THE HONG KONG POLYTECHNIC UNIVERSITY

DEPARTMENT OF INDUSTRIAL AND SYSTEMS ENGINEERING

A Supply Chain Collaborative Model: Integrating the Design, Operation and Measurement Stages of Supply Chain

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A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy

AUGUST 2010

CERTIFICATE OF ORIGINALITY

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ABSTRACT

Supply chain collaboration offers significant opportunities for supply chain entities in value creation, and developing collaborative and cohesive relationships between entities in the supply chain is essential for maintaining the competitiveness of the supply chain network. The research presented in this thesis aims to fill the gaps in the existing literature by conducting a study of supply chain collaboration from a perspective that extends the traditional study of the operation stage to its two extremes in the design and measurement stages. Accordingly, a Supply Chain Collaborative (SCC) model is proposed which covers the multiple stages of the design, operation and measurement of the supply chain. Under the SCC model, a Cross Functional Partnership Selection (CFPS) sub-model is proposed for the design stage to select and partner supply chain entities; a Cross Entity Operational Planning (CEOP) sub-model is proposed for the operation stage to develop effective and efficient collaboration between common supply chain operational activities; and a Cross Domain Performance Measurement (CDPM) sub-model is proposed for the measurement stage to measure and evaluate the collaborative performance of the entire supply chain.

In the development of the SCC model, network graph theory, mathematical programming and statistical methods are applied to the modelling of the design, operation and measurement stages. Following this, the SCC model is illustrated in a case study of the supply chain of a company in the made-to-order manufacturing industry. Heuristics methods using genetic algorithms are then adopted to solve the company’s different supply chain scenarios. In addition, statistical methods of analysis of variance (ANOVA), trend line and effect size are used to validate the feasibility and usefulness of the proposed model in enhancing supply chain collaboration. The results of the ANOVA testing show a significant difference between the means of testing hypotheses on the order fulfilment percentage (OFP), which means the SCC model does affect the collaborative performance of the supply chain of the company. The trend line analysis shows that a positive and steady high supply chain collaborative performance trend line can be plotted for the OFP value of the SCC model. Finally, the effect size analysis results show that the SCC model has a positive effect on supply chain collaboration and improves the collaborative performance of the overall supply chain of the company in the case study. Therefore, the analysis results from the case study demonstrate that the SCC model has potential significance and a positive effect on supply chain collaboration.

PUBLICATIONS ARISING FROM THE THESIS

(5 international journal papers, 2 international conference papers, and 1 book chapter have been published)

INTERNATIONAL JOURNAL PAPERS

1. Lam, C.Y., Chan, S.L., Ip, W.H., & Lau, C.W. (2008). Collaborative supply chain network using embedded genetic algorithms. *Industrial Management & Data Systems*, 108(8), 1101-1110.
2. Lam, C.Y., Ip, W.H., & Lau, C.W. (2009). A business process activity model and performance measurement using a time series ARIMA intervention analysis. *Expert Systems with Applications*, 36(3), 6986-6994.
3. Chau, K.Y., Liu, S.B., & Lam, C.Y. (2009). Multi-agent modelling in managing six sigma projects. *International Journal of Engineering Business Management*, 1(1), 9-14.
4. Lam, C.Y., & Ip, W.H. (2011). A customer satisfaction inventory model for supply chain integration. *Expert Systems with Applications*, 38(1), 875-883.
5. Lam, C.Y., & Ip, W.H. (2011). Constraint priority scheduling using an agent-based approach. *Industrial Management & Data System*, 111(2), 246-263.

INTERNATIONAL CONFERENCE PAPER

1. Lam, C.Y., Ip, W.H., & Wang, L. (2008). Simulation and analysis using a process centric activity model to achieve business process excellence. *Proceedings, 19th IASTED International Conference, Modelling and Simulation*, Quebec, Canada, 253-257.
2. Lam, C.Y., Ip, W.H., Wu, C.H., & Chan, S.L. (2010). Agent-based scheduling with a learning effect model. *Proceedings, IEEE International Conference on Industrial Engineering and Engineering Management 2010*, Macao SAR, P.R. China, 1702-1705.

BOOK CHAPTER

1. Lam, C.Y., Chan, S.L., & Ip, W.H. (2010). A structural reliability business process modelling with system dynamics simulation. *Modelling Simulation and Optimization - Focus on Applications*, Shkelzen Cakaj (Ed.), ISBN: 978-953-307-055-1, Intech.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my supervisor, Dr W.H. Ip for his excellent supervision and valuable advice throughout this research. I would also like to thank all the staff of the participating company for providing a genuine business environment for this research.

The financial assistance provided by the Research Committee and the Department of Industrial and Systems Engineering of the Hong Kong Polytechnic University is greatly appreciated. In addition, I would like to express my thanks to the departmental staff for assisting my research.

In particular, I am truly grateful to my family and would like to thank them for whole-heartedly supporting my study over the past many years. I deeply appreciate the support, motivation and encouragement they have given me at every stage of my research.

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ABBREVIATIONS

ANOVA	Analysis of Variance
CDP	Customer Demand Point
CDPM	Cross Domain Performance Measurement
CEOP	Cross Entity Operational Planning
CFPS	Cross Functional Partnership Selection
CIM	Centralized Inventory Management
CPFR	Collaborative Planning, Forecasting, and Replenishment
CR	Continuous Replenishment
CRM	Customer Relationship Management
EIS	Enterprise Information System
ERP	Enterprise Resource Planning
FG	Finished Goods
GA	Genetic Algorithms
IT	Information Technology
MDC	Manufacturers/Distribution Centres
MRP II	Manufacturing Resources Planning
nPD	Normalized Performance Data
OFP	Order Fulfilment Percentage
PD	Performance Data
PolyU	Hong Kong Polytechnic University
QR	Quick Response
RR	Rapid Replenishment
SCC Model	Supply Chain Collaborative Model
SCC	Supply-Chain Council
SCOR	Supply Chain Operations Reference

SCR	Synchronized Consumer Response
SSS	Supply Source/Suppliers
TCA	Teaching Company Associate
TCS	Teaching Company Scheme
UICP	University-Industry Collaboration Programmes
VICS	Voluntary Interindustry Commerce Standards
VMI	Vendor Managed Inventory
WIP	Work-in-process

1. INTRODUCTION TO THE STUDY

This thesis is a report on a research study in supply chain collaboration. The study involves the design and development of approaches for modelling collaboration among the various participants, or entities in a supply chain. The proposed Supply Chain Collaborative (SCC) model presents an original contribution to the knowledge of modelling and analysing supply chain collaboration. Section 1.1 presents the background to the study. Sections 1.2 and 1.3 specify the research statement, aims and objectives addressed in the study. Section 1.4 outlines the methodology used to develop and evaluate the SCC model. Finally, Section 1.5 describes the structure of the thesis.

