international customer orders received/processed by manufacturer on time at period t;
$\xi_i(t)$: the random variable representing the fraction of raw material orders received/processed by suppliers on time at period t;
$\xi_o(t)$: the random variable representing the fraction of perfect finished goods produced on time initiated at period t;
$\xi_s(t)$: the random variable representing the fraction of finished goods orders received by domestic customer on time at period t;
$\xi_{si}(t)$: the random variable representing the fraction of finished goods orders delivered from finished goods warehouse to manufacturer side of seaport at period t;
$\xi_{sI}(t)$: the random variable representing the fraction of finished goods orders on-time delivered from manufacturer side of seaport to customer's seaport at period t;
$\eta_d(t)$: the random variable representing the ratio of domestic customer demand at period t;
$\eta_{di}(t)$: the random variable representing the ratio of international customer demand at period t.

Dynamic input or derived variables

Customer ordering process variables

$d(t)$: the expected domestic customer demand of finished goods during period t, based on historical data;
$D(t)$: the random domestic customer demand of finished goods during period t;
$D_o^r(t)$: the on-time received domestic customer demand at period t;
$D_o^d(t)$: the delayed domestic customer demand that arrives at period t;

$DMD(t)$: manufacturer actually received domestic customer order at period t;

$d_i(t)$: the expected international customer demand of finished goods during period t, which is based on historical data;

$D_i(t)$: the random international customer demand of finished goods during period t;

$D_{oi}^r(t)$: the on-time received international customer demand at period t;

$D_{oi}^d(t)$: the delayed international customer demand that arrives at period t;

$DMDI(t)$: manufacturer actually received international customer order at period t.

Production process variables

$u_i^r(t)$: the amount of orders for raw material i received on time by suppliers at period t;

$u_i^d(t)$: the delayed amount of orders for raw material i at period t;

$URM_i(t)$: the raw material warehouse actually received raw material i at period t;

$u_o^r(t)$: the finished goods on-time production requirements at period t;

$u_o^s(t)$: produced finished goods at period t, which is subject to the constraints;

$u_o^S(t)$: produced finished goods after production quality uncertainty;

$u_o^d(t)$: the defective finished goods at period t;

$UFG_o(t)$: the amount of finished goods the manufacturer actually produces at period t, which is subject to production lead time.

Finished goods satisfying customer demand and shipping process variables

$SOI(t)$: the amount of finished goods actually planned for sale to the international market;

$s_o^r(t)$: the amount of finished goods that could be used to satisfy domestic customer demand at period t;

$s_o^R(t)$: the finished goods delivered to domestic customers on time at period t;

$s_o^d(t)$: the delayed delivery of finished goods to domestic customers on time at period t;

$CFG_o(t)$: domestic customer actually received finished goods at period t;

$s_{oi}^r(t)$: the amount of finished goods that could be used to satisfy international customer demand at period t;

$s_o^R(t)$: the finished goods delivered to international customers on time from finished goods warehouse to manufacturer side of seaport at period t;

$s_o^d(t)$: the delayed delivery of finished goods to international customers from finished goods warehouse to manufacturer side of seaport at period t;

$CFGI_i(t)$: actually delivered finished goods from finished goods warehouse to manufacturer side of seaport at period t;

$s_{oI}^R(t)$: the finished goods delivered to international customers on time from manufacturer side of seaport to customer's seaport at period t;

$s_{oI}^d(t)$: the delayed delivery of finished goods to international customers from manufacturer side seaport to customer's seaport at period t;

$CFGI_I(t)$: actually delivered finished goods from manufacturer side of seaport to customer's seaport at period t;

$BCO_d(t)$: cumulative unfulfilled domestic customer demand at period t (i.e., the amount of finished goods that the customer should have received but has not yet);

$BCO_i(t)$: cumulative unfulfilled international customer demand at period t (i.e., the amount of finished goods that the customer should have received but has not yet).

Cost coefficients

c_{o}^h: the inventory holding cost for per unit of finished goods;

c_i^h: the inventory holding cost for per unit of raw material i;

c_{o}^b: the penalty cost for domestic backordering one unit of finished goods;

c_{oi}^b: the penalty cost for international backordering one unit of finished goods;

c_o^p: the fixed cost for producing one unit of finished goods;

c_o^s: the setup cost for producing one unit of finished goods which is the sum of salary, depreciation cost, administration fee, tax, packaging, and so on;
c_o^d: the penalty cost for defective production;
c_o^t: the domestic market transportation cost for shipping one unit of finished goods;
c_{oii}^t: the international internal transportation cost (from finished goods warehouse to manufacturer's port) for shipping one unit of finished goods;
c_{oei}^t: the international external transportation cost (from manufacturer's port to customer's port) for shipping one unit of finished goods;
c_i^t: the transportation cost for shipping one unit of raw material *i*;
c_{or}^d: the penalty cost for one unit of domestic customer order delay or inaccurate customer order;
c_{ori}^d: the penalty cost for one unit of international customer order delay or inaccurate customer order;
c_f^d: the penalty cost for one unit of domestic delayed or inaccurate finished goods shipping;
c_{fii}^d: the penalty cost for one unit of international internal transportation delayed or inaccurate finished goods shipping;
c_{fei}^d: the penalty cost for one unit of international external transportation delayed or inaccurate finished goods shipping;
c_i^d: the penalty cost for one unit of delayed or inaccurate orders for raw material;
c_o^m: domestic bank payment committee fee with delay penalty cost;
c_{oi}^m: international bank payment committee fee with delay penalty cost;
c_{ol}^i: loss target international market penalty cost.

Performance indicators

J_d: domestic SC total cost in the planning horizon;
J_o: production and raw material procurement total cost within the planning horizon;
J_i: international SC total cost within the planning horizon;
J: total cost within the planning horizon;

$CEOR_d(t)$: domestic customer expected and received finished goods during period t;

$CEOR_i(t)$: international customer expected and received finished goods during period t;

CSL_d: the average domestic customer service level over periods;

CSL_i: the average international customer service level over periods;

CSL: the average SC customer service level over periods.

Customer order model

This model represents the periodic customer orders in the domestic and international market. The data has been time-based regressed according to the historical daily data (in total 217 days) collected from the case companies.

To represent the uncertainty in customer demand, the actual periodic customer demand is the amount from the regression function by multiplying a random variable $\eta_d(t)$ for domestic customer orders and by a random variable $\eta_{di}(t)$ for international customer orders, which follows the uniform distribution $U(0.8,1.2)$. The values 0.8 and 1.2 were estimated based on the information from interviews.

There are two types of lead-time uncertainty parameters, representing the domestic order placing lead time $l_c(t)$ and domestic order delay lead time $l_c^d(t)$ in the domestic SC; and two types of lead-time uncertainties in the ISC representing the international order placing lead time $l_{ci}(t)$ and international order delay lead time $l_{ci}^d(t)$. These lead-time parameters may influence the customer orders that the manufacturer actually receives during one period. Note both types of lead time are dynamic and stochastic variables that may be different over time periods.

The mathematical formulation for the domestic customer order model and the international customer order model are presented in the following two sub-sections, respectively.

Domestic customer order model

$$d(t) = \begin{pmatrix} -0.0000000035 * t^4 - 0.0000002988 * t^3 \\ +0.0003570609 * t^2 - 0.0408922814 * t \\ +2.9582935980 \end{pmatrix} * \tau(t) \tag{6.1}$$

$$D(t) = d(t)\eta_d(t) \tag{6.2}$$

$$D_o^r(t) = D(t) * \xi_d(t) \tag{6.3}$$

$$D_o^d(t) = D(t) * (1 - \xi_d(t)) \tag{6.4}$$

$$\begin{aligned} DMD(t) = &\sum_{j=1}^{t} D_o^r(j) * I\{j + l_c(j) = t\} \\ &+ \sum_{j=1}^{t} D_o^d(j) * I\{j + l_c^d(j) + l_c(j + l_c^d(j)) = t\}, \end{aligned} \tag{6.5}$$

where $I\,\{.\}$ is an indicator function, it takes 1 if the condition in {} is true; 0, otherwise.

A comparison of the company's strategy and parameterised and non-parameterised strategies in the experiment can be found in Chapters 8, 9 and 10. Eq. (6.1) represents the periodic customer orders from a polynomial regression function calculated based on case company historical data, in which $\tau(t)$ represents the percentage of total customer orders generated from the domestic market. The regression coefficients came from the customer demand data. Eq. (6.2) represents the customer orders with quantity uncertainty. Eq. (6.3) represents the part of customer orders that is released on time at period t, where $\xi_d(t)$ is a random variable to represent the incompleteness of customer order release. Eq. (6.4) represents the part of customer orders that is released with a delay at period t. Eq. (6.5) represents the amount of customer orders that the manufacturer actually receives at period t, which is the sum of on-time released customer orders, $D_o^r(.)$, generated at the period in advance of the required customer order information lead time, $l_c(.)$, and the sum of previously delayed released customer orders, $D_o^d(.)$, which reached the manufacturer during period t. It should be pointed out that there is a delay lead time $l_c^d(t)$, which represents the information delay lead time of the inaccurate part of the order.

International customer order model

$$d_i(t) = \begin{pmatrix} -0.0000000035 * t^4 - 0.0000002988 * t^3 \\ +0.0003570609 * t^2 - 0.0408922814 * t \\ +2.9582935980 \end{pmatrix} * (1 - \tau(t)) \tag{6.6}$$

$$D_i(t) = d(t)\eta_{di}(t) \tag{6.7}$$

$$D_{oi}^r(t) = D_i(t) * \xi_{di}(t) \tag{6.8}$$

$$D_{oi}^d(t) = D_i(t) * (1 - \xi_{di}(t)) \tag{6.9}$$

$$\begin{aligned} DMDI(t) = &\sum_{j=1}^{t} D_{oi}^r(j) * I\{j + l_{ci}(j) = t\} \\ &+ \sum_{j=1}^{t} D_{oi}^d(j) * I\{j + l_{ci}^d(j) + l_{ci}(j + l_{ci}^d(j)) = t\}. \end{aligned} \tag{6.10}$$

In order to compare the company's strategy and parameterised and non-parameterised strategies in chapters 8–10, Eq. (6.6) represents the periodic international customer orders from a polynomial regression function obtained based on case company historical data, in which $\tau(t)$ represents the percentages of total customer orders generated from the domestic market. The regression coefficients came from the customer demand data. Eq. (6.7) represents the international customer order with quantity uncertainty. Eq. (6.8) represents the part of international customer order that is released on time at period t, where $\xi_{di}(t)$ is a random variable to represent the incompleteness of customer order release. Eq. (6.9) represents the part of international customer order that is released with delay at period t. Eq. (6.10) represents the amount of international customer orders that the manufacturer actually receives at period t, which is the sum of on-time released customer orders, $D_{oi}{}^r(t)$, generated at the period in advance of the required customer order information lead time, $l_{ci}(t)$, and the sum of previously delayed released customer orders, $D_{oi}{}^d(t)$, which reached the manufacturer at period t. It should be pointed out that there is a delay lead time, $l_{ci}{}^d(t)$, which represents the information delay lead time of the inaccurate part of the order.

Production model

The production process follows the production plan $u_o(t)$ subject to constraints listed in Table 5.2. The uncertainties in Table 5.1 have been considered here. Here the quantity uncertainty is mainly caused by the defective products. The required amount of production at period *t* includes two parts: the production plan $u_o(t)$ and the sum of the amount requiring reworking ($u_o^d(.)$) that is scheduled at the current period taking into account the delay uncertainty.

$$u_o^r(t) = u_o(t) + \sum_{j=1}^{t} u_o^d(j) * I\left\{j + l_o(j) + l_o^d(j + l_o(j))\} = t\right\} \tag{6.11}$$

$$u_o^d(t) = u_o^s(t)\left(1 - \xi_o(t)\right) \tag{6.12}$$

$$u_o^s(t) = min\begin{Bmatrix} U_o - \sum_{j=1}^{t} u_o^s(j) * I\left\{j + l_o(j) > t\right\}, u_o^r(t), \\ (x_i(t) + URM_i(t))\ /r_i) \end{Bmatrix} \tag{6.13}$$

$$u_o^S(t) = u_o^s(t) * \xi_o(t) \tag{6.14}$$

$$UFG_o(t) = \sum_{j=1}^{t} u_o^S(j) * I\left\{j + l_o(j) = t\right\}, \tag{6.15}$$

$$SOI(t) = min\{UFG_o(t) * uI(t), DMDI(t)\} \tag{6.16}$$

$$\begin{cases} x_o^I(t+1) = x_o^I(t) + UFG_o(t) * uI(t) - SOI(t) \\ x_o^I(t+1) = UFG_o(t) * uI(t) - s_o^I(t), if x_o^I(t) \geq 0, \quad and\, x_o^D(t) < 0 \end{cases} \tag{6.17}$$

$$\begin{cases} x_o^D(t+1) = x_o^D(t) + UFG_o(t) * (1 - uI(t)) - DMD(t) \\ x_o^D(t+1) = x_o^D(t) + x_o^I(t) + UFG_o(t) * (1 - uI(t)) \\ \qquad\qquad - DMD(t), \quad if x_o^I(t) \geq 0, x_o^D(t) < 0. \end{cases} \tag{6.18}$$

Eq. (6.11) represents the production requirement at period *t*, in which the first part is the planned production $u_o(t)$ and the second part is the amount of required reworking production u_o^d that is the sum of defective finished goods to be reworked at this period. There is a delay lead-time uncertainty (also called remanufacturing lead time) $l_o^d(.)$, which implies that the defective products may not be reworked immediately after detection. Eq. (6.12) represents the amount of defective finished goods whose production is initiated at period *t*, in which $(1–\xi_o(t))$ represents the quantity uncertainty level (i.e., the defective products rate). Eq. (6.13) represents the production ability of the manufacturer at period t, which is subject to the available production capacity (i.e., $U_o(t)$ minus the work-in-process [WIP]), the production requirement $u_i^r(t)$ and the raw material availability. Where $(x_i(t) + URM_i(t))/r_i \frac{x_i(t)+u_i^r(t-l_i)}{r_1}$ is the availability of raw material i at period t, depending on the on-hand inventory $x_i(t)$, newly received raw material i quantity $URM_i(t)$ and the amount of raw material i required to produce one unit of finished goods (r_i). Eq. (6.14) represents the amount of perfect finished goods, whose production is initiated at period t. Eq. (6.15) represents the actual perfect finished goods that the manufacturer completes at period t. There is a production lead time $l_o(t)$, which is subject to uncertainty. Eq. (6.16) represents the manufacturer planning the quantity of produced finished goods that will be on sale in the international market, which is dependent upon its sales plan $CFG_o(t)$, international sales forecasting plan $uI(t)$ and received international customer demand $DMDI(t)$. Eq. (6.17) represents the finished goods for international market inventory updates. The finished goods inventory level at period t+1 equals the finished goods inventory level $x_o^I(t)$ at period t, plus the newly completed perfect finished goods $UFG_o(t)$ multiple sales plan (based on forecasting) $uI(t)$ minus sales plan $SOI(t)$ at period t. However, if the on-hand inventory level is positive, but the domestic market inventory level is in backorder, then the rest of $x_o^I(t)$ will go to the domestic inventory warehouse and therefore, the inventory level equals the newly completed perfect finished goods $UFG_o(t)$ multiplied by the sales plan (based on forecasting) $uI(t)$ minus the sales plan $SOI(t)$ at period t. Eq. (6.18) represents the finished goods for the domestic market inventory updates. The finished goods inventory level at period t+1 equals the finished goods inventory level $x_o^D(t)$ at period t, plus the newly completed perfect finished goods $UFG_o(t)$ multiplied by the sales plan (based on forecasting) $(1-uI(t))$ minus customer demand $DMD(t)$ at period t. However, if the on-hand inventory level is in backorder and the international market on-hand inventory level is positive, then the rest of $x_o^I(t)$ will go to the domestic inventory warehouse, and therefore, the inventory level equals the finished goods inventory level $x_o^D(t)$ at period t, plus the rest of $x_o^I(t)$, plus the newly completed perfect finished goods $UFG_o(t)$ multiplied by the sales plan (based on forecasting) (1–$uI(t)$) minus customer demand $DMD(t)$ at period t.

Raw material ordering and shipping model

This sub-model focuses on the activities of raw material procurement and of raw material on-hand inventory updating. The quantity uncertainty in Table 5.1 is represented by (1– $\xi_i(t)$). The lead-time uncertainties are represented by $l_i^s(t)$ and $l_i^p(t)$. The delay lead-time uncertainty is represented by $l_i^d(t)$.

$$u_i^r(t) = u_i(t) * \xi_i(t) \tag{6.19}$$

$$u_i^d(t) = u_i(t) * (1 - \xi_i(t)), \tag{6.20}$$

$$l_i(t) = l_i^p(t) + l_i^s(t) \tag{6.21}$$

$$\begin{aligned} URM_i(t) = & \sum_{j=1}^{t} [u_i^r(j) * I\{j + l_i(j) = t\} \\ & + \sum_{j=1}^{t} [u_i^d(j) * I\{j + l_i^d(j) + l_i(j + l_i^d(j)) = t\}], \end{aligned} \tag{6.22}$$

$$x_i(t+1) = x_i(t) + URM_i(t) - u_o^s(t) * r_i \tag{6.23}$$

Eq. (6.19) represents the amount of on-time procurement for raw material i, $u_i^r(t)$, which is influenced by the company procurement plan $u_i(t)$ and a random variable $\xi_i(t)$. Eq. (6.20) represents the delayed procurement quantity for raw material i, where (1–$\xi_i(t)$) represents the quantity uncertainty level (a fraction of raw material being delayed). Eq. (6.21) represents the total procurement (replenishment) lead time for raw material i, $l_i(t)$, which includes the raw material order information lead time and booking transportation lead time in information flow ($l_i^s(t)$) and the raw material availability and raw material transportation lead time in material flow ($l_i^p(t)$). Eq. (6.22) represents the total raw material i received by the manufacturer at period t taking into account the procurement lead time $l_i(t)$ and the delayed RM procurement lead time $l_i^d(t)$. Eq. (6.23) updates the on-hand inventory state of raw material i. The raw material i inventory level at period $t+1$ is equal to the raw material inventory level at period t, plus the received raw material i from suppliers at period t, minus the used amount of raw material at period t.