1.1 BACKGROUND OF THE STUDY

Supply chain management is defined as the use of a set of synchronized decisions and activities to manage the flow of material, information, and finance through a supply chain network (Li, 2007; Coyle et al., 2009) and to efficiently integrate suppliers, manufacturers, warehouses, distributors, retailers, and customers so that system-wide costs are minimized and customer service requirements are satisfied, because the right products or services have been distributed in the right quantities, to the right locations, at the right time and to the right customers (Branch, 2009; Bowersox et al., 2010). Accordingly, supply chain management covers an extensive range of activities, including purchasing, production, demand management, inventory management, transportation, logistics management, warehousing, order processing, and information management.

The particular entities within a supply chain are involved in a number of different activities and form the essential building blocks of the supply chain as a whole. Although these entities perform different roles at different stages, the ways in which they relate to other activities, or coordinate information and resources can directly influence the overall performance of the supply chain. Bauknight (2000) states that the collaboration between entities plays a significant role in the supply chain process and contains opportunities for value creation that are capable of driving effective supply chain management. Barratt (2004) further points out that relationship within the supply chain are most effective when there is collaboration among the entities.

Supply chain collaboration is a form of business practice that encourages individual entities to share information and resources to benefit the entire supply chain and allows entities to leverage each other on an operational basis so that they perform better together than they would separately, i.e. collaboration occurs when supply chain entities work together for mutual benefit. According to Lam et al. (2008), while all entities are expected to collaborate and coordinate with each other to maintain the responsiveness and performance of the network, the levels of collaboration vary from basic execution to operational planning for the cooperative optimization of the supply chain. Overall, collaboration can provide mutual benefits to all parties in the supply chain, such as improved information availability, improved service levels, improved end-customer satisfaction, increased flexibility in doing business, and reduced cycle time (Coyle et al., 2003; Simchi-Levi et al., 2003; Holweg et al., 2005; Daugherty et al., 2006).

As Li (2007) points out, in light of the current state of technological advancement and the increasingly globalised marketplace, organizations and industries all over the world need to improve the efficiency and productivity of their supply chains to remain competitive and attain world-class standards. In addition, information technology has fundamentally changed the way organizations and industries operate, such as the move from cost to revenue management and the change in focus from a functional to an order fulfilment process, from inventory to information management, and from partners' transactional relationships to strategic alliances. Ketikidis et al. (2008) suggest that these factors are making the modern supply chain network increasingly complicated and sophisticated, that the competition between supply chains is becoming serious, and that collaborative and cohesive relationships among entities is thus essential for maintaining the competitiveness of supply chain networks. Moreover, customers are always looking for new products of high quality, low cost, and with a short lead time. This poses further challenges to supply chain networks, as every entity in a network needs to react and respond efficiently and effectively to changes in demand.

For these reasons, collaboration is now of strategic importance to successful supply chain networks, and efficient and effective relationships are essential for achieving better supply chain management. The changing global business environment also presents an opportunity and a challenge for academics and industry practitioners to conduct further research on the connection and interaction between supply chain entities and the development of efficient and effective collaborative networks within the supply chain.

1.2 RESEARCH STATEMENT

Because the development of effective relationships between entities is of strategic importance to the success of a supply chain, supply chain collaboration presents an interesting and essential research topic.

There are many different activities in the supply chain and the requirements for collaboration vary with the complexity of each activity. Although research on collaboration between different activities in the supply chain can be found in the literature, the studies mostly concern the operation of the supply chain, and only focus on the ways different tools can be adopted to solve supply chain problems. Studying collaborative activities in isolation may not be helpful for achieving collaboration in the supply chain as a whole. The basic premise of supply chain collaboration is to develop effective and efficient collaborative networks for supply chain entities to interact, i.e. to design collaborative networks that embed collaboration among the supply chain entities during the design of the supply chain. However, limited research has been conducted on collaboration in the design stage of the supply chain. Moreover, while studies have investigated the adverse effects produced by a lack of collaboration, research is needed to measure and evaluate how collaboration contributes to the performance of the supply chain. However, few studies have measured supply chain collaborative performance.

The motivation and challenge of this study is to construct an approach to supply chain collaboration that extends the traditional study of the operation stage to the design and measurement stages. The perspective adopted in this study applies and extends collaboration to the entire supply chain by including the design, operation and measurement of the supply chain in the analysis. A detailed analysis and investigation of existing supply chain collaboration frameworks and models can be found in the literature review presented in Chapter 2 of this thesis. The research framework for this study is illustrated in Figure 1.1.

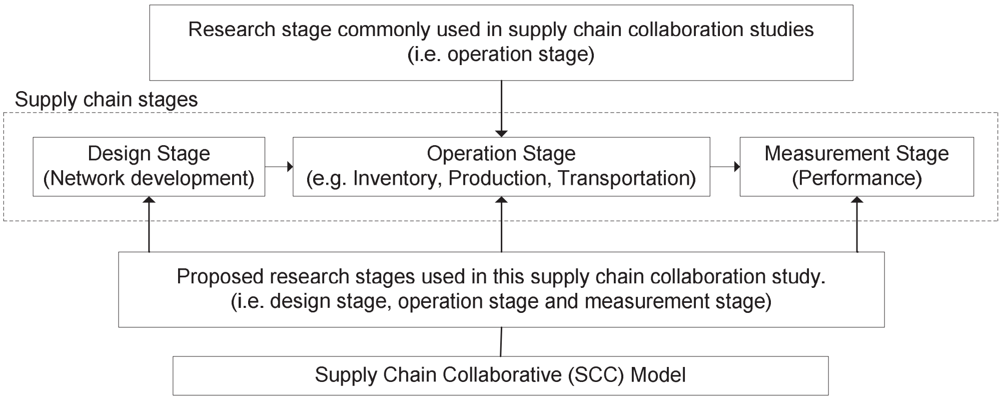


Figure 1.1 The research framework for this study

Most supply chain collaborative models focus on operations, which is only one of the stages of supply chain management. However, the effective management of a supply chain typically covers network design and measurement, as well as operations. Accordingly, in regard to the design and development of a supply chain collaborative model, the research statement for this study is “to design and develop a supply chain collaborative model that covers the stages of supply chain network design, operations and performance measurement to establish effective relationships in the supply chain network”.

1.3 RESEARCH AIMS OBJECTIVES

The aims of this research are to study the relationship between collaboration and performance in supply chain management, and to fill the gap in the existing literature that supply chain collaborative models are mostly focusing on the operation stage of supply chain.

This study has two specific objectives with regard to developing a supply chain collaborative model, i.e.

- Develop a supply chain collaborative model from a perspective that covers the multiple stages of design, operation and measurement of the supply chain;
- Analyse the performance of the proposed Supply Chain Collaborative (SCC) model through an industrial case study with different scenarios.

The first objective is to extend the traditional study of the operation stage to its two extremes, i.e. the design of a collaborative network and the measurement of it performance. So that collaboration applies and extends to the entire supply chain, a perspective covering the multiple stages of designing, operating and measuring the supply chain is employed. The design stage focuses on the construction of the supply chain, i.e. on how the supply chain entities are selected and partnered. Next, the operation stage focuses on establishing effective and efficient collaborative relationships between common supply chain activities, such as production, transportation, and inventory. Finally, the measurement stage focuses on measuring and evaluating the collaborative performance of the overall supply chain to provide feedback for the design and operation stages to further improve overall supply chain collaboration.

The second objective is to employ an industrial case study to demonstrate the feasibility of the SCC model. In this case, the proposed model is illustrated in the design, operation and performance measurement of the supply chain in the studied company. The data set is obtained from the suppliers, manufacturers, and customers that compose the supply chain of the company. The modelling approaches of the SCC model are illustrated in the case study.

1.4 RESEARCH METHODOLOGY

The SCC model is developed using the interrelationships between collaborating entities in the design, operation, and measurement of the supply chain. These three stages are common to the supply chain management models identified in the existing literature and from industrial practices. Moreover, employing all three stages ensures that most of the activities and entities involved in the supply chain are included in the model.

As the SCC model extends the operation stage to its two extremities, it thus includes the design and measurement of the supply chain, i.e. (1) the design of the supply chain is developed in accordance with how the entities are selected and partnered, (2) effective and efficient collaboration is maintained between common supply chain operational activities, and (3) the performance of the entire collaborative supply chain is measured and evaluated.

The case study of the proposed SCC model was supported by the Teaching Company Scheme (TCS) offered by the Hong Kong Polytechnic University and a participating company. The scheme is also supported by the Hong Kong Special Administrative Region Government's Innovation and Teaching Commission. A detailed description of the scheme is proved in Appendix I.

Conducted through the TCS, the study of the SCC model is a research and development project that is directly related to the needs of the participating company. The research has been conducted within the business environment of the participating company since early 2005. The participating company is a Hong Kong based manufacturer of custom made high frequency quartz crystal products, and its basic supply chain is comprised of suppliers, manufacturers, and customers worldwide across the stages of supply chain design, operation, and measurement. The background of the participating company is outlined in Chapter 7.

The SCC model was mainly developed during a period when the participating company reengineered its supply chain. Therefore, the approaches underlying the proposed model mainly evolved from practices observed in the participating company, such as through the review and analysis of internal and external business documents and process flows, the redesign of operational practices, and the implementation of new systems and databases. In addition, network graph theory, mathematical programming, and statistical methods were applied in developing the design, operation, and measurement stages of the SCC model.

As the SCC model is illustrated and validated in the case study of the participating company, the data set used in the study is the historical data that was obtained from the database of the participating company, which is a key entity in the global supply chain of the made-to-order manufacturing industry. The types of raw data used to illustrate the SCC model, include product types, forecasted demand, order processing records, operation time and cost, processing time and cost, and inventory cost. The data set has been slightly modified in the case study to comply with the business confidentiality requirements of the studied company. Heuristics methods using genetic algorithms are adopted to solve the different scenarios in the case study. In addition, statistical methods of analysis of variance (ANOVA), trend line, and effect size are used to corroborate the proposed model with the data set obtained from the studied company. A detailed account of the results of the analysis of the SCC model of the company is provided in Chapter 7. Furthermore, the research was generally conducted in two phases, and a timetable of the study can be found in Appendix II.

1.4.1 Phase 1 – Development of the SCC model

In this phase, the SCC model is developed based on the collaborative interrelationships in the design, operation and measurement stages of the supply chain. The aim of the SCC model is to extend the operation stage to develop a collaboration perspective covering the design, operation and measurement of the supply chain, so that collaboration applies and extends to the entire supply chain. The proposed model also quantitatively represents supply chain collaboration to enable of the relationship between supply chain entities across the three stages to be effectively analysed and evaluated.

1.4.2 Phase 2 – Illustration and Validation of the SCC model

In this phase, the SCC model is illustrated in an industrial setting using real data to demonstrate the feasibility of the proposed model. The data set was gathered from the global supply chain of the studied company, which comprises suppliers, manufacturers, and customers worldwide across the stages of supply chain design, operation, and measurement.

1.5 ORGANIZATION OF THE THESIS

This thesis, which is mainly devoted to the design and development of the Supply Chain Collaborative (SCC) model, is organised as follows.

Chapter 2 presents an extensive review of the supply chain collaboration models and theories contained in the existing literature. The general limitations of the existing research on supply chain collaboration are analysed and discussed. The results of the literature review provide the basis for the motivation and research significance of this study. Finally, a theoretical framework of the interrelationships among the different supply chain stages that are integral to the SCC model is also discussed.

Chapter 3 focuses on the role the design stage plays in the SCC model. A Cross Functional Partnership Selection (CFPS) sub-model which uses a hierarchical approach to partner and select appropriate entities in a supply chain is proposed for the design stage. A network graph approach is used to quantify the CFPS model, and the six basic types of collaborative partnership between supply chain entities in CFPS are then modelled. These results can be used for further analysis and optimization.

In Chapter 4, the role of the operation stage of the SCC model is discussed. A Cross Entity Operational Planning (CEOP) sub-model is proposed for the collaboration between activities in the operation stage of the SCC model. CEOP is a mixture of vertical and horizontal planning approaches that collaboratively considers the operational planning of the entire supply chain, and accounts for the interrelationships between distinct supply chain processes in the entity planning domain. A mathematical programming modelling approach is then used to quantify the modelling of CEOP. The objective function of this quantitative model is to minimize the total cost incurred from operational activities, such as production, transportation, and inventory. The CEOP sub-model can be used to further analyse and improve the operations stage of the SCC model.

Chapter 5 discusses the role of the measurement stage of the SCC model. A Cross Domain Performance Measurement (CDPM) sub-model is proposed which uses a quantitative performance measurement approach that is capable of representing the overall collaborative performance of a supply chain in a performance value. This quantitative approach to the measurement stage of the SCC model enables performance discrepancies over a period of time to be determined.