Finished goods satisfying customer demand and shipping model

This model represents how the finished goods satisfy customer demand and how to ship the products from the finished goods warehouse to domestic and international customers. The ability of the manufacturer to satisfy the customer order depends on the size of the customer order, the finished goods on-hand inventory level and the manufacturer's produced finished goods in the period. The manufacturer has to satisfy at least 10% of international customer demand in order to keep its international market share. Afterwards, the manufacturer has to decide how many of the finished goods should be used to satisfy domestic customer demands and how many of the finished goods should be used to satisfy international customer demands. In general, satisfying the domestic customer order has priority because it is more profitable.

It should be noted that transportation uncertainty might lead to shipment delays. There are two broad types of lead time in the model: shipping lead time and shipping delay lead time. For the domestic SC, the finished goods shipping lead time $l_s(t)$ depends on the period and size of the shipment and so does the shipping delay lead time $l_s^d(t)$. For the international SC, the lead time consists of two parts: the internal (inland) transportation part and the international transportation part. Firstly, the finished goods internal shipping lead time $l_{si}(t)$ refers to the finished goods transportation time from the finished goods warehouse to the manufacturer-side of the seaport, and the internal shipping delay lead time $l_{si}^d(t)$ refers to the delay lead time of finished goods in the transportation process from the finished goods warehouse to the manufacturer-side of the seaport. Secondly, the finished goods international shipping lead time $l_{sI}(t)$ is the transportation time of finished goods from the manufacturer-side of the seaport to the international customer's seaport, and the shipping delay lead time $l_{sI}^d(t)$ is the delay lead time of finished goods in the international shipping process from the manufacturer-side of the seaport to the international customer's seaport.

Domestic customer demand and shipping model

$$s_o^r(t) = \min(DMD(t), x_o^D(t) + UFG_o(t) * (1 - uI(t)), \quad if\ x_o^D(t) \geq 0 \tag{6.24}$$

$$\begin{aligned} s_o^r(t) = \min(&DMD(t) - x_o^D(t), \quad UFG_O(t) \\ &* (1 - uI(t)), \quad if\ x_o^D(t) < 0, x_o^I(t) < 0 \end{aligned} \tag{6.25}$$

$$\begin{aligned} s_o^r(t) = \min(&DMD(t) - x_o^D(t), \quad UFG_o(t) \\ &* (1 - uI(t) + x_o^I(t))), \quad if\ x_o^D(t) < 0, x_o^I(t) \geq 0 \end{aligned} \tag{6.26}$$

$$s_o^R(t) = s_o^r(t) * \xi_s(t) \tag{6.27}$$

$$s_o^d(t) = s_o^r(t) * (1 - \xi_s(t)) \tag{6.28}$$

$$l_s(t) = l_o^p(t) + l_o^s(t) \tag{6.29}$$

$$\begin{aligned} CFG_o(t) = &\sum_{j=1}^{t} s_o^R(j) * I\{j + l_s(j) = t\} \\ &+ \sum_{j=1}^{t} s_o^d(j) * I\{j + l_s^d(j) + l_s(j + l_s^d(j)) = t\}. \end{aligned} \tag{6.30}$$

Eq. (6.24), (6.25) and (6.26) represent the fulfilled domestic customer demands (also called domestic shipment) at period *t* corresponding to different situations. If the domestic on-hand finished goods inventory level is positive, then the fulfilled domestic customer demand is the smaller quantity between the received customer demand *DMD*(*t*) and the on-hand finished goods inventory level $x_o^D(t)$ plus the newly produced perfect finished goods that are planned to satisfy the domestic customer $UFG_0(t)*(1–uI(t))$. If the domestic on-hand finished goods inventory level and the international on-hand FGs inventory level are in backorder, then the fulfilled domestic customer demand is the smaller quantity between the received customer demand *DMD*(*t*) minus the on-hand finished goods inventory level $x_o^D(t)$ and the newly produced perfect finished goods that are planned to satisfy the domestic customer $UFG_0(t)*(1–uI(t))$. If the domestic on-hand finished goods inventory level is in backorder and the international on-hand finished goods inventory level is positive, then the fulfilled domestic customer demand is the smaller quantity between the received customer demand *DMD*(*t*) minus the on-hand finished goods inventory level $x_o^D(t)$ and the newly produced perfect finished goods that are planned to satisfy the domestic customer $UFG_o(t)*(1–uI(t))$ plus the international on-hand inventory. Eq. (6.27) represents the amount of shipment released on time at period t to the customer, subject to transportation uncertainty. Eq. (6.28) represents the delayed amount of shipment at period t. The quantity uncertainty level (i.e., a fraction of finished goods being delayed to release) is represented by $(1–\xi_s(t))$. Eq. (6.29) represents total shipping lead time $l_s(t)$ that includes the consideration of arranging finished goods transportation lead time in information flow ($l_o^s(t)$) and finished goods availability and finished goods transportation lead time in material flow ($l_o^p(t)$). Eq. (6.30) represents the amount of finished goods that the customer actually receives at period t, which is the sum of the shipments that were released on time and the shipments that were released with delay.

International customer demand and internal shipping model

$$\begin{aligned} s_{oi}^{r}(t) = \min(SOI(t),\ x_o^I(t) + UFG_o(t) * uI(t)),& \\ if\ x_o^I(t) \geq 0, x_o^D(t) \geq 0& \end{aligned} \tag{6.31}$$

$$s_{oi}^{r}(t) = \min(SOI(t) - x_o^I(t), UFG_o(t) * uI(t)),\quad if\ x_o^I(t) < 0 \tag{6.32}$$

$$s_{oi}^{r}(t) = min(SOI(t),\ UFG_o(t) * uI(t)),\quad if\ x_o^I(t) \geq 0, x_o^D(t) < 0 \tag{6.33}$$

$$s_{oi}^{R}(t) = s_{oi}^{r}(t) * \xi_{si}(t) \tag{6.34}$$

$$s_{oi}^{d}(t) = s_{oi}^{r}(t) * (1 - \xi_{si}(t)) \tag{6.35}$$

$$l_{si}(t) = l_{oi}^{p}(t) + l_{oi}^{s}(t) \tag{6.36}$$

$$\begin{aligned} CFGI_i(t) = \sum_{j=1}^{t} s_{oi}^{R}(j) * I\left\{j + l_{si}(j) = t\right\}& \\ + \sum_{j=1}^{t} s_{oi}^{d}(j) * I\left\{j + l_{si}^{d}(j) + l_{si}(j + l_{si}^{d}(j)) = t\right\}.& \end{aligned} \tag{6.37}$$

Eq. (6.31), (6.32) and (6.33) represent the fulfilled international customer demands (also called international shipment) at period t corresponding to different situations. If both the domestic on-hand inventory and international finished goods inventory are positive, then the fulfilled international customer demand is the smaller quantity between the planned international sales $SOI(t)$ and the on-hand finished goods inventory level $x_o^I(t)$ plus the newly produced perfect FGs that are allocated to the international market $UFG_o(t)*uI(t)$. If the international on-hand finished goods inventory level is in backorder, then the fulfilled international customer demand is the smaller quantity between the planned international sales $SOI(t)$ minus the international on-hand finished goods inventory level $x_o^I(t)$ and the newly produced perfect finished goods that are allocated to the international market $UFG_o(t)*uI(t)$. If the international on-hand finished goods inventory level is positive and the domestic on-hand finished goods inventory level is in backorder, then the fulfilled international customer demand is the smaller quantity between the planned international sales $SOI(t)$ and the newly produced perfect finished goods $UFG_o(t)*uI(t)$.

Eq. (6.34) represents the amount of international shipment released on time at period *t* to the customer, subject to transportation uncertainty. Eq. (6.35) represents the delayed amount of shipment at period *t*. The quantity uncertainty level (i.e., a fraction of finished goods being delayed to release) is represented by $(1-\xi_{si}(t))$. Eq. (6.36) represents the total internal (inland) shipping lead time for international shipments from the finished goods warehouse to the manufacturer's seaport $l_{si}(t)$ that includes the consideration of arranging international internal finished goods transportation in the information flow $(l_{oi}^p(t))$ and the international internal finished goods transportation in the material flow $(l_{oi}^s(t))$. Eq. (6.37) represents the amount of finished goods for international internal delivery from the finished goods warehouse to the manufacturer's seaport (internal transportation) at period *t*, which is the sum of the shipments that were released on time and the shipments that were released in delay.

International customer demand and international shipping model

$$s_{oI}^R(t) = CFGI_i(t) * \xi_{sI}(t) \tag{6.38}$$

$$s_{oI}^d(t) = CFGI_i(t) * (1-\xi_{sI}(t)) \tag{6.39}$$

$$l_{sI}(t) = l_{oI}^p(t) + l_{oI}^s(t) \tag{6.40}$$

$$
\begin{aligned}
CFGI_I(t) = {} & \sum_{j=1}^{t} s_{oI}^{R}(j) * I\left\{j + l_{sI}(j) = t\right\} \\
& + \sum_{j=1}^{t} s_{oI}^{d}(j) * I\left\{j + l_{sI}^{d}(j) + l_{s}(j + l_{sI}^{d}(j)) = t\right\}.
\end{aligned} \tag{6.41}
$$

Eq. (6.38) represents the amount of finished goods that is dispatched on time to the international customer, subject to international transportation (from the manufacturer's seaport to the customer's port) uncertainty. Eq. (6.39) represents the delayed amount of shipment at period *t*. The quantity uncertainty level (i.e., a fraction of finished goods being delayed to be dispatched) is represented by $(1-\xi_{sI}(t))$, and Eq. (6.40) represents total international shipping lead time for international shipments from the manufacturer's port to the international customer's port $l_{sI}(t)$, which includes the consideration of arranging international external transportation in information flow $(l_{oI}^{p}(t))$ and the international external transportation in material flow $(l_{oI}^{s}(t))$. Eq. (6.41) represents the amount of finished goods that the international customers received actually at period *t*, which is the sum of the shipments that were dispatched on time from the manufacturer's seaport and the shipments that were dispatched with delay from the manufacturer's seaport.

Supply chain performance

This study considers two SCP indicators, SC total cost and the average CSL. The total cost includes all cost elements in the SC. The CSL depends on the customer-expected received finished goods and the actual amount of finished goods that the customer receives over the planning horizon. These two indicators are often conflict and are defined as follows.

Supply chain total cost

The cost elements in Table 5.3 have been considered.

Domestic SC cost

$$
\begin{aligned}
J_d = \sum_{t=1}^{T} \{ & [D_o^d(t) + |\, d(t) - DMD(t)\,|]c_{or}^{d} + s_o^R(t)c_o^t + (s_o^r(t) \\
& - DMD(t))c_o^{b+} + [s_o^d(t) + |\, CFG_o(t) - s_o^r(t)\,|]c_f^d + CFG_o(t)c_o^m \}.
\end{aligned} \tag{6.42}
$$

where if $s_o^r(t) - DMD(t) > 0$, $c_o^{b+} = c_o^b$; otherwise, $c_o^{b+} = 0$

Eq. (6.42) represents the domestic SC operational cost in the planning horizon. There are many types of cost: (1) customer order delay penalty cost; (2) finished goods transportation cost; (3) finished goods backorder cost; (4) finished goods shipping delay and inaccurate quantity penalty cost; (5) banking fee; and (6) payment delay penalty cost.

Production and raw material procurement cost

$$\begin{aligned} J_o = \sum_{t=1}^{T} \{ & UFG_O(t)c_o^p + UFG_O(t)c_o^s + u_o^d(t)c_o^d + \sum_{i=1}^{I} x_i(t)c_i^h \\ & + x_o^+(t)c_o^h + \sum_{i=1}^{I} u_i^r(t)c_i^t + \sum_{i=1}^{I} [u_i^d(t) + |\, u_i(t) - URM_i(t) \,|]c_i^d \}. \end{aligned} \tag{6.43}$$

Eq. (6.43) represents the SC production and raw material procurement total costs in the planning horizon, which includes production fee, setup cost, defective quality penalty cost, raw material inventory holding cost, finished goods inventory holding cost, raw material transportation cost and raw material transportation delay penalty cost.

International SC cost

$$\begin{aligned} J_i = \sum_{t=1}^{T} \{ & [D_{oi}^d(t) + |\, d_i(t) - DMDI(t) \,|]c_{ori}^d + [s_{oi}^d(t) + |CFGI_i(t) \\ & - s_{oi}^r(t) \,|]c_{fii}^d + s_{oi}^R(t)c_{oii}^t + [s_{oI}^d(t) + |\, CFGI_I(t) - CFGI_i(t) \,|]c_{fei}^d \\ & + s_{oI}^R(t)c_{oei}^t + (s_{oi}^r(t) - SOI(t))c_{oi}^{b+} + CFGI_I(t)c_{oi}^m \\ & + (SOI(t) * 0.1 - uI(t))c_{ol}^{i+} \}. \end{aligned} \tag{6.44}$$

where if $s_{oi}^r(t) - uI(t) > 0$, $c_{oi}^{b+} = c_{oi}^b$, otherwise, $c_{oi}^{b+} = 0$; if $DMDI(t)*0.1 - SOI(t) > 0$, $c_{ol}^{i+} = c_{ol}^i$, otherwise $c_{ol}^{i+} = 0$.

Eq. (6.44) represents the international SC total cost in the planning horizon. The types of costs include: (1) international customer order delay and inaccurate penalty cost; (2) finished goods internal transportation (from finished goods warehouse to manufacturer's seaport) delay and inaccuracy penalty cost; (3) finished goods internal (inland) transportation cost; (4) finished goods external transportation (from manufacturer's seaport to customer's seaport) delay and inaccuracy penalty cost; (5) finished goods external transportation cost; (6) finished goods international backorder cost; (7) banking fee and payment delay penalty cost; and (8) loss of international market share penalty cost.

Supply chain total cost

$$J = J_d + J_o + J_i \tag{6.45}$$

Eq. (6.45) represents the total cost in the SC model, which is the sum of the domestic SC cost, production and RMs procurement cost and international SC cost.

Customer services level

The CSL has been identified as the customer order fulfilment rate within the contracted days, associated with SC uncertainties and constraints. The SC CSL is the average of domestic CSL (CSL_d) and international CSL (CSL_i).

Domestic CSL

The domestic customer-expected received finished goods in each period is defined in the first place, in which the contracted lead time between the customer and the manufacturer has to be considered, as shown in Eq. (6.46). The cumulative unfulfilled customer demand in Eq. (6.47) represents the amount of finished goods that the customer should have received according to the contracts but has actually not yet received. And then, the periodic customer service level in Eq. (6.48) and the average CSL over the whole planning horizon in Eq. (6.50) are defined. Eq. (6.49) represents the total number of periods in which the customer is expecting to receive some contracted shipments.

$$CERO_d(t) = \sum_{j=1}^{t} DMD(j) I\{j + s_l(j) = t\}; \tag{6.46}$$

$$BCO_d(t) = CERO_d(t) - CFG_o(t) + BCO_d(t-1); \tag{6.47}$$

$$csl_d(t) = \begin{cases} 0; & if\ CFG_o(t) - BCO_d(t-1) \le 0 \\ \dfrac{CFG_o(t) - BCO_d(t-1)}{CERO_d(t)}; & if\ CFG_o(t) - BCO_d(t-1) > 0, \\ & \quad CERO_d(t) > 0, \end{cases} \tag{6.48}$$

$$T_d = \sum_{t=1}^{T} I\{CERO_d(t) > 0\}; \tag{6.49}$$

$$CSL_d = \sum_{t=1}^{T} csl_d(t) / T_d. \tag{6.50}$$

International CSL

The international customer-expected received finished goods in each period, in which the contracted lead time between the customer and the manufacturer has to be considered, is shown in Eq. (6.51). The cumulative unfulfilled customer demand in Eq. (6.52) represents the amount of finished goods that the customer should have received according to the contracts but actually has not yet received. The periodic CSL in Eq. (6.53) and the average CSL over the complete planning horizon in Eq. (6.55) are defined. Eq. (6.54) represents the total number of periods in which the international customer is expecting to receive some contracted shipments.

$$CERO_i(t) = \sum_{j=1}^{t} SOI(j) I\{j + s_{li}(j) = t\}; \tag{6.51}$$

$$BCO_i(t) = CERO_i(t) - CFGI_I(t) + BCO_i(t-1); \tag{6.52}$$

$$csl_i(t) = \begin{cases} 0; & \text{if } CFGI_I(t) - BCO_i(t-1) \le 0 \\ \dfrac{CFGI_I(t) - BCO_i(t-1)}{CERO_d(t)}; & \text{if } CFGI_I(t) - BCO_i(t-1) > 0, \\ & CERO_i(t) > 0, \end{cases} \tag{6.53}$$

$$T_i = \sum_{t=1}^{T} I\{CERO_i(t) > 0\}; \tag{6.54}$$

$$CSL_i = \sum_{t=1}^{T} csl_i(t) / T_i. \tag{6.55}$$

Supply chain CSL

$$CSL = (CSL_d + CSL_i) / 2. \tag{6.56}$$

The problem is to make the optimal decisions on raw material ordering and finished goods production in order to achieve the best

SCP, defined in Eq. (6.45) and/or (6.56). Mathematically, the SCM problem in our context is to determine the best decisions ($u_i(t)$, $u_O(t)$, $u_I(t)$) so that the SCP can be optimised.

Non-parameterised and parameterised decision strategies

Regarding the complexity of the mathematical models, it is very difficult to solve the problem analytically. In the literature, many inventory and production management strategies have been proposed, which are shown to be effective in uncertain situations. Therefore, the focus is narrowed down to a set of specific types of management strategies with an emphasis on investigating the impact of information sharing and coordinated management on SCP.

This section introduces two groups of management strategies: non-parameterised and parameterised strategies. Non-parameterised strategies either do not require input control parameters or use pre-specified fixed control parameters to determine the decision variables (raw material ordering and finished goods production) $u_i(t)$ and $u_o(t)$. Parameterised strategies use a pair of control parameters, for example, (s, S) policy, which represent the low and high bounds of raw materials and finished goods inventory levels to trigger the ordering and production decisions (($u_i(t)$ and $u_o(t)$). Clearly, by appropriately designing the control parameters, s and S, the SCP can be improved.

Non-parameterised strategies

In this study there are six non-parameterised strategies which are applied and evaluated in the SC model using simulation, including: (1) JIT (lot-for-lot); (2) JIT (lot-for-lot) with safety stock; (3) Kanban (fixed WIP); (4) Kanban (fixed WIP) + safety stock; (5) VMI (based-stock policy); and (6) VMI (based-stock policy) with safety stock. The case company B's original strategy will also be evaluated and used as a base reference point. There are two fixed safety stock levels: 20% and 30%. The reason for their choice is based on the consideration of inventory capacity, the raw material product cycle time and the financial flow information (from the interview discussions).