Chapter 6 illustrates and validates the SCC model through a case study of a company that manufactures made-to-order high frequency quartz crystal products. The background of the company and its supply chain, the case problem scenarios, and the use of the different scenarios to illustrate and validate the SCC model case scenarios are described in detail in this chapter.

Chapter 7 discusses the potential academic and industrial contributions of the study. The limitations of the study and recommendations for further research are then outlined. Finally, this concluding chapter summarises the findings of the thesis.

2. LITERATURE REVIEW

This chapter reviews the current literature on collaboration in the supply chain, and is organized as follows. Section 2.1 presents an overview of supply chain management. Section 2.2 discusses the relationship between the supply chain and supply chain collaboration. Section 2.3 outlines the two main perspectives on supply chain collaboration, the collaboration between particular supply chain entities and the collaboration between supply chain stages. Section 2.4 presents the current models and theories of supply chain collaboration. Section 2.5 presents the results of an analysis conducted to identify the deficiencies in the existing supply chain collaboration research literature. The motivation for, and significance of this study in supply chain collaboration are discussed in Section 2.6. Section 2.7 presents a theoretical framework for a Supply Chain Collaborative (SCC) model that extends the operation stage in traditional collaboration research to the design and measurement stages. Finally, Section 2.8 summarises the findings presented in this chapter.

2.1 OVERVIEW OF SUPPLY CHAIN MANAGEMENT

In the 1990s, manufacturers and service providers began to collaborate with their suppliers to improve their purchasing and supply-demand activities by making them an integral part of business practice. Around this time, wholesalers and retailers also began to integrate their physical distribution and logistics activities to enhance their competitive advantage (Tan et al., 1998; Tan et al., 1999; Prasad & Babbar, 2000). Over the next ten years, these two traditionally distinct supporting activities evolved and eventually merged into the strategic business approach to operations, materials and logistics management now commonly referred to as supply chain management (Li, 2007; Coyle et al., 2009). Accordingly, supply chain management covers a range of business activities, including purchasing, production, demand management, inventory management, transportation, logistics management, warehousing, order processing, and information management.

Supply chain management, which integrates the perspectives of the two traditional supporting activities to encompass all value-adding activities, is a growing area of interest amongst academics and industry practitioners. Furthermore, the wide-ranging problem of using the processes, technology, and capabilities of suppliers to enhance competitive advantage has been studied by a variety of disciplines (Houlihan, 1985; Cooper & Ellram, 1993; Hines et al., 1998; Lummus et al., 1998; Johnson, 1999; Narasimhan & Jayaram, 1998; Vitasek, 2003; Branch, 2009; Bowersox et al., 2010).

The goal of supply chain management is to seamlessly and effectively integrate manufacturing processes and logistical functions to fulfil customer orders and demand (Lee & Billington, 1995; Anderson & Katz, 1998; Birou et al., 1998; Lummus et al., 1998; Leenders et al., 2002). A well integrated supply chain will coordinate the flow of materials and information between suppliers, manufacturers and customers (White et al., 1999; Narasimhan & Carter, 1998; Trent & Monczka, 1998; Burt et al., 2003), and implement product postponement and mass customization (Lee & Tang, 1998; Pagh & Cooper, 1998; Van Hoek et al., 1998).

Supply chain management can be applied to the sequence of supply chain activities, the flow of material, information, and finance or, as in higher level modern supply chain management, the design, operation and measurement stages of the supply chain (Ellram, 1995; Degraeve & Roodhooft, 1999; Leenders et al., 2002; Burt et al., 2003; Chopra & Meindl, 2004). Supply chain entities refer to the participants in the supply chain, such as organizations, suppliers, manufacturers, distributors, and customers. Accordingly, supply chain management entails using of a set of synchronized decisions and activities to manage the flow of material, information, and finance through a supply chain network (Li, 2007; Coyle, 2009) and to efficiently integrate suppliers, manufacturers, warehouses, distributors, retailers, and customers. Ultimately, the supply chain will serve to minimize system-wide costs and satisfy customer service requirements, by ensuring that the right products or services are distributed in the right quantities, to the right locations, at the right time and to the right customers (Branch, 2009; Bowersox et al., 2010). The general supply chain management structure is illustrated in Figure 2.1.

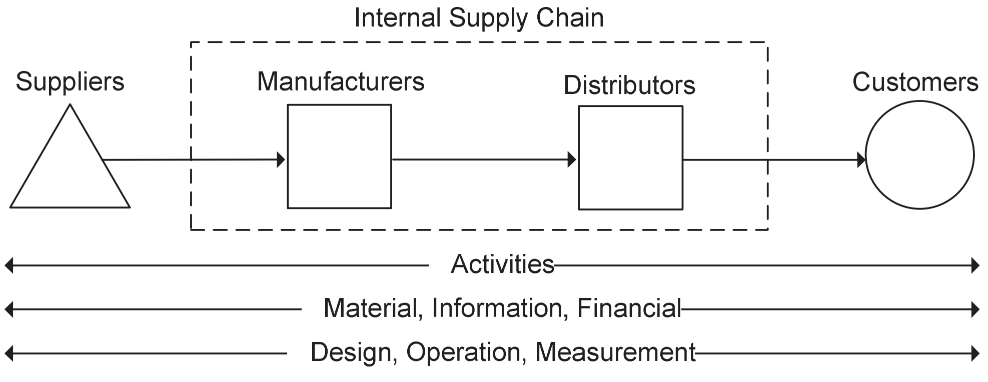


Figure 2.1 General supply chain management structure

2.2 SUPPLY CHAIN AND SUPPLY CHAIN COLLABORATION

As Chase (1998) notes, the supply chain links the various activities and entities involved in the operation of an organisation over a series of time horizons. Therefore, management of the supply chain involves overseeing a system of collaboration where explicitly defined processes, responsibilities and structures of entities are aligned with specific operational activities and the overall objectives of the supply chain.

As Simchi-Levi et al. (2003) point out, supply chains are typically complex and dynamic structures and this poses challenges for developing effective collaboration. For instance, value is added to raw materials at a number of stages and through various activities before becoming the item or final product purchased by the end customer. The entities along this supply chain cannot compete independently, as they have to act as part of a unified system and coordinate with each other to sustain competitiveness. Thus, supply chain collaboration comes into focus in the development of effective and efficient relationships between entities to enhance and improve the performance of the entire supply chain. Moreover, the uncertainty and complexity of decisions regarding interrelated supply chain activities, such as customers' different requirements and the different resources required, as well as increasing rates of unanticipated change and levels of goal difficulty among supply chain entities, also lead to a need for supply chain collaboration (Stank et al., 1999; Stank & Goldsby, 2000; Huiskonen & Pirttila, 2002).