1. **Just-in-time/lot-for-lot**

In this strategy, raw material and production planning is based on the information related to the receipt of domestic and international customer orders at each period. The production planning at one period is equal to the sum of received domestic customer and international customer orders during one period. The raw material planning is based on production planning with consideration of the consumption rate of main raw materials during the production. This type of JIT is the same as the traditional lot-to-lot policy. Under this strategy, only customer order information has been considered. The strategy has been described as follows:

$u_o(t) = \max(0, DMD(t) + DMDI(t));$
$u_i(t) = u_o(t) *r_i.$

2. **Just-in-time + safety stock**

Under this strategy, the manufacturer makes production decisions based upon received domestic and international customer orders plus an extra percentage of the received customer orders as safety stock; meanwhile the manufacturer makes raw material ordering decisions based on the finished goods production plan plus an extra percentage as raw material safety stocks. In the system, the strategy has been represented as:

$u_o(t) = \max(0, (1 + \text{SafetyStock})*(DMD(t)+DMDI(t)));$
$u_i(t) = (1 + \text{SafetyStock})*u_o(t) *r_i.$

3. **Kanban (fixed WIP) policy**

This inventory management policy is a type of fixed WIP policy. Under this strategy, the production decisions are made based upon the received domestic and international customer orders minus the finished goods on-hand inventory levels (both domestic and international inventory) at each period. The raw material procurement decisions are made based on the production plan and the raw material on-hand inventory at each period. In this strategy, not only customer order information, but also the on-hand inventory information of finished goods and raw materials are considered. In the system, the strategy has been represented as:

$u_o(t) = \max(0, DMD(t) + DMDI(t) - x_o^D(t) - x_o^I(t));$
$u_i(t) = \max(0, u_o(t) *r_i - x_i(t)).$

4. Kanban (fixed WIP) + safety stock

Under this policy, the production decisions are made based on the received domestic and international customer orders minus finished goods on-hand inventory level (both domestic and international inventory) plus a percentage (20% and 30%) of extra finished goods at each period. The raw material procurement decisions are made based on the production plan and the raw material on-hand inventory plus a percentage of (20% and 30%) extra amount at each period. In the system, the strategy has been represented as:

$$u_o(t) = \max(0,\ (1+ \text{SafetyStock})*(DMD(t)+DMDI(t) - x_o^D(t) - x_o^I(t)));$$
$$u_i(t) = \max(0,\ (1 + \text{SafetyStock})*(u_o(t) * r_i - x_i(t))).$$

5. Vendor management inventory/based-stock policy

This inventory management policy is a type of based-stock policy. The production decisions are made in the same way as the Kanban policy. The raw material procurement decisions are made based on the production plan and the raw material on-hand inventory and the finished goods on-hand inventory at each period. The difference between VMI policy and Kanban policy is that under VMI, the raw material procurement decision making also considers the information of the finished goods on-hand inventory level, as if a vendor is managing the inventory. In the system, the strategy has been represented as:

$$u_o(t) = \max(0,\ DMD(t)+DMDI(t) - x_o^D(t) - x_o^I(t));$$
$$u_i(t) = \max(0,\ u_o(t) * r_i - x_i(t) - (x_o^D(t)+x_o^I(t))*r_i\ ).$$

6. Vendor management inventory + safety stock/based-stock policy

Under this strategy, the production decisions are made based on the received domestic and international customer orders minus the finished goods inventory level (both domestic and international inventory) plus 20% and 30% extra finished goods at each period. The raw material procurement decisions are made based on the production plan and the raw material on-hand inventory plus 20%

and 30% extra amount at each period. In the system, the strategy has been represented as:

$$u_o(t) = \max(0, (1 + \text{SafetyStock})*(DMD(t) + DMDI(t) - x_o^D(t) - x_o^I(t)));$$
$$u_i(t) = \max(0, (1 + \text{SafetyStock})*(u_o(t) *r_i - x_i(t) - (x_o^D(t) + x_o^I(t))*r_i)).$$

The application and evaluation of these policies will be presented in Chapter 8.

Parameterised strategies

The non-parameterised strategies do not offer much opportunity for improvement. Therefore a number of parameterised strategies are adopted, in which their control parameters can be designed in an integrated way by using global optimisation algorithms such as genetic algorithms. In this work, the parameterised strategies combine the JIT and VMI concepts with (s, S) policy, in which s and S are the control parameters.

In the (s, S) policy, s and S represent the low and high boundaries of inventories, respectively. Whenever the inventory level drops below the re-order point s, a production or replenishment decision is made in order to bring the inventory level up to S. In our context, there are three main types of raw materials and one type of finished goods. Therefore, s_i (i=1,2,3) represents the re-order point for raw material i; S_i (i=1,2,3) represents the order-up-to point for raw material i; s_0 represents the low boundary of the finished goods inventory; and S_0 represents the high boundary of the finished goods inventory.

In order to distinguish them from the non-parameterised strategies, we use the terms PS-JIT and PS-VMI to represent the parameterised JIT and parameterised VMI strategies when dealing with a single objective of SCP (in Chapter 9); and we use the terms PM-JIT and PM-VMI when dealing with multiple objective situations (in Chapter 10).

1. PS(M)-JIT strategy

Under PS(M)-JIT strategy, for raw material ordering, only the raw material on-hand inventory level information is considered. Therefore, if the raw material on-hand inventory level is smaller than s_i, the company starts to place an order for raw materials. The order quantity equals S_i minus the on-hand inventory level. For the production plan, if the finished goods on-hand inventory level is smaller than s_0, the company starts to produce finished goods. The production quantity equals S_0 minus finished goods on-hand inventory level. The PS(M)-JIT is described mathematically as follows:

$u_i(t) = \max(0, S_i - x_i(t))$, if $x_i(t) <= s_i$;
$u_i(t) = 0$, if $x_i(t) > s_i$;
$u_o(t) = \max(0, S_0 - x_o^D(t) - x_o^I(t))$, if $x_o^D(t) + x_o^I(t) <= s_0$;
$u_o(t) = 0$, if $x_o^D(t) + x_o^I(t) > s_0$.

1. **PS(M)-VMI strategy**

Under PS(M)-VMI strategy, for raw material ordering, both the raw material and finished goods on-hand inventory information are considered for both raw material ordering and production decision making. More specifically, if the raw material on-hand inventory level plus the finished goods inventory multiplied by the corresponding consumption rate is smaller than s_i, the company starts to place the raw material order. The order quantity equals S_i minus the echelon base-stock (which is equal to the raw material on-hand inventory level plus the finished goods on-hand inventory multiplied by the consumption rate). For the production plan, it is the same as the PS(M)-JIT strategy. Mathematically, the PS(M)-VMI strategy is given by:

$u_i(t) = \max(0, S_i - x_i(t) - r_i{*}\,(x_o^D(t) + x_o^I(t)))$, if $x_i(t) + r_i{*}\,(x_o^D(t) + x_o^I(t)) <= s_i$; $u_i(t) = 0$, if $x_i(t) + r_i{*}\,(x_o^D(t) + x_o^I(t)) > s_i$;
$u_o(t) = \max(0, S_0 - x_o^D(t) - x_o^I(t))$, if $x_o^D(t) + x_o^I(t) <= s_0$;
$u_o(t) = 0$, if $x_o^D(t) + x_o^I(t) > s_0$.

Summary

In summary, this chapter has presented the mathematical models for the DSC and ISC. There are four sub-models: customer order; production; raw material ordering and transportation; and finished goods satisfying customer demand model. The differences between DSC and ISC are identified from several aspects, for example, uncertainty parameters, finished goods on-hand inventory level update and SCP calculation, which exist in the customer order sub-model, the finished goods satisfying customer order and transportation sub-model and the SCP section. Note that the DSC and ISC are coupled in the production sub-model and in the raw material procurement and transportation sub-model. Therefore, the manufacturer has to make raw material procurement and finished goods production decisions considering both DSC and ISC simultaneously in order to optimise the SCP.

Given the complexity of the mathematical problem, it is difficult to determine the decision variables in the SC model. A set of non-parameterised strategies and a set of parameterised strategies are introduced to manage the procurement and production decisions. In the next few chapters, the focus is on how to evaluate the proposed strategies and how to optimise the parameterised strategies in the SC context with the emphasis on investigating the impacts of information sharing and coordinated management on SCP.

7

Single Objective and Multiple Objective Genetic Algorithms

In this chapter, a simulation program representing the generalised SC model and flows outlined in Chapters 5 and 6 is developed. The simulation program will be used as a tool to evaluate SCP under given strategies. A SOGA and a MOGA program will be developed to tackle the optimisation problem, which will be used to optimise the parameterised management strategies in later chapters.

Introduction

In this section, the relationship between the SC simulation program and the optimisation programs (i.e., SOGA and MOGA) is described. How the simulation program and the optimisation programs will be used in relation to the non-parameterised strategies and the parameterised strategies is explained. The differences between SOGA and MOGA are briefly outlined.

The SC simulation program and the SOGA and MOGA optimisation programs are developed using a Matlab platform. Both SOGA and MOGA programs rely on the SC system simulation program to evaluate the fitness functions. The simulation program is used to evaluate the non-parameterised management strategies. On the other hand, SOGA and MOGA are used to optimise the control parameters in the parameterised management strategies presented in Chapter 6. The relationships among the SC simulation program, the optimisation programs (SOGA and MOGA), the non-parameterised strategies and the parameterised strategies are illustrated in Figure 7.1.

There are three main differences between SOGA and MOGA. Firstly, the purposes of these two optimisation programs are

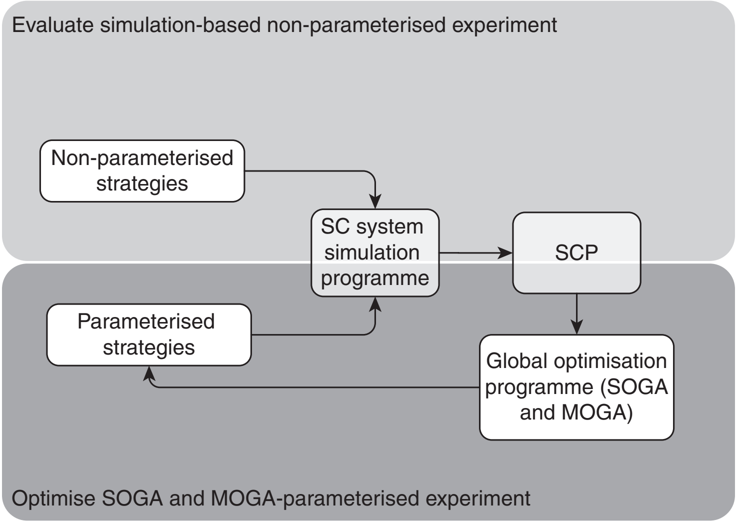


Figure 7.1 The relationship of SC simulation program and global optimisation program

Source: Authors.

different. SOGA is employed to optimise a single SCP; however, MOGA is used to optimise multiple SCPs. Secondly, the solution ranking is different, for example, MOGA is based upon non-dominated thinking to rank the solutions. Thirdly, MOGA is able to identify a diverse set of solutions, in which the users can select a solution according to their expectations of the solution's performance in multiple criteria.

Supply chain system simulation

Regarding the generalised SC model in Chapter 5 and mathematical model in Chapter 6, the SC system simulation program has been developed using the Matlab platform. The purposes of developing this program include: (1) to simulate the SC system; (2) to evaluate the non-parameterised strategies; and (3) to serve as a component of the global optimisation program (SOGA and MOGA). The SC system simulation program is outlined as follows:

1. *Initialisation*: initialise all modelling variables, non-parameterised strategies and parameterised strategies.
2. *Setting up*: set up all input variables, the lower and upper boundaries of time and quantity uncertainty variables and cost coefficients.
3. *Customer ordering*: simulating customer ordering model (Sub-model I).
4. *Strategy selection*: non-parameterised or parameterised.
5. *Dynamic system simulation*: simulate raw material ordering and shipping model (Sub-model III); simulate production model and update raw material and finished goods inventory level (Sub-model II); and simulate finished goods satisfying customer demand and shipping model (Sub-model IV).
6. *Evaluation*: evaluating the SCP.
7. *Until* termination conditions (t=T) are satisfied *End*.

To have a clearer view of the structure of the simulation program, Figure 7.2 shows the flows of the processes and activities in the program.

Genetic algorithm assumption

1. The initial population is created randomly within the feasible ranges of the solutions.

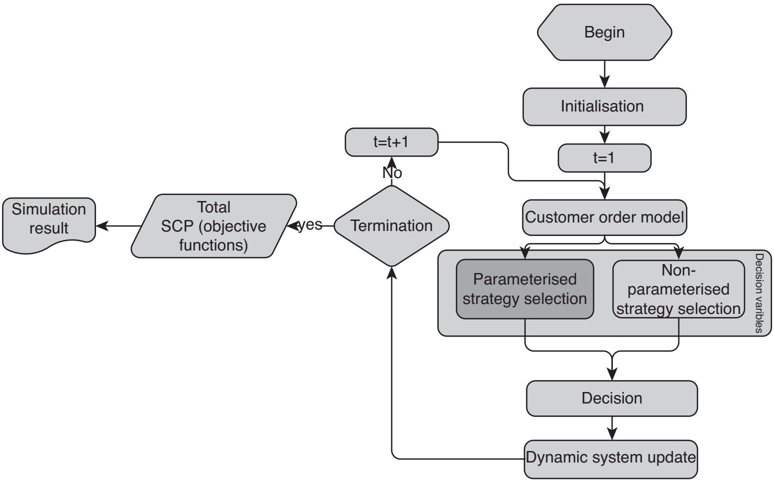


Figure 7.2 The flowchart of SC system simulation
Source: Authors.

2. The random selection of choosing parent sets of A and B in order to produce offspring follows uniform distribution.
3. The crossover rate uses the blend crossover (BLX) approach.
4. The mutation rate is set up to 0.5.
5. After generating the offspring population, the solutions are checked against their feasibility. The infeasible solutions are repaired, for example, taking the value 0 if it is negative.

SOGA development

Figure 7.3 shows the flowchart of SOGA. The dashed-line boxes are the main differences between SOGA and MOGA. The dark grey boxes are the main differences of the GA program in SC from other GA programs used for other purposes.

Here *P* denotes the population set of the parent solutions and *N* denotes the number of decision parameters in each solution.

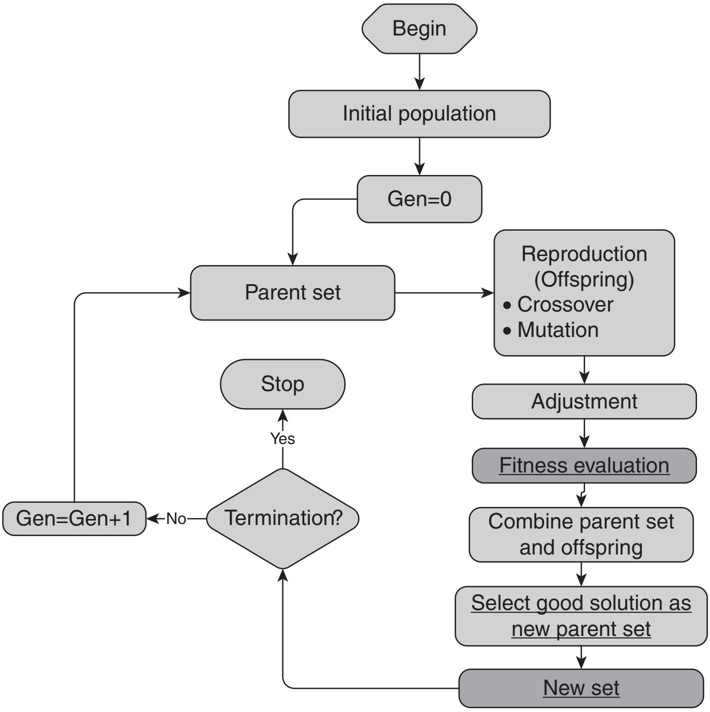


Figure 7.3 A flowchart of the working principle of SOGA

The overall procedure of the SOGA developed in this study is described as follows:

1. *Initialisation*: initialise a random parent population. *Repeat*.
2. *Evaluation*: Evaluate the objective function of each solution.
3. *Selection*: Select two solutions as parents from the parent population for reproduction. The selection criterion is based on the fitness assignment (or objective function).
4. *Recombination*: Apply crossover to selected solutions to produce offspring, which may produce better solutions.
5. *Mutation*: Apply mutation locally to some genes of the offspring with a particular probability.
6. *Adjustment*: Adjust the offspring based upon the constraints to solutions. For example, if the offspring solution violates the constraints, the solution will be forced to be 0.
7. *Evaluation offspring*: Evaluate the objective function of each solution in offspring set.
8. *Replacement*: Combine the parents' set and the offspring's set, and then rank the combined set in accordance with the fitness value. The new parent population is created by selecting the best set of solutions from the combined set.
9. *Until* termination conditions are satisfied *End*.

The key steps in the SOGA program shown in Figure 7.3 are explained in the following sections, including initialisation, reproduction and adjustment (in which all solutions will be forced within the reasonable boundary in terms of constraints), fitness evaluation and combine offspring set with parent set, new parent set and termination.

Initialisation

In the study, a gene represents a real number (e.g., the reorder point s, or the order-up-to-point S, if an (s, S) policy is to be optimised). A chromosome represents a complete set of all control parameters. For example, if (s, S) policies are applied for raw material procurement and finished goods production, a chromosome will consist of eight real numbers since there are four types of raw materials and one type of finished goods. The real parameter GA can use the objective fitness value directly. The SOGA program is applied to optimise one objective, for example, SC total cost or CSL.

The solution consists of eight decision parameters, that is, $\{(s_i, S_i)$ for $i=0,1,2,3\}$. These parameters may take values from different intervals due to the physical and logical constraints, for example, the raw material consumption rates to produce finished goods are different for different raw materials. Therefore, it is important to define the decision boundaries for each decision parameter. In this experiment, the decision boundaries are designed based upon industrial data, and the initial population is randomly generated within the decision boundaries. The initialisation process is described here:

1. Randomly create a population set, $P_{0,}$ in which each solution consists of N decision parameters (in this research, there are eight decision parameters, thus N=8).
2. Evaluate the fitness of each solution in terms of the objective function.
3. Rank the solutions according to the fitness in decreasing order (if doing maximum).
4. Create an empty set as the parent set P_0'.
5. Select the best solution in the light of the fitness ranking and fill the parent set until the parent population size is reached.
6. Set the number of generations to be zero, that is, Gen=0.