Supply chain collaboration is a central lever of supply chain management. It involves cooperation and the fair sharing of risks and benefits among supply chain entities over time, and can be characterized by effective communication, information exchange, partnering and performance monitoring, joint planning, and joint product development (Stank et al., 1999; Ballou et al., 2000; Larsen, 2000). Supply chain collaboration can also serve as a vehicle for redesigning the decision making, workflow, and resources assigned to individual entities to improve the overall performance of the supply chain, through higher profit margins, improved customer service and/or faster response times (Lee, 2000; Simatupang & Sridharan, 2002; McClellan, 2003; Xu & Beamon, 2006). Thus, supply chain collaboration is a strategic response to the challenges arising from interdependent supply chain entities that has the potential to improve the performance of the entire supply chain.

Malone and Crowston (1994) state that collaboration is a prerequisite for integrating the operations of discrete entities to achieve common objectives, which involves managing the relations between interdependent supply chain entities so that they work together towards mutually defined goals. The mutual benefits of supply chain collaboration include the elimination of excessive inventory, the reduction of lead times, increased sales and revenue, improved customer service, more efficient product design and development, lower manufacturing costs, increased flexibility in manufacturing, and increased customer retention (Fisher et al., 1994; Lee et al., 1997a; Lee et al., 1997b; Horvath, 2001; Sahin & Robinson, 2002). However, studies also show that a lack of collaboration can have a range of adverse effects on supply chain performance, including inaccurate demand forecasts, low capacity utilization, low quality products, excess/redundant inventory, inadequate customer service, and high logistics costs (Fisher et al., 1994; Horvath, 2001; Tan, 2001; Sahin & Robinson, 2002).

2.3 PERSPECTIVES ON SUPPLY CHAIN COLLABORATION

Research on supply chain collaboration is generally conducted from one of two perspectives, focusing on (1) the collaboration between discrete supply chain activities (a non-holistic perspective) or (2) the collaboration across all stages of the supply chain (a holistic perspective).

The non-holistic studies mainly focus on collaborations that aim to get the job done by integrating specific jobs or activities in the supply chain, such as buyer-supplier collaboration (Hoyt & Huq, 2000; Sarmah et al., 2006), production-distribution collaboration (Sarmiento & Nagi, 1999; Sharafali & Co, 2000; Sarmah et al., 2007), inventory-distribution collaboration (Thomas & Griffin, 1996), and procurement-production collaboration (Goyal & Deshmukh, 1992). From the non-holistic perspective, the collaboration are primarily operational and resources, information and capabilities are sharing among specific directly participating entities solely to meet customers' demands and needs (Narus & Anderson, 1996; Wang, 2001; Wang, 2004).

On the other hand, the holistic approach to collaboration considers the activities at various stages across the supply chain that interact directly and indirectly with other entities. Holistic collaboration among supply chain entities serves to enhance overall business performance through the sharing of risks and rewards (Lambert et al., 1999; Klastorin et al., 2002). In this regard, collaboration represents a form of shared responsibility in that it involves integrating the interrelated activities and authority of distinct supply chain entities, and working towards joint planning, joint product design and development, mutual information sharing and integrated information systems, to achieve long term cross collaboration in the supply chain and the fair sharing of risks and benefits (Ballou et al., 2000; Larsen, 2000; Lee et al., 2000; Moinzadeh, 2002). Given the interdependent nature of supply chain activities, the holistic collaboration perspective can offer a way of redesigning workflow and resources to reflect the mutual objectives of the entire supply chain as well as the individual entities involved (Lee, 2000; Simatupang et al., 2002). In addition, holistic collaboration can be a way to jointly plan supply chain activities and synchronize the forecasting of production and replenishment processes. This can help to minimize operational costs and share the mutual benefits of collaboration between supply chain entities (Larsen et al., 2003; Hill & Omar, 2006).

There are two main types of holistic collaboration across stages of the supply chain, vertical collaboration and horizontal collaboration.

2.3.1 Vertical Collaboration

Vertical collaboration refers to the relationships between entities at different stages in the supply chain, i.e. the traditional links between supply chain entities such as retailers, distributors, manufacturers, and suppliers (Choi & Hong, 2002;

Kim, 2009; Jayaram & Tan, 2010). The activities of entities at different stages of the supply chain can be automated, and efficiencies can be significantly improved (Flynn et al., 2010). Under vertical collaboration, supply chain entities can better align supply and demand through the direct sharing of plans and critical information, and attain a form of mutual visibility that enables them to mutually adapt their behaviour. Vertical collaboration in the supply chain is illustrated in Figure 2.2.

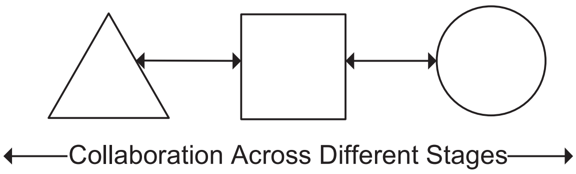


Figure 2.2 Vertical collaboration in the supply chain

2.3.2 Horizontal Collaboration

Horizontal collaboration refers to the relationships between entities at same stages in the supply chain (Zhao et al., 2008; Nagurney, 2009). This form of collaboration is typical in business arrangements between entities that have parallel or complementary positions in the supply chain, such as joint product design, sourcing, co-manufacturing, and logistics. Under horizontal collaboration, entities at the same stage in the supply chain collaborate and leverage with each other, thus enabling hidden costs in the supply chain to be eliminated (Bahinipati et al., 2009; Nagurney, 2010). Horizontal collaboration in the supply chain is illustrated in Figure 2.3.

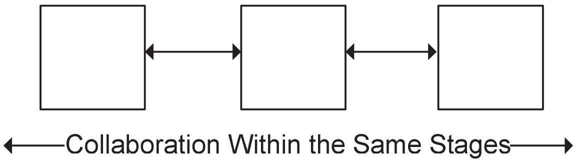


Figure 2.3 Horizontal collaboration in the supply chain

2.4 SUPPLY CHAIN COLLABORATIVE MODELS

Supply chain collaboration is essential for coordinating activities and entities across the entire supply chain. Different models of collaboration have been developed to help align supply chain entities and to ensure better collaborative performance in the supply chain. There are two basic models of collaborative supply chains in the literature, i.e. mathematical models, and business models.

The mathematical models of supply chain collaboration typically propose mathematical programmes that optimize supply chain collaboration and provide solutions to assist and enhance relationships between entities in particular scenarios of supply chain activities. Examples include a heuristic model to develop joint replenishment ordering, an inventory model to implement supply-side forecasting, a pricing model to establish revenue sharing contracts, and constructing computer-based architecture for information sharing. Other mathematical models for achieving supply chain collaboration are based on the likes of effective communication, information exchange, partnering, channel collaboration, operational efficiency, and performance monitoring (Lee et al., 1997a; Lee et al., 1997b; Stank et al., 1999). Further mathematical models can be identified by the modes and means of collaboration, the mechanisms for collaboration and the conceptual models they employ (Lee, 2000; Fawcett &

Magnan, 2002; Simatupang et al., 2002; Simatupang & Sridharan, 2002). For instance, Barratt (2004) focused on supply chain collaboration between the purchasing habits, behaviours and service needs of customers and the various entities that make up the entire supply chain; Sinha and Sarmah (2007) proposed an outsourcing model for supply chain collaboration when suppliers have insufficient production capacity. Furthermore, some of the tools used to mathematically model supply chain collaboration include genetic algorithms, fuzzy theory, and integer programming (Gokce et al., 2002; Pourakbar et al., 2007; Lam et al., 2008). In general, mathematical models are mainly used for collaboration between particular supply chain entities, i.e. non-holistic collaboration.

A number of business models for supply chain collaboration suggest specific steps or practice approaches for building effective relations among supply chain entities. Conducted from a holistic perspective, these pragmatic initiatives have been adopted as business reference models for achieving collaboration between stages as well as activities involved in the supply chain (Holweg et al., 2005). Business models commonly found in the literature include the Collaborative Planning, Forecasting, and Replenishment (CPFR) model, the Supply Chain Operations Reference (SCOR) model, the Vendor Managed Inventory (VMI) model, among others.

2.4.1 Collaborative Planning, Forecasting, and Replenishment (CPFR) Model

The Collaborative Planning, Forecasting, and Replenishment (CPFR) model was proposed by the Voluntary Interindustry Commerce Standards Association

(VICS) to describe supply chain collaboration (VIC, 2002). CPFR emphasises the importance of using information sharing to establish strong links between business planning, forecasting, and replenishment. This can effectively optimize the performance of the supply chain by improving demand forecasts, enabling the right product to be delivered at right time to the right location, reducing inventories, avoiding stock-outs, and improving customer service. The value of CPFR lies in its capacity to improve forecasting accuracy through the broad exchange of forecasting information, where both the buyer and seller collaborate by sharing knowledge of sales, promotions, and relevant supply and demand information. The primary driving forces for implementing the CPFR model include fierce competition, a shorter life cycle, offshore production, and the supply chain cost structure (Raghunathan, 1999; Aviv, 2002; Fliedner, 2003).

The CPFR model comprises three major activities, planning, forecasting, and replenishment (VICS, 2000; Barratt & Oliveira, 2001; Seifert, 2003; Crum & Palmatier, 2004). The CPFR Workgroup suggests that planning should start with a termed contract that states the responsibilities of each supply chain entity in collaborating to provide the right products for customers. Following this, the parties need to develop a joint business plan for demand management, sales promotion, production quantity, timing, and inventory level. Forecasting involves predicting the customer demands of all the collaborating supply chain entities. As any differences in demand among the collaborating entities can be subsequently identified and resolved, feasible sales forecasts can ultimately be developed for each of the collaborating entities. Reviews and modifications may be carried out periodically to reflect the changes in market demand (Aviv, 2001; CPFR Workgroup, 2002; Aviv, 2007). Finally, replenishment follows forecasting, in maintaining sufficient stocks to fulfil orders based on the development of efficient production and delivery schedules (CPFR Workgroup, 2002).

The idea of collaborative planning, forecasting, and replenishment represented in CPFR was initiated in the mid 1990s. VICS later developed a nine-step model as a guideline for implementing CPFR to further facilitate the collaboration required in supply chains (VICS, 2000). The nine steps proposed by VICS to effectively implement CPFR can be summarized as follows: (1) develop collaboration arrangements, (2) create a joint business plan, (3) prepare sales forecasts, (4) identify exceptions to the sales forecast, (5) resolve/collaborate on excepted items, (6) create order forecast, (7) identify exceptions to the order forecast, (8) resolve/collaborate on excepted items, and (9) generate orders.

The nine steps have successfully guided companies to implement CPFR in the supply chain. The establishment of a collaborative supply chain can give companies a significant competitive edge over their competitors. For instance, a number of prominent companies, including Wal-Mart, Dell Inc., and Proctor & Gamble, share point of sales and inventory data with all the other entities in their respective supply chains. Foote and Krishnamurthi (2001) point out that this kind of information sharing enables each entity to make decisions about the activities that yield better efficiencies and more profits for itself and the entire supply chain. The benefits of implementing CPFR include a diminished bullwhip effect, reduced inventory, reduced safety stock, and reduced probability of stock outs (Aghazadeh, 2003; Aichlmayr, 2003; Fliedner, 2003).

2.4.2 Supply Chain Operations Reference (SCOR) Model

The Supply Chain Operations Reference (SCOR) model is a business reference model that was introduced by the Supply-Chain Council (SCC). The model integrates business operations, metrics, best practice, and features associated with the execution of unique supply chain formats (Stephens, 2001; SCC, 2001).

Compared to the classical models of process decomposition, which were developed to address specific configurations of elements and to aggregate series of hierarchical processes, the SCOR model provides a balance of horizontal and vertical views. Under the SCOR model, entities in vertically connected along the supply chain use common terminology and standard descriptions of elements in their respective supply chains, which can help improve management processes and best practices for achieving optimal performance across the overall supply chain (Intel, 2002; Bolstorff & Rosenbaum, 2003). Bolstorff and Rosenbaum (2003) suggest that the SCOR model is also able to identify performance measurements and supporting tools for each supply chain activity, thereby enabling each entity involved in developing and managing the integrated supply chain to collaborate effectively.

The SCOR model integrates the concepts of business process reengineering, benchmarking, and process measurement into a cross-functional framework

(Stephens, 2001; SCC, 2001). The model was originally founded on five distinct management processes - Plan, Source, Make, Deliver, and Return - known as Level 1 processes. These Level 1 processes are decomposed into Level 2 process categories, depending on the type of supply chain the SCOR model is applied. The process categories in Level 2 are further decomposed into Level 3 process elements that contain the performance attributes, metrics, best practices and software features the SCOR model requires for that element (Stephens, 2001; SCC, 2001).