Reproduction and adjustment

The reproduction step includes two operations, crossover and mutation, which are described further, and the adjustment is implied.

Crossover

There are many ways to perform the crossover operation including linear crossover (Wright, 1991), BLX and its variants (Michalewicz and Janikow, 1991; Goldberg, 1991; Eshelman and Schaffer, 1993), a naive crossover (Deb, 2009) and simulated binary crossover (Deb and Agarwal, 1995; Deb and Kumar, 1995).

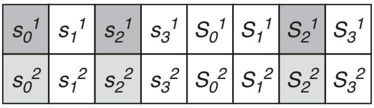
In this study, the BLX method has been employed for the crossover operators as it is commonly suggested with fuzzy recombination and is easy to adopt in the real parameter GA. It has good search ability for separable fitness functions (Takahashi and Kita, 2001). The list of how to select crossover positions includes: (1) play a tournament selection mechanism in order to randomly pick two solutions from the parent solution set P_0'; (2) in order to improve the performance of GA (suppose two solutions (A and B) are randomly selected), if solution A is better than solution B, then solution A will be kept as parent 1. Otherwise solution B will be kept as parent 1; (3) repeat this process to choose parent 2; (4) perform step 1, step 2 and step 3 repeatedly until $2^*|P_0'|$ solutions are selected, in which $|P_0'|$ represents the size of the parent set; (5) randomly identify the crossover positions (following the uniform distribution) of each pair of the selected parent solutions, which indicates which genes will be undergoing crossover. Finally, perform the BLX operations to produce inner-offspring set *O*.

More details of these steps are explained later. Note that there are eight decision variables, ((s_i, S_i) for i=0,1,2,3), in the solution.

1. Generate a paired solution set through random tournament selection from the parent set. The paired solution set is denoted as $\{P'(i,k)\}$:$i=0,1,2,3$, k=1,2…K, $K=2^*|P_0'|$).

$$P' = \begin{bmatrix} s_0^1 & s_1^1 & s_2^1 & s_3^1 & S_0^1 & S_1^1 & S_2^1 & S_3^1 \\ s_0^2 & s_1^2 & s_2^2 & s_3^2 & S_0^2 & S_1^2 & S_2^2 & S_3^2 \\ s_0^3 & s_1^3 & s_2^3 & s_3^3 & S_0^3 & S_1^3 & S_2^3 & S_3^3 \\ s_0^4 & s_1^4 & s_2^4 & s_3^4 & S_0^4 & S_1^4 & S_2^4 & S_3^4 \\ . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . \\ s_0^K & s_1^K & s_2^K & s_3^K & S_0^K & S_1^K & S_2^K & S_3^K \end{bmatrix}$$

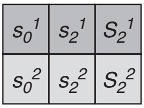
2. For each pair of solutions in the paired solution set, randomly select the crossover points. Figure 7.4 shows the first pair in P' and Figure 7.5 shows the selected crossover points in the first pair.



s_0^1	s_1^1	s_2^1	s_3^1	S_0^1	S_1^1	S_2^1	S_3^1
s_0^2	s_1^2	s_2^2	s_3^2	S_0^2	S_1^2	S_2^2	S_3^2

Figure 7.4 The first pair in the paired solution set

3.



s_0^1	s_2^1	S_2^1
s_0^2	s_2^2	S_2^2

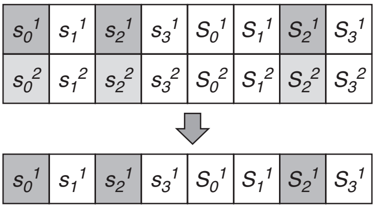
Figure 7.5 The randomly selected crossover position in the first pair

4. Use the following function to perform the crossover operations and produce an offspring (Deb, 2009):

$$x_i'(t+1) = (1-\gamma_i(t))x_i^1(t) + \gamma_i(t)x_i^2(t). \tag{7.1}$$

$$\gamma_i(t) = (1+2\alpha)u_i(t) - \alpha \quad (u_i \in [0,1];\ \alpha = 0.5;\ t = 1,2\ldots T). \tag{7.2}$$

Eq. (7.1) represents how the genes (e.g., $x_i^1(t)$ and $x_i^2(t)$) in two parents are crossed over to generate the gene for the offspring. In Figure 7.3, s_0^1, s_2^1 and S_2^1 can be understood as $x_i^1(t)$; s_0^2, s_2^2 and S_2^2 can be understood as $x_i^2(t)$. Eq. 7.2 represents how many percentage values of the offspring gene are obtained from parent one ($x_i^1(t)$) and from parent two ($x_i^2(t)$), where u_i follows the uniform distribution in (0, 1); therefore γ_i is uniformly distributed for a fixed value α. According to Deb (2009), this crossover could perform better than using a fixed percentage split. For the example in Figure 7.5, the result of the crossover operation is shown in Figure 7.6, in which s_0', s_2', $S_2'$are obtained using Eq. (7.1).



s_0^1	s_1^1	s_2^1	s_3^1	S_0^1	S_1^1	S_2^1	S_3^1
s_0^2	s_1^2	s_2^2	s_3^2	S_0^2	S_1^2	S_2^2	S_3^2

s_0^1	s_1^1	s_2^1	s_3^1	S_0^1	S_1^1	S_2^1	S_3^1

Figure 7.6 The selected crossover points in the first pair

5. After finishing the crossover operations for all pairs in the paired solution set, the inner-offspring set O is created, which will then be mutated.

Mutation and adjustment

Mutation is another important operation in the reproduction process. Random mutation has been employed in this study because it is easy to use and control (Michalewicz, 1996). However, random mutation may result in infeasible solutions because they may violate the capacity constraints for raw material inventory and productivity in the SC model; therefore, after mutation it requires an adjustment process in order to ensure all solutions are feasible. The mutation selection is done universally. Each gene of an offspring solution can be selected with a probability equalling the mutation rate and then perform Eq. (7.3) to do the mutation.

The details of the mutation operation can be described as follows:

1. Select the new genes x_i' in the inner-offspring solutions after the crossover operation, for example, in Figure 7.6, x_i' represents s_0', s_2' and S_2'.
2. Mutate the genes using the following equation,

$$y_i'(t+1) = x_i'(t) + (r_i(t) - 0.5)\Delta_i, \ (r_i(t) \in [0,1], \ \Delta_i = x_i^{max} - x_i^{min}). \qquad (7.3)$$

In this equation, r_i is a random number following the uniform distribution between 0 and 1 and Δ_i is a given number representing the user-defined maximum perturbation allowed in the i^{th} decision variable. In this context, it could control the decision parameters' variation considering the constraints in the SC model. For the example in Figure 7.6, the aforementioned mutation is illustrated in Figure 7.7, in which s_0'', s_2'' and S_2'' represent y_i' in Eq. (7.3).

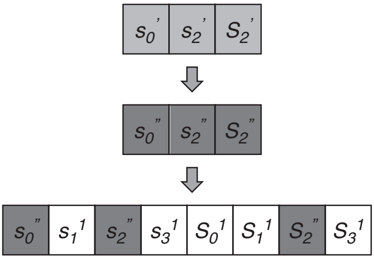


Figure 7.7 The mutation operation on the new gene

3. Repeat the earlier two steps (1 and 2) for each solution in the inner-offspring set O, and the new offspring set has been created, which is denoted as Q.

4. The value of decision parameters is not greater than the upper bounds and not smaller than 0′. Thus, in this study, the feasibility has been checked based on the productivity and raw materials' inventory capacities. Adjust each solution in the offspring set *Q* to make it feasible. For example, all decision parameters must be non-negative and within the boundaries. If the solution is infeasible, the solution has to be re-thought, for example, force the parameter to take the upper bound or the lower bound of the feasible interval.

Fitness evaluation and combine offspring set with parent set

In this step, firstly, the fitness value of each solution in the offspring set is evaluated using the simulation model. In the study, the objective(s) function(s) in the SC simulation model is employed for the fitness evaluation. (In SOGA, the fitness function is the cost function; in the MOGA, the fitness functions are cost function and customer services function.) Using the Monte Carlo method, 100 samples are used to average the performance in order to estimate the results reasonably and accurately. Secondly, combine the offspring set *Q* and the parent set P' together to form a new set *R*. Thirdly, rank the solutions in *R* according to their fitness values.

New parent set

The new parent set is created from the solutions in *R* using the elitist selection rule, that is:

1. Set a new parent population set $P'' = \varnothing$.
2. Fill the parent set P'' using the best $|P''|$ solutions in *R*.

Termination

Terminate the iterative search procedure and return the best solution so far if the termination criteria are satisfied. Otherwise, set Gen = Gen + 1, and go through the reproduction process in which the parent set should be updated by the new set P''.

MOGA development

In MOGA, two important SCP measures are considered, that is, the SC total cost and the CSL, simultaneously. Similar to the SOGA, there are eight decision parameters to be optimised. The overall procedure of MOGA can be described as follows. The italicised parts represent the main differences from SOGA.

1. *Initialisation*: Initialise a random parent population. *Repeat*.
2. *Non-dominated fitness evaluation*: Evaluate every objective function for each solution in the parent population and rank them with non-dominated thinking.
3. *Selection*: Select two solutions as parents from the parent population for reproduction. The selection criterion is based on the *fast-non-dominated sort selection*.
4. *Recombination*: Perform crossover operation to the selected solutions to produce offspring.
5. *Mutation*: Perform mutation operations locally to some genes of the offspring with a certain probability.
6. *Adjustment*: Adjust the offspring based upon the constraints of decision parameters in the SC model.
7. *Non-dominated evaluation offspring*: Evaluate the objective functions of each solution in the offspring set.
8. *Replacement*: Combine the parent set and the offspring set, and then rank the combined set based on the *fast-non-dominated sort selection* and the *crowding distance calculation*. The new parent population is created by replacing it with the best set of solutions in the combined set.
9. *Until* termination conditions *End*.

In MOGA, the initialised parent population can be created in the same way as in SOGA. The reproduction, adjustment and termination processes are also the same as in SOGA. The main differences are the steps and activities including the non-dominated fitness selection, the crowd distance calculation and the new parent set creation, which will be explained in detail later. Figure 7.8 shows the flowchart of the MOGA in our study, in which the components that are different from the SOGA are indicated using shaded boxes.

Non-domination

The traditional optimisation method undertakes multiple objective optimisation by allocating different weights over different objective functions in order to transform the multiple objective optimisation problems into a normal single objective optimisation problem.

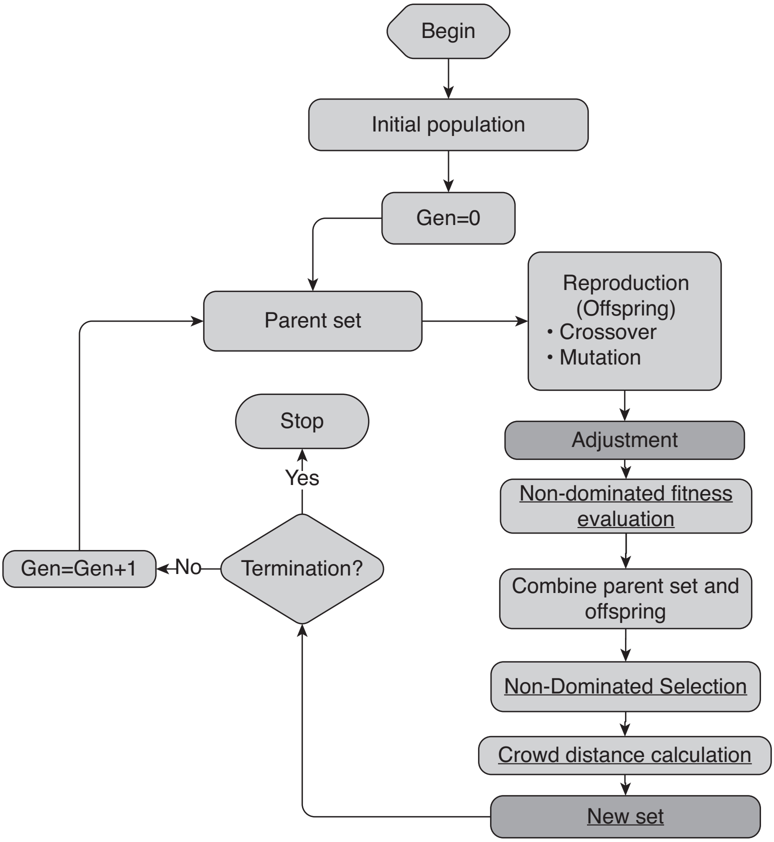


Figure 7.8 A flowchart of the working principle of MOGA

Source: Authors.

However, MOGA has employed a different thinking (called non-domination) to find a non-dominated set, which represents a set of good solutions instead of a single solution (as in traditional optimisation methods). Therefore, even though the weights of objective functions are unknown, the set of non-dominated solutions could provide a range of good solutions that cover all objectives.

1. In this study, according to Deb (2009), the definition of non-domination is explained as: assuming A dominates B means (1) solution

A is no worse than B in all objectives, and (2) A is strictly better than B in at least one objective ($A \triangleleft B$ or $A \preceq B$). The traditional MOGA program usually implements non-dominated selection by comparing each solution's fitness in the light of all objective functions. For each generation, it requires overall MP^3 comparisons (Deb, 2009) (where M is the total number of objective functions and P is the population size), and it influences the efficacy of MOGA. A more efficient non-dominated sorting approach is proposed by Deb (43) and is adopted in this MOGA; there are four steps in the fast non-dominated solution selection. Suppose A and B are two solutions; n_A is a domination count, which means the number of solutions which dominate the solution A; D_A represents a set of solutions that solution A dominates. The sorting algorithm requires MP^2 times comparisons. At the end of this procedure, all solutions in the first non-dominated front (denoted by the set $F_{i,}$ with i=1) will have their domination count as zero. Select two solutions (A and B), compare their fitness values in all objectives.

2. If A is strictly better than B in all objectives, then keep A, otherwise keep B; if A is strictly better than B in one objective and no worse than B in other objectives then keep A, otherwise keep B.
3. Randomly select another solution and repeat process 2 (comparing with the winner solution in step 2) until all solutions have been compared.
4. Based on non-dominated fitness evaluation, classify all solutions into different fronts and create front set F_i for i=1,2,3,…I; $F_{1.}$ includes the group of the best solutions.

Fast non-dominated sort selection

Based on these four logical steps, according to Deb (2009: 43), a fast non-dominated sort has been employed in this study. It introduces how to compare two solutions and how to classify the solution into different non-dominated fronts.

Input Parameters: population (P), consisting of solutions, for example, A and B

```
Begin:
for each $A \in P$ do
    $n_A = 0$ and $D_A = \phi$ (empty set);
    for each $B \in P$ do
```

```
            if ($A \le B$) then
                $D_A = D_A \cup \{B\}$ {if $A$ dominates $B$ – save it in set of solutions $D_A$}
            else if ($B \le A$) then
                $n_A = n_A + 1$ {if $B$ dominates $A$ – keep the count of the solutions}
        if $n_A = 0$ then
            $F_1 = F_1 \cup \{A\}$ {if nothing dominates $A$ then keep it in the first front},
    $i = 1$ {set a front counter}
    while $F_i \ne 0$ do
        $Q = \phi$ (empty set);
        for each $A \in F_i$ do
            for each $B \in D_A$ do
            $n_B = n_B - 1$
            if $n_B = 0$ then
                $Q = Q \cup \{B\}$ { keep $B$ in list $Q$}
    $i = i + 1$
    $F_i = Q$ {form current front with solutions of $Q$}
    Return a list of non-dominated fronts $F_1$.
```

The complexity of this non-dominated sorting algorithm is of $O(MN^2)$. Along with the convergence to the Pareto-optimal set, it is also desired to maintain a good spread of solutions in the parent set so that the users have a diverse choice of solutions. The use of density-estimation metric and the crowded-comparison operator can achieve the diversity of the solutions in the parent set (Deb, 2009), which will be explained in the next section.

Crowding distance calculation

In order to estimate the density of solutions surrounding a particular solution A in the population, calculating the distance of two solutions on either side of solution A along each of the objectives could contribute. The quantity d_A serves as an estimate of the perimeter of the cuboid formed by using the nearest neighbours as the vertices named crowding distance. In our MOGA, the crowding-sort using Deb's (2009, 248) elitist non-dominated sorting genetic algorithm (NSGA II) to calculate the crowd distance of the solutions in $F_{i\ is}$ is employed.

New set

In this process, a new set will be created by using the solutions in F_i. There are two steps:

1. Setting a new population set $P''=\emptyset$.
2. Filling all P'' by F_1 to F_l, (from the best solutions in front 1) if there are more solutions in the same front (e.g., F'), then they are selected according to the rank of crowding distance as described in Deb (2009). Step 2 continues until a new set P'' has been created.

Summary

In summary, this chapter has described the simulation tool and the SOGA and the MOGA optimisation tools adopted in the study. How they are related to solve the SCM problem is explained. In order to ensure all solutions are feasible, there is an adjustment process after the reproduction process in SOGA and MOGA. In the adjustment process, all solutions are forced to be zero. In MOGA, a non-dominated thinking is employed so that all objectives are optimised simultaneously. The crowd distance sorting is used to improve the diversity of the non-dominated solutions in the parent population (which provides an estimate of the density of the solutions surrounding a particular solution in the population).

The GA parameters are selected mainly based on suggestions from the literature (e.g., Deb, 2009) and the pilot runs in our context. In the experiments, in Chapters 9 and 10, the GA input parameters are set as follows:

In SOGA, the population size is 30; the generation number is 60; the crossover rate is 0.5; and the maturation rate is 0.5. The average CPU time used by SOGA in Matlab 7.11.0 (R2010b) versions is 612.886 seconds on a PC with 1.86 GHz processor.

In the MOGA procedure, a number of parameters are selected based on a non-dominated front. In the experiments, the population size is 120; the maximum generation number is 60; the mutation probability is 0.5. MOGA is coded using Matlab 7.11.0 and run on a PC with 1.86 GHz. The running time (or CPU time) of each optimisation experiment is about 669.56 seconds.