In essence, the SCOR model first captures the "as-is" state of a process and then derives the desired "to-be" state of the corresponding entities in the supply chain. It quantifies and characterizes the operational performance and management practices of similar entities/supply chains and establishes internal targets based on "best-in-class" results. Although the model has undergone several major revisions in response to the practical needs of different supply chains, the basic structural framework of the SCOR model still contains the following fundamental elements (Stephens, 2001; SCC, 2001):

- Standard descriptions of the individual elements that make up the supply chain processes.
- Standard definitions of key performance measures.
- Descriptions of best practices associated with each of the process elements.
- Identification of software functions that enable best practices.

2.4.3 Vendor Managed Inventory (VMI) Model

The Vendor Managed Inventory (VMI) model, also known as continuous replenishment or supplier-managed inventory, is a supply chain collaborative model for managing inventory. The model describes partnering initiatives to encourage collaboration and information sharing among supply chain entities (Angulo et al., 2004). Popularized during the late 1980s, VMI was adopted and implemented by many leading companies in a number of different industries (Waller et al., 1999; Danese, 2004; De Toni & Zamolo, 2005; Micheau, 2005; Watson, 2005).

The VMI model is a supply chain initiative where the vendor decides the appropriate inventory levels and policies for the products supplied its various retailers and where the vendor can access the retailer's inventory, sales and stock level data. In this partnering relationship, the retailer may set certain service level and/or shelf-space requirements, which the vendor then takes into consideration (Simchi-Levi et al., 2003; Mishra & Raghunathan, 2004).

Under the VMI model, the vendor is responsible for creating and maintaining the inventory plan. The model creates stockless scenarios for the supply chain entities and develops a new collaborative channel to gain a supply-demand perspective within the supply chain. This offers competitive advantages for both retailers and vendors. For the retailer, the model results in higher product availability, improved service levels and lower inventory monitoring and ordering costs (Waller et al., 1999; Achabal et al., 2000). Alternatively, for the vendors, the VMI model reduces the bullwhip effect (Lee et al., 1997b; Disney

& Towill, 2003a; Disney & Towill, 2003b) and leads to the better utilization of manufacturing capacity (Waller et al., 1999) and more synchronized replenishment planning (Waller et al., 1999; Cetinkaya & Lee, 2000).

A number of different variations of VMI have been developed (Cachon & Fisher, 1997; Lee et al., 1997a; Lee et al., 2000) in response to the application, ownership and implementation requirements of each sector, including the Quick Response (QR), Synchronized Consumer Response (SCR), Continuous Replenishment (CR), Rapid Replenishment (RR), and Centralized Inventory Management (CIM) models.

2.5 GENERAL FINDINGS FROM THE ANALYSIS OF EXISTING SUPPLY CHAIN COLLABORATION RESEARCH

The existing research on supply chain collaboration still contains deficiencies with regard to the role collaboration plays in the supply chain. A wide range of academic article databases, including Science Direct, ProQuest, EBSCOhost (BSC), IEEE Xplore, Wiley InterScience, and Informaworld, were used to compile information about the published research on supply chain collaboration.

To avoid loss of generality, the databases were searched using complementary search terms such as “collaboration”, “cooperation”, “coordination”, and “integration”. Phrases relating to the terms, for instance cooperation (joint operation), coordination (working jointly), and integration (combining to an integral whole) can be assumed to signify collaboration. The phrases were searched in the “Subject/Title/Abstract” field options to reduce the number of irrelevant articles or articles where the main topic of study was not supply chain collaboration.

The data on the existing supply chain collaboration literature was analysed according to the collaboration perspective (i.e. holistic or non-holistic), the stage in the supply chain in which collaboration is covered (i.e. collaboration in the design, operation or measurement stages), and the methodology employed (i.e. mathematical or descriptive qualitative). Between 1990 and 2010, a total of 100 articles were found to relate to supply chain collaboration. The results of the statistical analysis of the approaches and methods employed in the exiting literature are presented in Tables 2.1(a) to 2.1(e), and summarized in Table 2.2.

Table 2.1(a) Statistical investigation of the research approaches and methods in the literature

Articles (1990-2010)	1. Collaboration Perspective	a. holistic	b. non holistic	2. Coverage of Collaboration	a. design stage	b. operation stage	c. measurement stage	3. Methodology	a. mathematical	b. descriptive qualitative
Abrahamsson et al. (2003)			*			*				*
Agrawal et al. (2002)			*			*			*	
Alfredsson & Verrijdt (1999)			*			*			*	
Anupindi & Akella (1993)			*			*			*	
Arntzen et al. (1995)		*				*	*			*
Aviv (2001)		*			*	*				*
Bagahana & Cohen (1998)			*			*			*	
Bahinipati et al. (2009)			*			*				*

Table 2.1(b) Statistical investigation of the research approaches and methods in the literature

Articles (1990-2010)	1. Collaboration Perspective	a. holistic	b. non holistic	2. Coverage of Collaboration	a. design stage	b. operation stage	c. measurement stage	3. Methodology	a. mathematical	b. descriptive qualitative
Baker (2006)			*			*				*
Barron (2007)			*		*					*
Bassok & Anupundi (1997)			*			*			*	
Berry & Naim (1996)		*			*		*		*	*
Bessant et al. (1994)			*				*			*
Boyaci & Gallego (2002)			*			*			*	*
Cachon & Zipkin (1999)			*			*			*	
Camm et al. (1997)			*			*			*	*
Canel & Khumawala (1996)		*				*	*		*	
Cetinkaya & Lee (2000)			*			*			*	
Chaharsooghi & Heydari (2010)			*			*			*	
Chandra & Fisher (1994)			*			*			*	
Chen & Chen (2005)			*		*				*	
Chen & Xiao (2009)			*			*			*	
Chen (1999)			*				*		*	
Chen et al. (2010)			*			*			*	
Choi et al. (2008)			*			*			*	
Das & Abdel Malik (2003)			*			*				*
Ding & Chen (2008)			*			*			*	
Duclos et al. (2003)			*			*				*
Fisher & Raman (1996)			*		*				*	
Ganeshan (1999)			*			*			*	*
Garg & Tang (1997)			*			*			*	
Gaudreault et al. (2009)			*		*					*
Graves et al. (1998)			*			*			*	
Grout (1998)			*			*			*	*
Gurnani (2001)			*			*				*
Gutierrez & Kouvelis (1995)		*				*	*		*	

Table 2.1(c) Statistical investigation of the research approaches and methods in the literature