In the following chapters, the simulation tool and SOGA and MOGA will be applied to the SCM problem under study.

8

The Impact of Information Sharing

This chapter will define the concepts of information sharing and coordinated management used throughout this research. A range of simulation experiments is undertaken to evaluate non-parameterised operational strategies to investigate the impact of information sharing on SCP.

The definition of information sharing and coordinated management

According to the literature review in Chapter 2, information sharing and coordinated management can generally improve SCP. However, to implement information sharing and coordinated management, additional effort has to be committed. Therefore, it is interesting to know to what degree information sharing and coordinated management could improve the SCP because such knowledge would be helpful for managers to decide whether the benefits would exceed the costs.

The concepts of information sharing and coordinated management are defined in the model context. Information sharing refers to different functions and entities in the SC system, exchanging information that is more relevant or exchanging the relevant information in a more timely and accurate way. Coordinated management refers to how different functions and entities in the SC system can make decisions cooperatively. This chapter will focus on information sharing. Coordinated management will be investigated in more detail in the later chapters.

This study will not address the technology aspect on how to implement the information sharing mechanism. Instead, the focus is on how information sharing impacts on the SCP. Information sharing is directly linked to the timeliness and accuracy of information flow. Therefore, it is reasonable to represent the level of information sharing using lead times, lead-time reliability and quantity uncertainty. For example, Mason-Jones and Towill (1998) state that one of the greatest opportunities for lead-time compression is via information sharing. Machuca and Barajas (2004) use order information delays to represent whether or not EDI is implemented to share order information in the SC.

In this study, information sharing is mainly represented by the combination of the degree of time uncertainty and the degree of quantity uncertainty. In other words, longer lead times and higher levels of lead-time uncertainties represent a lower level of information sharing; and a higher degree of quantity uncertainty also represents a lower level of information sharing.

In the light of data from the interviews, all uncertainties are represented by uniform distributions in the simulation. The distribution of uncertainties (time and quantity) is based on the earlier interviews. In addition, according to the interviews, time uncertainty is generally within the range of (0, 7) days, and quantity uncertainty is in the range of (0, 0.3). However, managers believe that by choosing a suitable application of IT (e.g., the ERP system) time uncertainty can be reduced to within 3 days and quantity uncertainty can be reduced to the range of (0, 0.1). Thus, in this study, two levels (high and low) for both types of uncertainties in the experiments are considered, and the experimental strategy is to follow a 2^2 full factorial design in order to evaluate the impact of factors in time and quantity uncertainties upon two SCPs:

- Time uncertainty:
  - high level: lead times follow a uniform distribution U(0, 7);
  - low level: lead times follow a uniform distribution U(0, 3).
- Quantity uncertainty:
  - high level: the delayed fraction of quantities follows a uniform distribution U(0, 0.3);
  - low level: the delayed fraction of quantities follows a uniform distribution U(0, 0.1).

Therefore, the combination of these two types of uncertainty levels gives rise to a total of four scenarios representing four information sharing levels:

1. Time uncertainty ~ U(0, 7) and quantity uncertainty ~ U(0, 0.3)
2. Time uncertainty ~ U(0, 7) and quantity uncertainty ~ U(0, 0.1)
3. Time uncertainty ~ U(0, 3) and quantity uncertainty ~ U(0, 0.3)
4. Time uncertainty ~ U(0, 3) and quantity uncertainty ~ U(0, 0.1)

In the rest of this chapter, a range of simulation experiments are conducted to evaluate the six non-parameterised operational strategies presented in Chapter 6 to investigate the impact of information sharing on SCP. It assumes that the international sales strategy has been set to 30% which represents using 30% of produced finished goods in each period to satisfy international customer orders. Note that different operational strategies utilise different pieces of information; they can also be interpreted as different types of information sharing.

In the following sections, Obj 1 represents the SC total cost in thousand UK£; Obj 2 represents the SC average CSL. There are 217 periods in each sample. The simulation sample size is 200. "Mean" represents the mean value of samples (200 samples). Standard deviation is represented by "SD".

Just-in-time/lot-for-lot

Table 8.1 shows the results of the original and JIT strategy in four scenarios, in which the better performance between the original strategy and JIT are indicated in bold font. In all four scenarios, the JIT strategy outperforms the company's original strategy in terms of the total SC cost (e.g., in scenario i, the total cost is reduced from £16,121 thousand to £10,628 thousand). However, in terms of the CSL, the original strategy is better than JIT in the first three scenarios but worse than JIT

Table 8.1 The simulation result of the company's strategy and the JIT strategy under four uncertain scenarios

	Original strategy				**JIT**			
	Mean		**SD**		**Mean**		**SD**	
Uncertainty scenarios	**Obj 1**	**Obj 2**	**Obj 1**	**Obj 2**	**Obj 1**	**Obj 2**	**Obj 1**	**Obj 2**
i	16121	**0.013056**	6054.9	0.013021	**10628.0**	0.007405	6431.7	0.010802
ii	15043	**0.02068**	5844.3	0.016719	**9906.5**	0.011663	6177.4	0.01399
iii	14981	**0.2973**	3629.4	0.057159	**5942.7**	0.294350	3146.1	0.090614
iv	13981	0.31056	3367.3	0.057797	**5551.6**	**0.319150**	2890.5	0.099791

in the fourth scenario. Nevertheless, the CSLs are quite poor for both strategies in all four scenarios.

Since the four scenarios represent different levels of information sharing, Table 8.1 shows the impacts of sharing information on SCP. For example, by reducing the quantity uncertainty from *U*(0, 0.3) to *U*(0, 0.1) but maintaining the time uncertainty at *U*(0, 7), the total cost under the company's original strategy can be reduced from £16,121 thousand to £15,043 thousand. Both SCP measures can be improved when the time and the quantity uncertainties are at the lower level, that is, in the fourth scenario. In other words, the highest SCP can be achieved at the highest information sharing level.

Performance difference in percentage between the JIT and the company's strategy

Table 8.2 summarises the performance differences between each company's strategy and JIT in percentages under four uncertainty scenarios. It shows that JIT can reduce the SC cost by 34~60% compared to the original strategy. The improvement is higher when the time uncertainty is reduced from (0, 7) to (0, 3). However, the company's original strategy is significantly better than JIT in terms of CSL in the first two scenarios but has a similar customer service performance in the last two scenarios.

Performance difference in percentage between four scenarios under the JIT and the company's strategy

Table 8.3 shows the performance difference in percentage between uncertain scenarios ii, iii and iv and uncertain scenario i. Under the company strategy, the total cost can be reduced by 7%, 7% and 13% in scenario ii, iii and iv, respectively; the customer services level

Table 8.2 Performance difference between the JIT and the company's strategies (%)

Uncertainty scenarios	**Obj 1**	**Obj 2**
i	34	–43
ii	34	–44
iii	60	–1
iv	60	3

Table 8.3 The performance difference in percentage between four scenarios under the JIT and the company's strategies

Uncertainty scenarios	**Original strategy**		**JIT**	
	Obj 1	**Obj 2**	**Obj 1**	**Obj 2**
ii	–7	58	–7	58
iii	–7	2177	–44	3875
iv	–13	2279	–48	4210

increases by 58%, 2177% and 2279%, respectively. Moreover, sharing information is more important under the JIT strategy as the cost can be reduced by 7%, 44% and 48% and CSL can be improved by 58%, 3875% and 4210% under scenario ii, iii and iv, respectively.

Just-in-time + safety stock

In order to cope with the uncertainties, holding extra raw material and finished goods may help to improve SCP. The performance of the strategies and JIT + safety stock at 20% and 30% will be investigated in this section.

Safety stock at 20%

Table 8.4 shows the performance of the company's original strategy and the JIT + safety stock at 20% strategy in four scenarios, in which the best performance between the original strategy and the JIT + safety stock at 20% strategy are indicated in bold font. The JIT + safety stock at 20% strategy outperforms the company's original strategy in terms of the SC CSL (e.g., from 0.013 to 0.166 in scenario i and from 0.311 to 0.630 in scenario iv). However, in terms of the SC total cost, the original strategy is better than the JIT + safety stock at 20% strategy in four scenarios. However, the CSLs are quite poor in all four scenarios under the original strategy and in the first two scenarios under the JIT + safety stock at 20% strategy.

Comparing the results of four scenarios, similar results to the JIT strategy can be observed. For example, by reducing the quantity uncertainty from *U*(0, 0.3) to *U*(0, 0.1) but maintaining the time uncertainty at U(0, 7), the original strategy for the CSL can be

Table 8.4 The simulation result of the company's strategy and JIT + safety stock at 20% strategy under four uncertain scenarios

Uncertainty scenarios	Original strategy				JIT+ safety stock at 20%			
	Mean		SD		Mean		SD	
	Obj 1	Obj 2	Obj 1	Obj 2	Obj 1	Obj 2	Obj 1	Obj 2
i	**16121**	0.013056	6054.9	0.013021	19749	**0.16551**	6020.5	0.1105
ii	**15043**	0.02068	5844.3	0.016719	19904	**0.20639**	17336	0.1076
iii	**14981**	0.2973	3629.4	0.057159	15076	**0.61183**	2913.6	0.083512
iv	**13981**	0.31056	3367.3	0.057797	14605	**0.62972**	2791.6	0.075041

improved from 0.013056 to 0.02068; under the JIT + safety stock at 20% strategy, the CSL can be improved from 0.16551 to 0.20639. Both SCP measures can be improved when the time and the quantity uncertainties are at the lowest level, that is, in the fourth scenario. In other words, the highest SCP can be achieved at the highest information sharing level.

Safety stock at 30%

Table 8.5 shows the performance of case company B's original strategy and the JIT + safety stock at 30% strategy in four scenarios, in which the best performances between the original strategy and the JIT + safety stock at 30% strategy are indicated in bold font. Similar results to those noted earlier can be observed in terms of the comparison between strategies and between different scenarios.

Difference in percentage between the JIT + safety stock and company's strategy

Table 8.6 summarises the performance differences of company B's strategy and the JIT + 20% and the JIT + 30% safety stock strategies in percentages under four uncertain scenarios. It shows that JIT+ safety stock at 20% can improve CSL by 1168%~103%. The JIT + safety stock at 30% can improve CSL by 1688%~112%. However, the company's original strategy is significantly better than the JIT + safety stock strategies in terms of the total cost.

Difference in percentage between four scenarios under the JIT + safety stock and the company's strategy

Table 8.7 shows the performance difference in percentage between uncertain scenarios ii, iii and iv and the uncertain scenario i under

Table 8.5 The simulation result of the company's strategy and JIT + safety stock at 30% strategy under four uncertain scenarios

Uncertainty scenarios	Original strategy				JIT+ safety stock at 30%			
	Mean		SD		Mean		SD	
	Obj 1	Obj 2	Obj 1	Obj 2	Obj 1	Obj 2	Obj 1	Obj 2
i	**16121**	0.013056	6054.9	0.013021	26845	**0.23350**	4964.7	0.094047
ii	**15043**	0.020680	5844.3	0.016719	25727	**0.25903**	4860.9	0.088853
iii	**14981**	0.297300	3629.4	0.057159	22109	**0.64200**	3173.3	0.065446
iv	**13981**	0.310560	3367.3	0.057797	21491	**0.65726**	3048.4	0.064265

Table 8.6 The performance difference in percentage between JIT + safety stock strategies and the company's strategy

Uncertainty scenarios	Stock at 20%		Stock at 30%	
	Obj 1	Obj 2	Obj 1	Obj 2
i	–23	1168	–67	1688
ii	–32	898	–71	1153
iii	–1	106	–48	116
iv	–4	103	–54	112

Table 8.7 The performance difference in percentage between four scenarios under the company's strategy and the JIT + safety stock strategies

Uncertainty scenarios	Original strategy		Stock at 20%		Stock at 30%	
	Obj 1	Obj 2	Obj 1	Obj 2	Obj 1	Obj 2
ii	–7	58	1	25	–4	11
iii	–7	2177	–24	270	–18	175
iv	–13	2279	–26	280	–20	181

the original strategy and the JIT + safety stock strategies. Under the JIT + 20% safety stock strategy, although the cost increases by 1% in scenario ii, the cost can be reduced by 24% and 26% in scenarios iii and iv; the CSL can be improved by 25%, 270% and 280% in scenarios ii, iii and iv, respectively. Under the JIT + 30% safety stock strategy, the cost can be reduced by 4%, 18% and 20%; the CSL can be improved by 11%, 175% and 181%, respectively.

Kanban (fixed WIP) policy

Table 8.8 shows the results of the original and the Kanban strategy in four scenarios, in which the best performances between the original and the Kanban strategy are indicated in bold font. The Kanban strategy outperforms the company's original strategy in all scenarios in both performance measures, for example, in scenario i, the total cost has been reduced from £16,121 thousand to £7357 thousand and the CSL has been improved from 0.013056 to 0.35899.

Since four scenarios represent different levels of information sharing, Table 8.8 shows the impacts of sharing information on SCP. For example, by reducing the quantity uncertainty from *U*(0, 0.3) to *U*(0, 0.1) and the time uncertainty from *U*(0, 7) to *U*(0, 3), the total cost under the Kanban strategy can be reduced from £7357.1 thousand to £2381.5 thousand, and the CSL can be improved from 0.35899 to 0.68952. The highest SCP can be achieved at the highest information sharing level.

Difference in percentage between the Kanban and the company's strategies

Table 8.9 summarises the performance difference between the company's strategy and the Kanban strategy in percentages under four uncertain scenarios. It shows that the Kanban strategy can reduce SC total cost by 54%~83% and can improve CSL by 2650%~122% compared to the original strategy.

Difference in percentage between four scenarios under the Kanban and the company's strategies

Table 8.10 shows the difference in percentage between uncertainty scenarios ii, iii and iv and uncertainty scenario i under the Kanban

Table 8.8 The simulation result of the company's and the Kanban strategies under four uncertain scenarios

Uncertainty scenarios	Original strategy				Kanban			
	Mean		SD		Mean		SD	
	Obj 1	Obj 2	Obj 1	Obj 2	Obj 1	Obj 2	Obj 1	Obj 2
i	16121	0.013056	6054.9	0.013021	**7357.1**	**0.35899**	9139.9	0.05633
ii	15043	0.020680	5844.3	0.016719	**6169**	**0.37291**	6057.3	0.050755
iii	14981	0.297300	3629.4	0.057159	**2844.1**	**0.67543**	3950.2	0.057159
iv	13981	0.310560	3367.3	0.057797	**2381.5**	**0.68952**	3213.4	0.053302

Table 8.9 The performance difference in percentage between the Kanban and the company's strategies

Uncertainty scenarios	Obj 1	Obj 2
i	54	2650
ii	59	1703
iii	81	127
iv	83	122

Table 8.10 The performance difference in percentage between four scenarios under the company's and the Kanban strategies

Uncertainty scenarios	Original strategy		Kanban	
	Obj 1	Obj 2	Obj 1	Obj 2
ii	–7	58	–16	4
iii	–7	2177	–61	88
iv	–13	2279	–68	92

and the company's strategies. Under the Kanban strategy, the total cost can be reduced by 16%, 61% and 68%, and the CSL increases by 4%, 88% and 92%, respectively.

Kanban (fixed WIP) + safety stock

Under the Kanban + safety stock strategies, the dynamic raw material procurement decisions are made based on the planned production plan and raw material on-hand inventory plus 20% and 30% extra at one period. The dynamic production decisions are based on received customer orders plus a percentage as safety stock.

Safety stock at 20%

Table 8.11 shows the results of the original strategy and the Kanban + safety stock at 20% strategy in four scenarios, in which the best performances between the original strategy and the Kanban + safety stock at 20% strategy are indicated in bold font. The Kanban + safety stock at 20% strategy outperforms the company's original strategy in all four scenarios in both SCP measures.

Note that four scenarios represent different levels of information sharing; Table 8.11 shows the impacts of sharing information on SCP.

Table 8.11 The simulation result of the company's strategy and Kanban + safety stock at 20% strategy under four uncertain scenarios

Uncertainty scenarios	**Original strategy**				**Kanban + 20% safety stock**			
	Mean		**SD**		**Mean**		**SD**	
	Obj 1	**Obj 2**	**Obj 1**	**Obj 2**	**Obj 1**	**Obj 2**	**Obj 1**	**Obj 2**
i	16121	0.013056	6054.9	0.013021	**6691.2**	**0.38425**	6627.7	0.035522
ii	15043	0.020680	5844.3	0.016719	**6655.1**	**0.39739**	8169.2	0.036636
iii	14981	0.297300	3629.4	0.057159	**2968.6**	**0.69933**	4498.4	0.054506
iv	13981	0.310560	3367.3	0.057797	**2958.3**	**0.70484**	4469.1	0.056081

For example, by reducing the quantity uncertainty from *U*(0, 0.3) to *U*(0, 0.1) and the time uncertainty from *U*(0, 7) to *U*(0, 3), the total cost under the Kanban + safety stock at 20% can be reduced from £6691.2 thousand to £2958.3 thousand, and the CSL can be improved from 0.38425 to 0.70484. The highest SCP can be achieved at the highest information sharing level.

Safety stock at 30%

Table 8.12 shows the results of the original strategy and the Kanban + safety stock at 30% strategy in four scenarios, in which the best performances between the original strategy and the Kanban + safety stock at 30% strategy are indicated in bold font. The Kanban + safety stock at 30% strategy again outperforms the company's original strategy in all four scenarios in both SCP measures.

Note that the four scenarios represent different levels of information sharing; Table 8.12 shows the impacts of sharing information on SCP. For example, by reducing the quantity uncertainty from *U*(0, 0.3) to *U*(0, 0.1) and the time uncertainty from *U*(0, 7) to *U*(0, 3), the total cost under the Kanban + safety stock at 30% can be reduced from £7252.2 thousand to £2458.6 thousand, and the CSL can be improved from 0.39128 to 0.70946. The highest SCP can be achieved at the highest information sharing level.

Difference in percentage between the Kanban + safety stock and the company's strategies

Table 8.13 summarises the performance differences in percentage between the company strategy, Kanban + 20% and Kanban + 30%

Table 8.12 The simulation result of the company's strategy and Kanban + safety stock at 30% strategy under four uncertain scenarios

	Original strategy				**Kanban + 30% safety stock**			
	Mean		**SD**		**Mean**		**SD**	
Uncertainty scenarios	**Obj1**	**Obj 2**	**Obj1**	**Obj 2**	**Obj1**	**Obj 2**	**Obj1**	**Obj 2**
i	16121	0.013056	6054.9	0.013021	**7252.2**	**0.39128**	9129.4	0.03185
ii	15043	0.020680	5844.3	0.016719	**7947.3**	**0.40100**	8804.4	0.032971
iii	14981	0.297300	3629.4	0.057159	**2322.4**	**0.70124**	2751.2	0.055057
iv	13981	0.310560	3367.3	0.057797	**2458.6**	**0.70946**	3452.3	0.060602

Table 8.13 The performance difference between Kanban + safety stock strategies and the company's strategy (%)

	Stock at 20%		**Stock at 30%**	
Uncertainty scenarios	**Obj 1**	**Obj2**	**Obj 1**	**Obj 2**
i	58	2843	55	2897
ii	56	1822	47	1839
iii	80	135	84	136
iv	79	127	82	128

safety stock strategies in four uncertain scenarios. It shows that the Kanban + safety stock at 20% strategy can reduce total cost by 58~79% and improve customer services level by 2843~127%. The Kanban + safety stock at 30% strategy can reduce total cost by 55~82% and improve the CSL by 2897~128%.

Difference in percentage between four scenarios under the Kanban + safety stock and the company's strategies

Table 8.14 shows the performance difference in percentage between scenarios ii, iii and iv and scenario i under the Kanban + safety stock and company strategies. Under the Kanban + 20% safety stock strategy, the cost decreases by 1%, 56% and 56% in scenarios ii, iii and iv and the CSL increases by 3%, 82% and 83%, respectively. Under the Kanban +30% safety stock strategy, the cost decreases by 10%, 68% and 66% and the CSL increases by 2%, 79% and 81%, respectively.

Table 8.14 The performance difference in percentage between four scenarios under the company's strategy and the Kanban + safety stock strategies

Uncertainty scenarios	Original strategy		Stock at 20%		Stock at 30%	
	Obj 1	**Obj 2**	**Obj 1**	**Obj 2**	**Obj 1**	**Obj 2**
ii	–7	58	–1	3	10	2
iii	–7	2177	–56	82	–68	79
iv	–13	2279	–56	83	–66	81

Vendor management inventory/based-stock policy

Table 8.15 shows the results of the original strategy and the VMI (a kind of echelon base-stock) strategy in four scenarios, in which the best performances between the original and the VMI strategies are indicated in bold font. The VMI strategy outperforms the company's original strategy in all four scenarios in both SCP measures.

Note that the four scenarios represent different levels of information sharing; Table 8.15 shows the impacts of sharing information on SCP. For example, by reducing the quantity uncertainty from $U(0, 0.3)$ to $U(0, 0.1)$ and the time uncertainty from $U(0, 7)$ to $U(0, 3)$, the total cost under the VMI strategy can be reduced from £9307.6 thousand to £2923.1 thousand, and the CSL can be improved from 0.39742 to 0.7074. The highest SCP can be achieved at the highest information sharing level, that is, in scenario iv.

Difference in percentage between the VMI and the company's strategies

Table 8.16 summarises the difference in percentage between the company's strategy and the VMI strategy in four uncertain scenarios. It shows that the VMI strategy can reduce the SC total cost by 42%~79% and improve the CSL by 2944%~128% compared to the original strategy. The improvement appears to be higher when the time uncertainty is reduced from (0, 7) to (0, 3) than when the quantity uncertainty is reduced from (0, 0.3) to (0, 0.1).

Difference in percentage between four scenarios under the VMI and the company's strategies

Table 8.17 shows the difference in percentage between scenarios ii, iii and iv and scenario i under the VMI strategy and the company's

Table 8.15 The simulation result of the company's and the VMI strategies under four scenarios

Uncertainty scenarios	Original strategy				VMI			
	Mean		SD		Mean		SD	
	Obj 1	Obj 2	Obj 1	Obj 2	Obj 1	Obj 2	Obj 1	Obj 2
i	16121	0.013056	6054.9	0.013021	**9307.6**	**0.39742**	9687.5	0.02768
ii	15043	0.020680	5844.3	0.016719	**8949.2**	**0.40787**	11441	0.02861
iii	14981	0.297300	3629.4	0.057159	**3054.9**	**0.70527**	3574.2	0.051706
iv	13981	0.310560	3367.3	0.057797	**2923.1**	**0.70740**	3593.6	0.057168

Table 8.16 The performance difference between VMI and the company's strategy (%)

Uncertainty scenarios	Obj 1	Obj 2
i	42	2944
ii	41	1872
iii	80	137
iv	79	128

Table 8.17 The performance difference in percentage of the company's and the VMI strategies in scenarios

Uncertainty scenarios	Original strategy		VMI	
	Obj 1	Obj 2	Obj 1	Obj 2
ii	–7	58	–4	3
iii	–7	2177	–67	77
iv	–13	2279	–69	78

strategy. Under the VMI strategy, the cost decreases by 4%, 67% and 69% and the CSL increases by 3%, 77% and 78%, respectively.

Vendor management inventory + safety stock/based-stock policy

The results of using VMI plus safety stock at 20% and 30% are reported in this section.

Safety stock at 20%

Table 8.18 shows the results of the original and the VMI + safety stock at 20% strategies in four scenarios, in which the better performances between the original and the VMI + safety stock at 20% strategies are indicated in bold font. The VMI + safety stock at 20% strategy outperforms the company's original strategy in all four scenarios in both SCP measures.

Note that the four scenarios represent different levels of information sharing; Table 8.18 shows the impacts of sharing information on SCP. For example, by reducing the quantity uncertainty from *U*(0, 0.3) to *U*(0, 0.1) and the time uncertainty from *U*(0, 7) to *U*(0, 3), the total cost under the VMI + safety stock at 20% can be reduced from £9189.4 thousand to £2836.8 thousand, and the CSL can be improved from 0.39784 to 0.71272. The highest SCP can be achieved at the highest information sharing level, that is, scenario iv.

Safety stock at 30%

Table 8.19 shows the results of the original and the VMI + safety stock at 30% strategies in four scenarios, in which the better performances between the original and the VMI + safety stock at 30% strategies are indicated in bold font. Similar results to those noted earlier can be observed.

Difference in percentage between the VMI + safety stock and the company's strategies

Table 8.20 summarises the difference in percentage between company, VMI + 20% and VMI + 30% safety stock strategies in four uncertain

Table 8.18 The simulation results of the company's strategy and VMI + safety stock at 20% strategy in four uncertain scenarios

	Original strategy				**VMI + 20% safety stock**			
	Mean		**SD**		**Mean**		**SD**	
Uncertainty scenarios	**Obj 1**	**Obj 2**	**Obj 1**	**Obj 2**	**Obj 1**	**Obj 2**	**Obj 1**	**Obj 2**
i	16121	0.013056	6054.9	0.013021	**9189.4**	**0.39784**	9053.4	0.027496
ii	15043	0.020680	5844.3	0.016719	**9337.2**	**0.41096**	9430.7	0.031511
iii	14981	0.297300	3629.4	0.057159	**3374.5**	**0.70627**	3574.5	0.058457
iv	13981	0.310560	3367.3	0.057797	**2836.8**	**0.71272**	3109.5	0.056677

Table 8.19 The simulation results of the company's strategy and VMI + safety stock at 30% strategy in four uncertain scenarios

Uncertainty scenarios	Original strategy				VMI + 30% safety stock			
	Mean		SD		Mean		SD	
	Obj 1	Obj 2	Obj 1	Obj 2	Obj 1	Obj 2	Obj 1	Obj 2
i	16121	0.013056	6054.9	0.013021	**9782.6**	**0.39994**	10076	0.027123
ii	15043	0.020680	5844.3	0.016719	**9549.3**	**0.41395**	7351.9	0.028935
iii	14981	0.297300	3629.4	0.057159	**3700.5**	**0.70307**	6353.9	0.056632
iv	13981	0.310560	3367.3	0.057797	**3209.1**	**0.70788**	3778.6	0.057144

Table 8.20 The performance difference between the VMI + safety stock strategies and company's strategy (%)

Uncertainty scenarios	Stock at 20%		Stock at 30%	
	Obj 1	Obj 2	Obj 1	Obj 2
i	43	2947	39	2963
ii	38	1887	37	1902
iii	77	138	75	136
iv	80	129	77	128

scenarios. It shows that VMI + 20% safety stock can reduce total cost by 43%~80% and improve CSL by 2947%~129%. The VMI + safety stock at 30% can reduce total cost by 39%~77% and can improve CSL by 2963%~128%.

Difference in percentage between four scenarios under the VMI + safety stock and the company's strategies

Table 8.21 shows the performance difference in percentage between scenarios ii, iii, iv and scenario i under the VMI + safety stock and the company's strategies. Under the VMI + 20% safety stock strategy, the cost increased by 2% in scenario ii, decreased by 63% and 69% in scenarios iii and iv and the CSL increased by 3%, 78% and 79%, respectively. Under the VMI + 30% safety stock strategy, the cost decreased by 2%, 62% and 67% and the CSL increased by 4%, 76% and 77%, respectively.

The impact of information sharing on SCP

The results quantify the performance differences between different information sharing scenarios – sharing more information (in scenario iv) can improve SCP significantly. As an example, Table 8.22 shows the performance difference in percentage between four scenarios under the JIT + safety stock and VMI + safety stock. According to the definition of JIT + safety stock and VMI + safety stock in Chapter 6, the customer demand information has been shared under JIT + safety stock strategy and the customer demand information, raw material and finished goods inventory information and production information have been shared under VMI + safety stock strategy. It shows that under VMI + safety stock strategy, sharing more information can improve both SCPs under four scenarios. However, the impacts of sharing information on the total cost and CSL are different in terms of the uncertain scenarios. Sharing more information reduces the total cost more under the lower uncertainty level (from 53% to 81% with 20% safety stock and from 64% to 85% with 30% safety stock),

Table 8.21 The performance difference in percentage between four scenarios under the company's strategy and VMI + safety stock strategies

Uncertainty scenarios	**Original strategy**		**Stock at 20%**		**Stock at 30%**	
	Obj 1	**Obj 2**	**Obj 1**	**Obj 2**	**Obj 1**	**Obj 2**
ii	–7	58	2	3	–2	4
iii	–7	2177	–63	78	–62	76
iv	–13	2279	–69	79	–67	77

Table 8.22 The performance difference between the VMI + safety stock strategies and JIT + safety stock strategies (%)

Uncertainty scenarios	**Stock at 20%**		**Stock at 30%**	
	Obj 1	**Obj 2**	**Obj 1**	**Obj 2**
i	–53	140	–64	71
ii	–53	99	–63	60
iii	–78	15	–83	10
iv	–81	13	–85	8

however, the CSL has been improved more by sharing more information when the uncertainty level is higher (from 140% to 13% with 20% safety stock and from 71% to 8% with 30% safety stock).

Summary

In summary, this chapter has undertaken and discussed the simulation experiments to evaluate non-parameterised operational strategies in order to investigate the impact of the information sharing mechanisms. The information sharing is represented by the combination of the degree of time uncertainty and the degree of quantity uncertainty. In the experiment, there are two degrees of time uncertainty (low level ~$U(0, 7)$ periods; low level ~ $U(0, 3)$ periods) and quantity uncertainties (high level ~$U(0, 0.3)$; low level ~ $U(0, 0.1)$. As a result, firstly, for all strategies, sharing information can improve SCP significantly. For example, under the company's original strategy, sharing information reduces the total cost by around 7–13% and improves the CSL by around 58–2279% (compared with the worst CSL). Secondly, as a tool, simulation can quantify and compare different strategies with multiple objectives in order that the SC managers can be helped in making decisions using simulation. Thirdly, sharing different information influences the SCP. The non-parameterised strategies determined what information is used in the strategy; for example, only customer demand information has been shared under the JIT strategy; customer demand, raw material and finished goods inventory information have been shared under the VMI strategy. It has been observed that sharing more information improves SCP (VMI strategy outperforms JIT strategy).

In the next chapter, the parameterised strategies will be evaluated and the difference with simulation-based non-parameterised strategies will be discussed and compared.

9

Evaluating the Single Objective Genetic Algorithm

In this chapter, the SC total cost will be optimised and discussed by using a SOGA tool under parameterised operational strategies. As a result, the impact of the coordinated management mechanism on SCP can be investigated.

Coordinated management and scenarios description

Coordinated management refers to different functions and entities in the SC system making decisions cooperatively. The main decisions in the SC model are the dynamic decisions on raw material procurement and finished goods production. With the assumption that the SC system is under the management of the parameterised strategies presented in Chapter 6, coordinated management can be archived by cooperatively designing the control parameters of the parameterised strategies. Therefore, the entire SC has been treated as an integrated system and uses GA optimisation methods to optimise the control parameters. Meanwhile, the impacts of such coordinated management on SCP can be quantified.

In order to compare the performance with the simulation results in Chapter 8, the same levels of (high and low level) uncertainties in lead time, quantity and delay lead time have been set up, namely:

1. Time uncertainty: high level ~ U(0, 7) periods; low level ~ U(0, 3) periods
2. Quantity uncertainties: high level ~ U(0, 0.3); low level ~ U(0, 0.1)

To simplify the experiment design, we consider two uncertain scenarios (which correspond to scenarios i and iv in Chapter 8):

1. High level of uncertainties: time uncertainty ~ U(0, 7) and quantity uncertainties ~ U(0, 0.3)
2. Low level of uncertainties: time uncertainty ~ U(0, 3) and quantity uncertainties ~ U(0, 0.1)

In earlier chapters, it was mentioned that an international sales plan is another important decision for case company B. As an international sales plan is a longer term decision compared with raw material procurement and finished goods production, the international sales plan has been treated as a high level strategy in the scenario design. In other words, it is assumed that the international sales (denoted by INT) strategy takes two levels: a high level with 50% of produced finished goods planned to satisfy international orders, and a low level with 30% of produced finished goods planned to satisfy international orders. Combined with two levels of uncertainty, it gives rise to a total of four scenarios as follows:

1. INT at 50%, time uncertainty ~ U(0, 7) and quantity uncertainties ~ U(0, 0.3)
2. INT at 30%, time uncertainty ~ U(0, 7) and quantity uncertainties ~ U(0, 0.3)
3. INT at 50%, time uncertainty ~ U(0, 3) and quantity uncertainties ~ U(0, 0.1)
4. INT at 30%, time uncertainty ~ U(0, 3) and quantity uncertainties ~ U(0, 0.1)

The strategies, PS-JIT and PS-VMI, defined in Chapter 6, will be optimised and evaluated using SOGA. In SOGA, the population size is 30; the generation number is 60; crossover rate is 0.5; and maturation rate is 0.5. The average CPU time used by SOGA in Matlab 7.11.0 (R2010b) versions is 612.886 seconds on a PC with 1.86 GHz processor.

Figures 9.1–9.8 show the GA's convergence in different environments. The horizontal axis represents the number of generations with best performance up to the current generation, and the vertical axis represents the SCP (SC total cost – in £000). The best solution in each figure is shown in Tables 9.1–9.16. For each generation, only the best solution is output and is shown in the figure.

The company's original strategies of JIT and VMI (non-parameterised) strategies are compared with PS-JIT and PS-VMI at 30% of international sales level (because the INT level had been set up to 30% in Chapter 8). Therefore, the following four scenarios (with INT at 30%) are compared between the non-parameterised and parameterised strategies:

1. INT at 30%, time uncertainty ~ U(0, 7) and quantity uncertainties ~ U(0, 0.3)
2. INT at 30%, time uncertainty ~ U(0, 7) and quantity uncertainties ~ U(0, 0.1)
3. INT at 30%, time uncertainty ~ U(0, 3) and quantity uncertainties ~ U(0, 0.3)
4. INT at 30%, time uncertainty ~ U(0, 3) and quantity uncertainties ~ U(0, 0.1)

PS-JIT strategy

Optimising control parameters in PS-JIT at high level of uncertainty

International sales plan at high level (50%)

Figure 9.1 shows the results of SOGA under the PS-JIT strategy at a high level of uncertainty. Table 9.1 shows the best solution for the

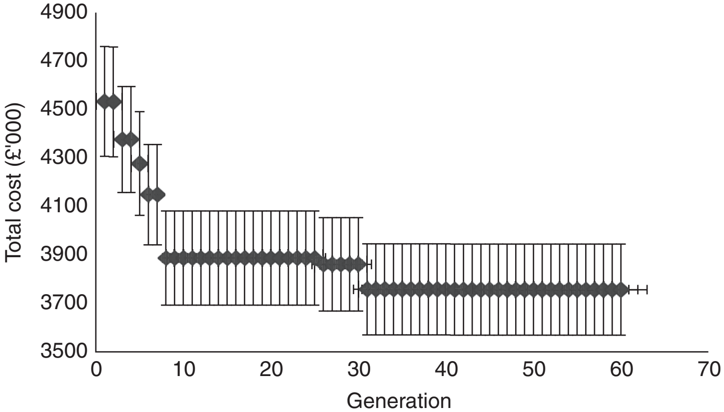


Figure 9.1 SOGA results under the PS-JIT strategy at high uncertainty level with 50% international sales level

eight control parameters. After 60 generations in SOGA, the total cost is reduced to £3756 thousand. It appears that the SOGA converges after 30 generations.

International sales plan at low level (30%)

Figure 9.2 shows the results of SOGA under the PS-JIT strategy at a high level of uncertainty. Table 9.2 shows the best solution for the eight control parameters. After 60 generations in SOGA, the total cost is reduced to £4637 thousand. It appears that the SOGA converges

Table 9.1 The best solution of PS-JIT at high uncertainty level and 50% international sales level

s_1	S_1	s_2	S_2	s_3	S_3	s_0	S_0	**Cost**
0.4939	6.8403	0.8292	5.1215	0.3988	6.1091	0.1997	19.7110	3756

Table 9.2 The best solution of PS-JIT at high uncertain level and 30% international sales level

s_1	S_1	s_2	S_2	s_3	S_3	s_0	S_0	**Cost**
0.1361	19.5971	0.4694	6.0002	0.8737	31.1634	0.6798	19.7548	4637

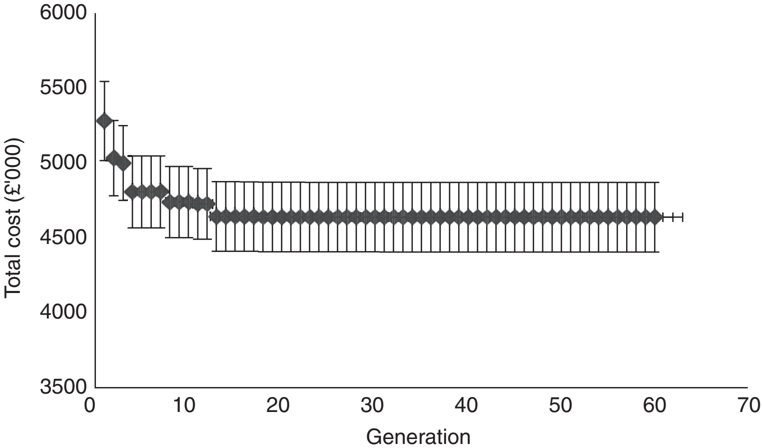


Figure 9.2 SOGA results under the PS-JIT strategy at high uncertainty level with 30% international sales level

after 12 generations. Additionally, comparing with Figure 9.1, under the same uncertain environment (high uncertainty) and managing solution, the international sales plan at different percentages influences the performance on total cost. In this condition, international sales at a high level improve nearly 10% over the low level.

After SOGA optimisation, under the same environment and managing solution, SOGA also performs better than the simulation PS-JIT result (in Table 8.1) outlined in the last chapter (£10,628 thousand). SOGA improves 70% at high INT sales level, and improves 60% at low INT sales level which is the same environment as PS-JIT in Table 8.1. Compared with the company's original strategy (£16,121 thousand), SOGA improves around 77% at the high INT sales level and around 71% at the low INT sales level.

Optimising control parameters in PS-JIT at low level of uncertainty

International sales plan at a high level (50%)

Figure 9.3 shows the results of SOGA under the PS-JIT strategy at a low level of uncertainty. Table 9.3 shows the best solution for the eight control parameters. After 60 generations in SOGA, the total cost reduced to £3,418 thousand. It appears that the SOGA converges after 40 generations.

International sales plan at low level (30%)

Figure 9.4 shows the results of SOGA under the PS-JIT strategy at a low level of uncertainty. Table 9.4 shows the best solution for the eight control parameters. After 60 generations in SOGA, the total cost has been reduced to £3756 thousand. It appears that the SOGA converges after 30 generations.

As a result, compared with Figure 9.3, under the same uncertain environment and managing strategy, the international sales strategy influences the performance. International sales strategy at a high level is better (improves 9%) than at a low level.

Compared with solutions in a high uncertainty environment (Figures 9.1 and 9.2), sharing information and enhancing cooperation (reducing uncertainty) could improve SCP, which has been shown in Chapter 8. Using SOGA under low level uncertainty (same international sale strategy and managing strategy) could achieve a better performance as well. The total cost reduced around 9% at low

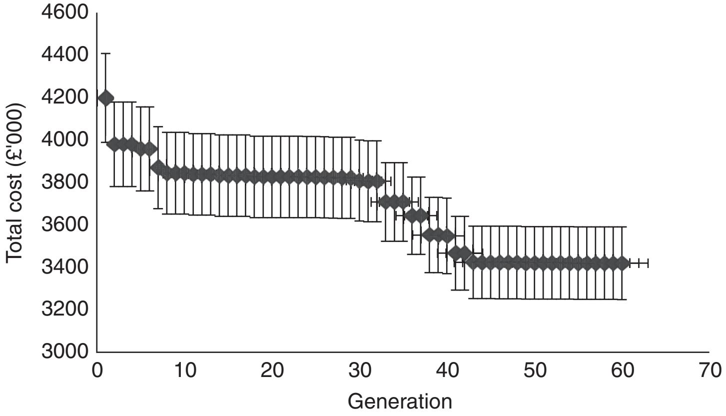


Figure 9.3 SOGA results under the PS-JIT strategy at low uncertainty level with 50% international sales level

Table 9.3 The best solution of PS-JIT at low uncertainty level and 50% international sales level

s_1	S_1	s_2	S_2	s_3	S_3	s_0	S_0	**Cost**
0.1048	18.1379	1.0679	5.3865	0.7087	33.7998	0.2059	15.8553	3418

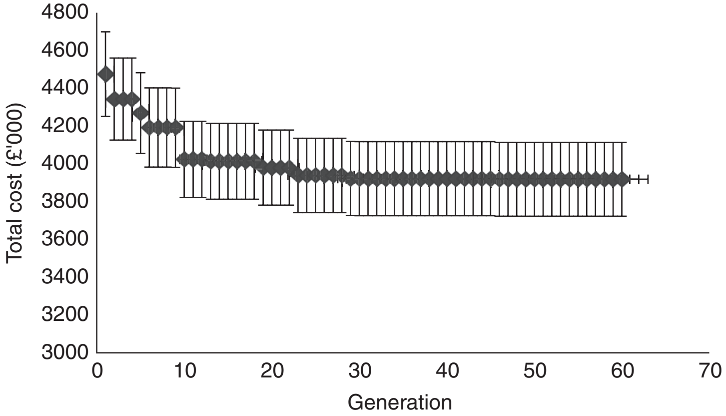


Figure 9.4 SOGA results under the PS-JIT strategy at low uncertainty level with 30% international sales level

Table 9.4 The best solution of PS-JIT at low uncertainty level and 30% international sales level

s_1	S_1	s_2	S_2	s_3	S_3	s_0	S_0	**Cost**
0.4939	6.8403	0.8292	5.1215	0.3988	6.1091	0.1997	19.7110	3756

reduction at low level INT, and SOGA makes 76% reduction at high level INT and makes 73% reduction comparing with company's original strategy (£13,981 thousand).

PS-VMI strategy

In this section, integrated raw material procurement and production planning managing by PS-VMI under (s, S) policy with a level of high and low uncertainties are optimised and compared.

Optimising control parameters in PS-VMI at high level of uncertainty

International sales plan at high level (50%)

Figure 9.5 shows the results of SOGA under the PS-VMI strategy at a high level of uncertainty. Table 9.5 shows the best solution for the eight control parameters. After 60 generations in SOGA, the total cost is reduced to £4881 thousand. It appears that the SOGA converges after 10 generations.

Compared with PS-JIT under the same uncertainty environment and same INT sales scenario, PS-JIT in Figure 9.5 performs better (around 32%) after running 60 generations of SOGA.

International sales plan at low level (30%)

Figure 9.6 shows the results of SOGA under the PS-VMI strategy at a high level of uncertainty. Table 9.6 shows the best solution for the eight control parameters. After 60 generations in SOGA, the total cost is reduced to £4809 thousand. It appears that the SOGA converges after 20 generations. Compared with PS-JIT under the same uncertainty environment and low INT sales scenario, PS-JIT in Figure 9.6 performs better (around 4%) after running 60 generations of SOGA.

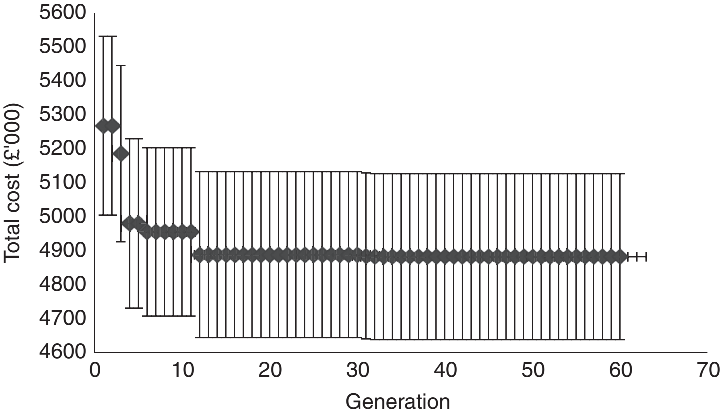


Figure 9.5 SOGA results under the PS-VMI strategy at high uncertainty level with 50% international sales level

Table 9.5 The best solution of PS-VMI at high uncertainty level and 50% international sales level

s_1	S_1	s_2	S_2	s_3	S_3	s_0	S_0	**Cost**
0.3189	18.4745	0.1627	19.9197	0.6052	9.8512	0.4098	10.2614	4881

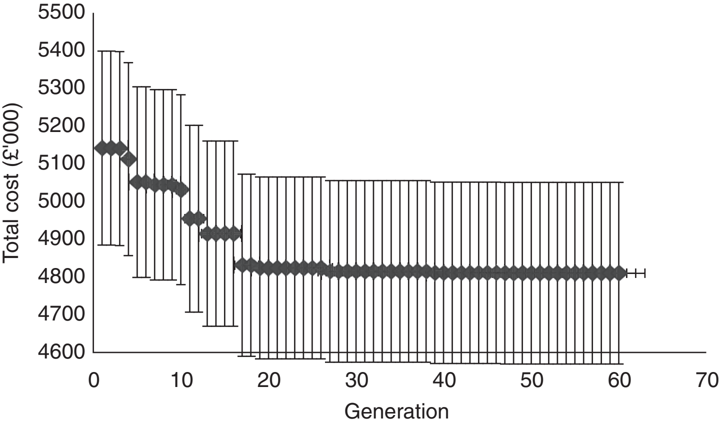


Figure 9.6 SOGA results under the PS-VMI strategy at high uncertainty level with 30% international sales level

Table 9.6 The best solution of PS-VMI at high uncertainty level and 30% international sales level

s_1	S_1	s_2	S_2	s_3	S_3	s_0	S_0	**Cost**
0.4997	18.4729	0.1800	19.9348	0.6406	9.7565	0.6511	9.9106	4809

Additionally, compared with Figure 9.5, under the same uncertainty environment and managing strategy, the INT sales strategy in different scenarios influences the performance. International sales at low level are better than at high level (improves 2%), which is different from PS-JIT noted earlier.

After SOGA optimisation, if only a single objective total cost is to be considered, under the same environment and managing strategy, SOGA also performs better than the simulation PS-VMI results as mentioned in Chapter 8 (9,307,600 pounds), which is nearly 48% reduction in the high INT sales strategy and nearly 50% reduction in the low INT sales strategy. SOGA improves 70% at high INT sales and 71% at low INT sales compared with the company's original strategy (£16,121 thousand).

Optimising control parameters in PS-VMI at low level of uncertainty

International sales plan at high level (50%)

Figure 9.7 shows the results of SOGA under the PS-VMI strategy at a low level of uncertainty. Table 9.7 shows the best solution for the eight control parameters. After 60 generations in SOGA, the total cost reduced to £4808 thousand. It appears that the SOGA converges after 10 generations.

Compared with PS-JIT under the same uncertainty environment and same INT sales scenario, PS-JIT in Figure 9.3 performs better (around 29%) after running 60 generations of SOGA.

Compared with PS-VMI under high uncertainty environment at high INT sales in Figure 9.5 (£4881 thousand), sharing information and enhancing cooperation and therefore reducing uncertainty to a lower level could reduce total cost around 2%.

International sales plan at low level (30%)

Figure 9.8 shows the results of SOGA under the PS-VMI strategy at a low level of uncertainty. Table 9.8 shows the best solution for the

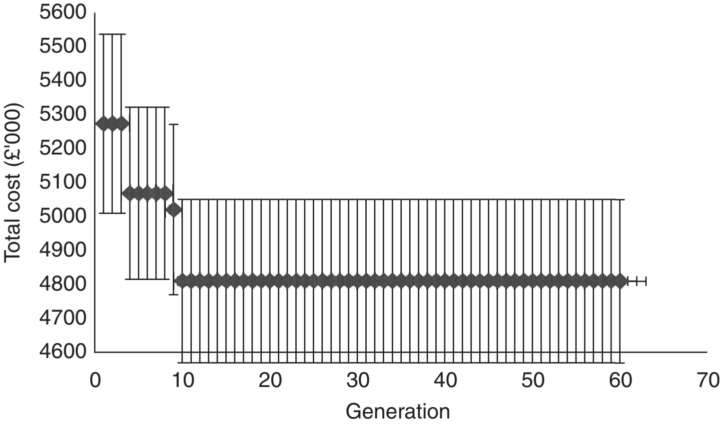


Figure 9.7 SOGA results under the PS-VMI strategy at low uncertainty level with 50% international sales level

Table 9.7 The best solution of PS-VMI at low uncertainty level and 50% international sales level

s_1	S_1	s_2	S_2	s_3	S_3	s_0	S_0	**Cost**
0.1042	5.9308	0.2391	39.4058	0.3206	6.5116	0.2404	6.3468	4808

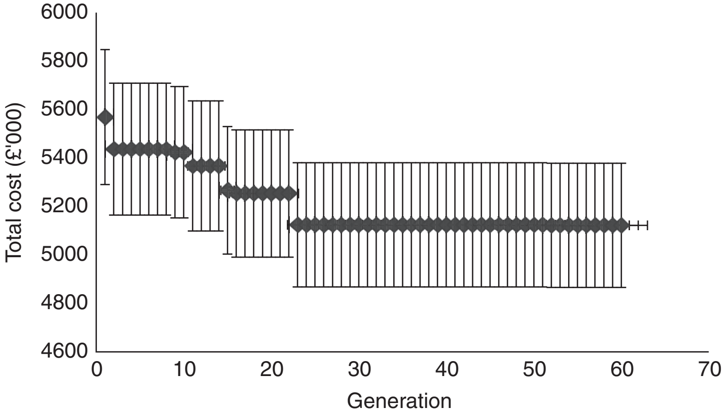


Figure 9.8 SOGA results under the PS-VMI strategy at low uncertainty level with 30% international sales level

Table 9.8 The best solution of PS-VMI at low uncertainty level and 30% international sales level

s_1	S_1	s_2	S_2	s_3	S_3	s_0	S_0	Cost
0.1374	5.4072	0.5226	7.9021	0.5740	40.8035	0.5035	19.6233	3756

eight control parameters. After 60 generations in SOGA, the total cost reduced to £3756 thousand. It appears that the SOGA converges after 20 generations.

Compared with PS-JIT under the same uncertainty environment and same INT sales scenario, PS-JIT policy in Figure 9.3 performs similarly (£3756 thousand) after running 60 generations of SOGA.

Compared with PS-VMI under high uncertainty environment at low INT sales in Figure 9.6 (£4809 thousand), sharing information and enhancing cooperation and therefore reducing uncertainty to a lower level could reduce total cost by around 22%. It reduces by around 24% in comparison with PS-VMI under the high uncertainty environment at high INT sales in Figure 9.5 (£4881 thousand).

Compared with the result of simulation PS-VMI under low uncertainty environment, SOGA is not as good as the simulation PS-VMI result. The simulation PS-VMI results (£2923 thousand) are an improvement by 22% over the SOGA results. However, SOGA improves by 73% compared with the company's original strategy (£13,981 thousand).

Comparison of PS-JIT and PS-VMI in number and the percentage of cost

Table 9.9 shows the differences of PS-JIT and PS-VMI in percentage under four uncertain scenarios. PS-VMI strategy dominates PS-JIT strategy in an uncertainty environment. However, the SOGA could improve PS-JIT when the uncertainty level is reducing (scenario iv).

Comparison of company strategy and simulation-based JIT and VMI strategy in number and percentage of cost under INT at 30%

Table 9.10 shows the difference in the company's strategy, JIT, VMI (from Chapter 8), PS-JIT and PS-VMI in numbers. The difference in percentages is shown in Table 9.11. It is significant that the SOGA can improve the performance compared with the company's strategy and simulation results under all INT at 30% scenarios.

Summary

This chapter has undertaken the second group experiments: the parameterised results using SOGA experiments, which show the difference from the simulation-based non-parameterised experiments outlined in Chapter 8. The mechanism of coordinated management refers to different functions and entities in the SC system when they make decisions cooperatively. In the SC model, the dynamic decisions

Table 9.9 Comparison of PS-JIT and PS-VMI in number and the percentage of cost

Scenarios	PS-JIT	PS-VMI	PS-JIT vs. PS-VMI %
i	3756	4881	–30
ii	4637	4809	–4
iii	3418	4808	–41
iv	3756	3756	0

Table 9.10 The total cost difference of company's strategy, PS-JIT, PS-VMI, JIT and VMI in numbers

Scenarios	Company strategy	JIT	VMI	PS-JIT	PS-VMI
1	16121	10628	9307.6	4637	4809
2	15043	9906.5	8949.2	/	/
3	14981	5942.7	3054.9	/	/
4	13981	5551.6	2923.1	3756	3756

Table 9.11 The total cost difference of PS-JIT, PS-VMI, JIT and VMI with company's strategy in percentage

Scenarios	JIT	VMI	PS-JIT	PS-VMI
1	34	42	71	70
2	34	41	/	/
3	60	80	/	/
4	60	79	73	73

related to coordinated management are integrated raw material procurement and finished goods production. It has been observed that coordinated management using SOGA improves SCP more than a similar simulation-based non-parameterised strategy. The third group experiments, parameterised results using MOGA experiments, will be discussed in the next chapter.

10

Evaluating the Multiple Objective Genetic Algorithm

This chapter investigates the SCP under coordinated management, which is achieved through the MOGA program. The experimental scenarios will be introduced and then the results will be discussed.

Scenario description and MOGA parameter setting

Two parameterised strategies presented in Chapter 6 will be adopted to manage the integrated raw material procurement and production planning. In order to facilitate the comparison of the performances with the results in Chapters 8 and 9, the following setting in terms of uncertainties in lead time are considered; quantity and delay lead time and international sales plan (INT):

1. Time uncertainty: high level ~ U(0, 7) periods; low level ~ U(0, 3) periods
2. Quantity uncertainties: high level ~ U(0, 0.3); low level ~ U(0, 0.1)
3. INT at high level (at 50%) and low level (at 30%)

In order to compare with the results under PS-JIT and PS-VMI strategies in Chapter 9, four scenarios will be analysed in this chapter:

1. INT at 50%, time uncertainty ~ U(0, 7) and quantity uncertainties ~ U(0, 0.3)

2. INT at 50%, time uncertainty ~ U(0, 3) and quantity uncertainties ~ U(0, 0.1)
3. INT at 30%, time uncertainty ~ U(0, 7) and quantity uncertainties ~ U(0, 0.3)
4. INT at 30%, time uncertainty ~ U(0, 3) and quantity uncertainties ~ U(0, 0.1)

In the MOGA procedure, a number of parameters are selected based on non-dominated front. In the experiments, the population size is 120; the maximum generation number is 60; the mutation probability is 0.5. The MOGA is coded using Matlab 7.11.0 and run on a PC with 1.86 GHz. The running time (or CPU time) of each optimisation experiment is about 669.56 seconds.

In Figures 10.1–10.6, the horizontal axis represents Obj 1, SC total cost (in £'000), the vertical axis represents Obj 2, SC average customer services. The notation hUC_PM-JIT represents the PM-JIT strategy under high uncertainty environment; lUC_PM-JIT represents the PM-JIT strategy under low uncertainty environment; hUC_PM-VMI represents the PM-VMI strategy under high uncertainty environment; lUC_PM-VMI represents the PM-VMI strategy under low uncertainty environment.

International sales plan at high level (50%)

Optimising control parameters in PM-JIT strategy

Figure 10.1 shows the results of the final generation in the MOGA procedure optimising the PM-JIT strategy in high and low uncertainty environments with the high international sales plan. There are three main contributions using MOGA. Firstly, it can quantify the impacts of the uncertainty level on single SCP similar to SOGA in Chapter 9. It can be observed that reducing the uncertainty level could significantly improve the SCP, especially the CSL which can be improved by 40–90%. Secondly, the MOGA produces a set of good options with multiple objective considerations to decision makers instead of a single objective in the SOGA. Thirdly, in reality, when the decision maker has an expectation on one objective such as cost at £5500 or £6000 thousand, the MOGA provides a set of options with other objectives quantified, and therefore the decision

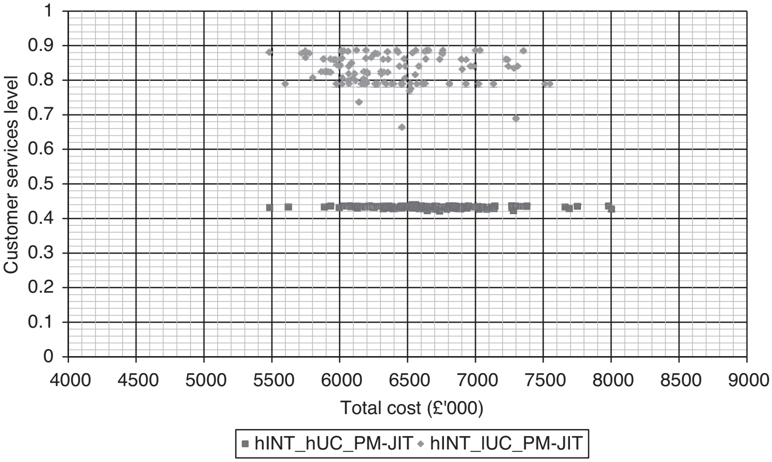


Figure 10.1 The last generation of MOGA under PM-JIT at high and low uncertainty levels with high international sales plan (at 50%)

maker can easily select the most suitable option when the company wants to control cost within £6000 thousand with different uncertainty scenarios.

Optimising control parameters of PM-VMI strategy

Figure 10.2 shows the results of the final generation in the MOGA procedure under PM-VMI strategy in high and low uncertainty environments at a high international sales level. Similar phenomena to Figure 10.1 can be observed.

Comparison of PM-JIT and PM-VMI at high level of international sales

Figure 10.3 compares the results of PM-JIT and PM-VMI at two uncertainty levels with a high international sales plan. It can be observed that PM-VMI outperforms PM-JIT in the low level of uncertainty environment in both SC total cost and SC service level. However, in the high level of uncertainty environment, PM-JIT achieves a better SC service level whereas PM-VMI achieves a lower SC total cost.

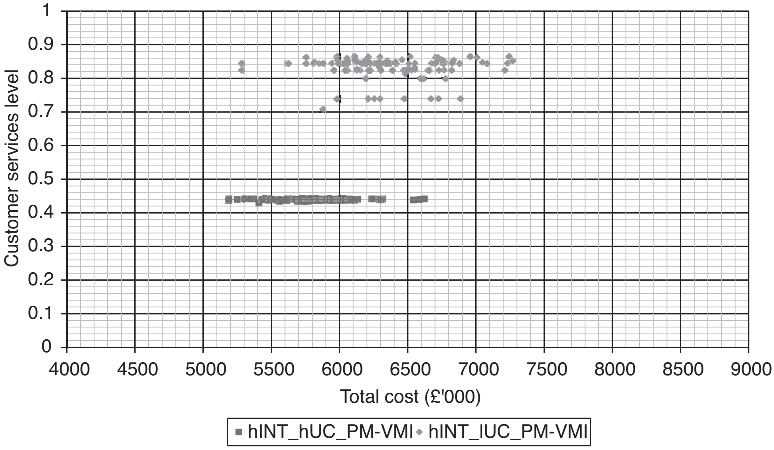


Figure 10.2 The last generation of MOGA under PM-VMI at high and low uncertainty levels with high international sales strategy (at 50%)

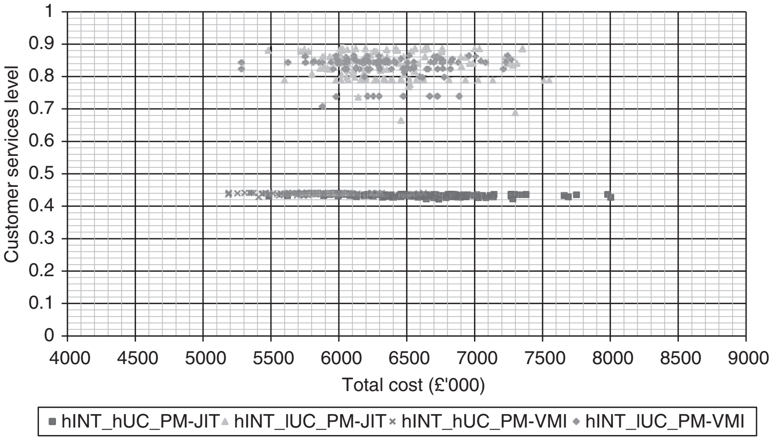


Figure 10.3 Comparison of the last generation of MOGA under PM-JIT and PM-VMI at high and low uncertainty levels with high international sales plan (at 50%)

International sales plan at low level

Optimising control parameters of PM-JIT strategy

Figure 10.4 shows the results of the final generation in the MOGA procedure optimising the PM-JIT strategy in high and low uncertain environments plan at the low international sales level. Similar phenomena to Figures 10.1 and 10.2 can be observed.

Figure 10.5 shows the results of the final generation in the MOGA procedure under PM-VMI strategy in high and low uncertainty environments at low international sales level. Similar phenomena to Figures 10.1, 10.2 and 10.3 can be observed.

Optimising control parameters of PM-VMI strategy

Figure 10.6 compares the results of PM-JIT and PM-VMI at two uncertainty levels with a low international sales plan. It can be observed that PM-VMI outperforms PM-JIT at the low level of uncertainty environment in both SC total cost and SC service level. However, at the high level of uncertainty environment, PM-JIT achieves a better SC service level whereas PM-VMI achieves a lower SC total cost.

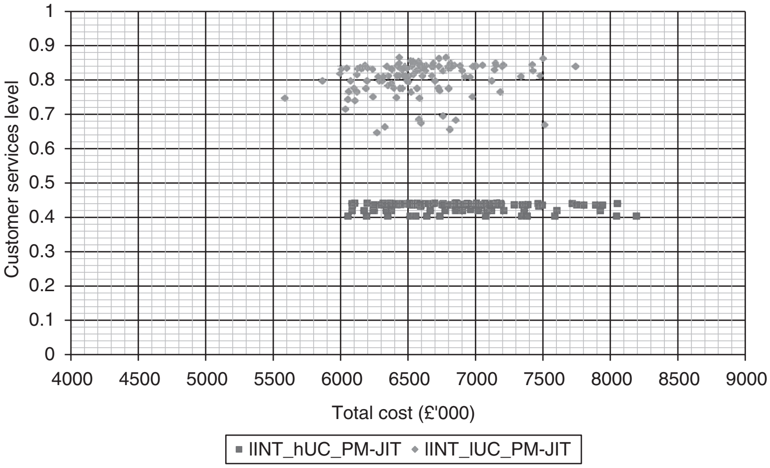


Figure 10.4 The last generation of MOGA under PM-JIT at high and low uncertainty levels with low international sales plan (at 30%)

Comparison of PM-JIT and PM-VMI at low level of international sales

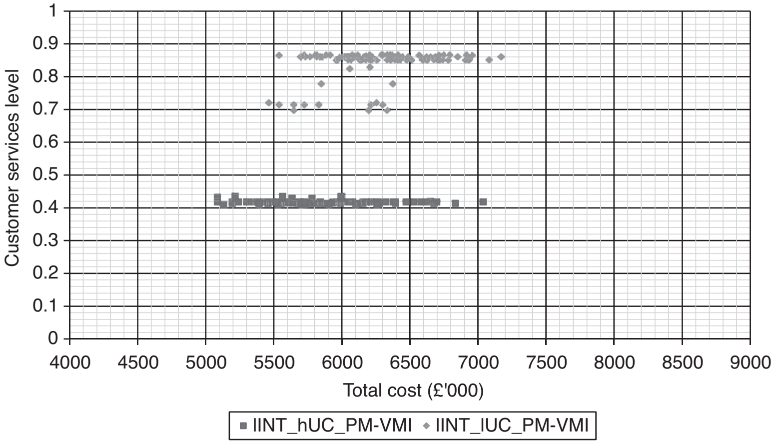


Figure 10.5 The last generation of MOGA under PM-VMI at high and low uncertain levels with low international sales strategy (at 30%)

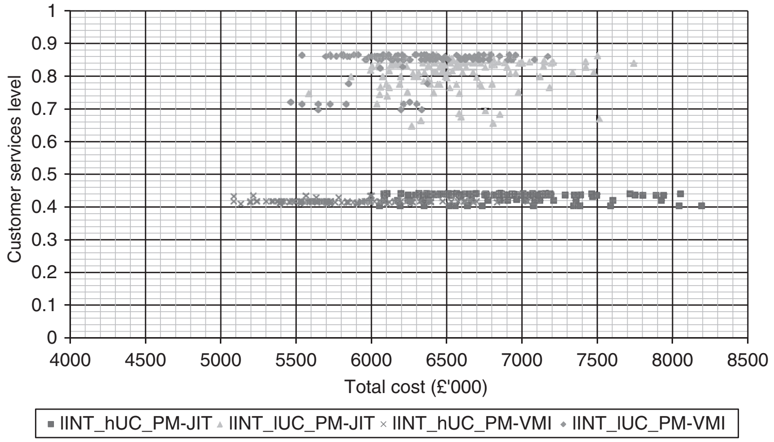


Figure 10.6 Comparison of the last generation of MOGA under PM-JIT and PM-VMI at high and low uncertain levels with low international sales plan (at 30%)

Comparison of results between non-parameterised and parameterised experiments

The differences of the experimental results among simulation, SOGA and MOGA in Table 10.1 have been observed. According to Table 10.1, firstly, SOGA outperforms MOGA in the total cost under all strategies and scenarios. The results are closer under PS-VMI and PM-VMI than under the PS-JIT and PM-JIT strategies. However, MOGA quantifies both objectives and provides a set of solutions to the SC managers, rather than SOGA only, which can provide a single solution with quantifying a single objective (which has been discussed previously). Secondly, SOGA and MOGA outperform simulation results in general (except VMI in total cost under low level of INT and low level of uncertainty); in particular, MOGA outperforms simulation results in both objectives (above 50%).

Summary

The simulation-based optimisation experiments using the MOGA tool under parameterised operational strategies have been investigated, and as a result, the impact of a coordinated management mechanism on SCP has been observed. If the SC partner cooperates more, the SCP can improve more, for example, the PM-VMI strategy

Table 10.1 Comparison of results among simulation, SOGA and MOGA

		Simulation			**SOGA**		**MOGA**	
Scenarios	**SCP**	**Original strategy**	**JIT**	**VMI**	**PS-JIT**	**PS-VMI**	**PM-JIT**	**PM-VMI**
hINT/hUC	**Obj 1**	/	/	/	3756	4881	5400–8000	5100–6700
	Obj 2	/	/	/	/	/	0.42–0.44	0.43–0.46
hINT/lUC	**Obj 1**	/	/	/	3418	4808	5400–7500	5200–7400
	Obj 2	/	/	/	/	/	0.68–0.89	0.71–0.88
lINT/hUC	**Obj 1**	16121	10628	9307.6	4637	4809	6000–8200	5200–7100
	Obj 2	0.01	0.01	0.40	/	/	0.40–0.45	0.41–0.45
lINT/lUC	**Obj 1**	13981	5551.6	2923.1	3756	3756	5800–7800	5400–7200
	Obj 2	0.31	0.32	0.71	/	/	0.65–0.88	0.7–0.88

outperforms PM-JIT strategy in general. However, compared with SOGA, MOGA reduces the total cost less than SOGA. The MOGA provides a set of options to SC managers instead of simulation-based non-parameterised strategy and parameterised strategy using SOGA.

11

Conclusions

This final chapter will highlight the main issues that have been analysed, point out the limitations of the research and suggest further work that would be useful.

Contribution highlights

Although SCM has been studied extensively in the past two decades, study of the Chinese SME manufacturing SC is lagging behind. This study has attempted to understand, generalise and improve the performances of the manufacturing SC in the context of Chinese SMEs and has developed simulation-based tools to assist SC managers in decision making. The main contributions include:

1. This study provides a wide range of systemically reviewed literature including SCM, SCP, uncertainties in SC, SC mapping and integration, information sharing strategies, coordinated management strategies, optimisation and the current status of SCM in China.
2. This study has systemically reviewed and explained the research methodology and relevant techniques. The benefits and disadvantages of employing multiple case studies are discussed. The data collection methods, including interviews and observations, are discussed and applied in this study, which provides an example for other relevant studies.
3. Two real SCs from two Chinese SME manufacturers have been described and explained in detail, which provides an in-depth understanding of the operations of Chinese SME manufacturing SCs.

4. The study has developed a generalised SC model including a DSC and an ISC based upon two real case studies. The key characteristics within the SC model and the differences between the DSC and the ISC have been identified and classified from three aspects: uncertainties, constraints and cost elements. The important SCM issues within the case SCs have been identified and discussed, which provide an example for other users. The generalised model is represented by using the SC process mapping approach, which provides an example of how to use the SC mapping process and integration theories to understand a SC and then identify the issue.
5. The generalised SC model has been formulated into a mathematical model considering the complex uncertainties in the SC system. Typical non-parameterised and parameterised strategies are presented to tackle the SCM issues. Therefore, the differences and similarities among those strategies can be evaluated and compared. The mathematical model can be referenced in other studies.
6. The objective function in the mathematical model is based on the data from the interviews and the cost elements which appear in the literature, such as raw material cost and delay penalty cost. However, the interview data provides a comprehensive study for identifying all main cost elements.
7. A simulation tool has been developed using the Matlab platform to represent the mathematical model that enables us to evaluate the non-parameterised and parameterised strategies. Both tailored SOGA and MOGA tools have been developed for the purpose of optimising parameterised strategies. The development process provides an example of how to develop and use SOGA and MOGA in a complex SC system for other users. It also demonstrates that the GA can be used in the optimisation study in the field of SCM.
8. Three groups of experiments are undertaken and discussed: (i) the first group of simulation experiments evaluates non-parameterised operational strategies, which investigate the impact of the information sharing mechanism; (ii) the second group of simulation-based optimisation experiments uses the SOGA tool to optimise parameterised operational strategies, which investigates the impact of the coordinated management mechanism; (iii) the third group of

simulation-based optimisation experiments uses the MOGA tool to optimise parameterised operational strategies with multiple objectives simultaneously, which also investigates the impact of the coordinated management mechanism.

9. The results of the three groups of experiments demonstrate in practice the impacts of information sharing and coordinated management on SCP in the literature, namely: (i) the range of SCP improvement is up to 28% to 80% for objective one and -1% to 3000% in objective two, which represent a managerial insight that different strategies and uncertainty levels can make considerable differences, and thus, the results can assist managers to make better decisions at the daily operational level and long-term sales level. (ii) Both the parameterised strategies dominate the original company strategy while the non-parameterised strategies and original strategy dominate in most experiments. The parameterised strategy is better than the non-parameterised strategy in general, but at some uncertainty levels, their performances are very close. (iii) Both parameterised and non-parameterised strategies represent different information (e.g., raw materials inventory, finished goods inventory, customer order and production) that has been shared within the SC. Thus, the results of these strategies can show the impacts of sharing different information on the SCP. According to the results, sharing customer order information can improve both SCPs and it contributes more to the CSL. Sharing customer order information, finished goods inventory level and production can make much greater improvement on SCP than only sharing customer order information. However, the result of sharing raw material inventory level information, finished goods inventory, customer order and production is similar to that if the raw material inventory information is not shared. (iv) For the parameterised strategies experiments, the result is better than the company's original strategy and non-parameterised strategies by setting probable parameters; the result may be worse than the non-parameterised strategy otherwise.

Limitations of the study

There are several limitations to the study. Firstly, this study has used only two case studies to generalise the SC model, mainly due to the extreme difficulty of obtaining detailed operational data from Chinese SME manufacturers.

Secondly, it focused on a set of specific non-parameterised and parameterised strategies selected to manage the SC system. Other types of management strategies may be interesting. In addition, the implementation costs of information sharing and coordinated management mechanisms were not incorporated within the research.

Thirdly, in the processes of SC decision making, there are many other factors that may also influence decisions but are hard to quantify and incorporate, for example, the impact of the global economy on the industry, government policy, human factors and so on.
Further research

Further studies could be conducted on the following aspects:

1. It would be interesting to conduct more case studies and/or test the generalised model in other industries and more companies.
2. Although the study has reviewed and discussed the impacts of technologies, especially IT, on SCM, it could be attempted to further investigate, model and discuss the influences from technology using a management aspect and try to analyse the impact of technological innovation and services innovation on SCM.
3. The model has included the main characteristics of the case SCs. However, it would be useful to incorporate other factors that may influence decision making such as the global economy, technology, labour quality and so on. For example, the influences of increased labour cost and higher quality of workforce in China but cheaper labour cost in other emerging economic regions.
4. This study used the fulfilment rate to measure CSL in the generalised SC model. It is interesting to investigate the services quality measure in SC systems as the SC is a complex system and each member can be a service provider and a service receiver.
5. Other types of management strategies may be worth investigating. The barriers and costs associated with implementing information sharing and coordinated management mechanisms could also be investigated.

6. The global optimisation tool for optimising single and multiple objectives is based on a GA due to the complexity of the SC optimisation problem. In the future, the GA tool could be compared with other global optimisation algorithms

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