Articles (1990-2010)	1. Collaboration Perspective	a. holistic	b. non holistic	2. Coverage of Collaboration	a. design stage	b. operation stage	c. measurement stage	3. Methodology	a. mathematical	b. descriptive qualitative
Hadjinicola & Kumar (2002)		*				*	*		*	*
Haq & Kannan (2006)			*		*				*	
Haug (1992)		*				*	*		*	
Henig et al. (1997)			*			*			*	
Hill & Omar (2006)			*			*			*	
Holweg & Pil (2008)		*			*	*				*
Hou et al. (2009)			*			*			*	
Hua et al. (2006)			*			*			*	
Huchzermeier &Cohen (1996)		*				*	*		*	
Huiskonen & Pirttila (2002)		*			*	*				*
Huq et al. (2006)			*		*				*	*
Hwarng et al. (2005)			*			*				*
Jang et al. (2002)			*			*			*	
Jayaraman & Pirkul (2001)			*			*			*	
Jayaraman (1999)		*			*	*			*	*
Kouvelis & Gutierrez (1997)		*			*		*		*	
Kulp (2002)			*		*				*	
Lam et al. (2008)			*		*				*	
Lee & Wei (2001)			*			*			*	*
Lee (2004)		*			*	*				*
Li et al. (1996)			*			*			*	
Lowe et al. (2002)		*				*	*		*	
Lu (1995)			*			*				*
Manthou et al. (2004)		*			*	*				*
Moinzadeh & Aggarwal (1997)			*			*			*	
Moinzadeh (2002)			*			*			*	
Moses & Seshadri (2000)			*			*			*	
Munson & Rosenblatt (1997)		*			*		*		*	

Table 2.1(d) Statistical investigation of the research approaches and methods in the literature

Articles (1990-2010)	1. Collaboration Perspective	a. holistic	b. non holistic	2. Coverage of Collaboration	a. design stage	b. operation stage	c. measurement stage	3. Methodology	a. mathematical	b. descriptive qualitative
Munson & Rosenblatt (2001)		*			*	*			*	
Nagurney et al. (2003)		*			*		*		*	
Naim et al. (2006)			*			*				*
Nair & Narasimhan (2003)		*			*	*				*
Paraskevopoulos et al. (1991)		*			*	*			*	
Piplani & Fu (2005)			*		*				*	*
Prater et al. (2001)			*			*				*
Pyke & Cohen (1993)			*			*			*	
Raghunathan (1999)			*			*			*	
Revelle & Laporte (1996)		*			*	*			*	
Robinson & Satterfield (1998)			*			*			*	
Rosenfield (1996)		*				*	*		*	
Ryu & Yucesan (2010)			*			*			*	
Sahin & Robinson Jr. (2005)			*			*			*	
Slack (2005)			*			*				*
Stank & Goldsby (2000)		*			*	*				*
Stank et al. (1999)		*			*	*			*	
Stevenson & Spring (2007)		*			*	*				*
Stock et al. (2000)			*			*			*	
Swafford et al. (2008)			*		*					*
Tachizawa & Thomsen (2007)			*			*				*
Tagaras & Lee (1996)			*				*		*	
Talluri & Narasimhan (2003)			*		*		*		*	
Talluri (2002)			*			*			*	
Tang (1990)			*			*			*	
Verwijmeren et al. (1996)		*			*	*				*
Vidal & Goetschalckx (2001)			*			*	*		*	
Wang & Gerchak (1996)			*			*			*	

Table 2.1(e) Statistical investigation of the research approaches and methods in the literature

Articles (1990-2010)	1. Collaboration Perspective	a. holistic	b. non holistic	2. Coverage of Collaboration	a. design stage	b. operation stage	c. measurement stage	3. Methodology	a. mathematical	b. descriptive qualitative
Wang et al. (2004)			*			*			*	
Wu & Ouyang (2003)			*			*				*
Xue et al. (2007)		*			*	*				*
Yang & Wee (2002)			*		*				*	
Yao & Chiou (2004)			*			*				*
Zhang et al. (2003)		*			*	*				*
Zhao et al. (2002)		*			*	*				*
Zou et al. (2004)			*		*				*	*

Table 2.2 Analysis of the research approaches and methods in the literature

		Number of count	Percentage (%)
1	Collaboration Perspectives		
	a. holistic	29	29
	b. non-holistic	71	71
2	Coverage of Collaboration		
	a. design stage	34	26
	b. operation stage	80	61
	c. measurement stage	17	13
3	Methodology		
	a. mathematical	69	62
	b. descriptive qualitative	42	38

The analysis of the existing research on supply chain collaboration reveals that numerous studies have discussed the need for collaboration, the difficulties in achieving collaboration, and the impact of collaboration on supply chain performance. While the importance of supply chain collaboration is emphasized in the literature, as shown in Tables 2.1 and 2.2, relatively few studies focus on holistic supply chain collaboration. Furthermore, none of the studies employ a fully holistic perspective on supply chain collaboration covering the design, operation, and measurement stages. Supply chain collaboration studies are mostly conducted from a non-holistic perspective, which may be due to the expectations of various stakeholders that resolving the operational difficulties in the supply chain appears to be the crucial task.

The results of the research analysis also reveal that some studies focus on the capabilities or intangibles that require collaborating, such as mutuality, responsibility, cooperation and trust. Other perspectives are based on the collaboration efforts required to achieve the common goals and objectives of the supply chain. The requirements for collaboration presented in the literature are also varied, which may be due to the complex nature of supply chain activities. Collaboration is discussed in relation to a variety of supply chain problems, and a number of different collaborative approaches are also used in the study of supply chain activities and entities. The supply chain problems most frequently mentioned in the literature are those associated with the joint consideration of the operational costs associated with ordering, planning, delivery, and replenishment. This may also reflect the fact that most of the studies in the literature focus on the operation stage. Moreover, relatively few studies discuss the design of supply chain collaboration or the monitoring and measurement of supply chain collaboration.

The methodologies adopted in supply chain collaboration studies tend to be quantitative rather than qualitative. Most studies focus on the two-dimensional collaboration between supply chain activities and entities, such as between supplier and manufacturer, manufacture and distributor, and distributor and customer. Thus, the main objective of the research is to seek how to either minimize costs or maximize profits, though some studies collectively consider the costs of different activities to minimize the costs of the overall supply chain. Various models are applied to supply chain collaboration to study the relationships between supply chain entities, such as transaction cost theory, strategy structure theory, resource-based theory, operations research and information management, joint decision making, information sharing, resource sharing, and risk sharing. Various tools are also proposed to optimize supply chain collaboration. Although most mathematical models regard the collaboration of different supply chain activities and entities in isolation, the business models consider the means and mechanisms achieving supply chain collaboration in a holistic manner.

2.6 MOTIVATION FOR AND RESEARCH SIGNIFICANCE OF THIS STUDY

There are many different activities involved in the supply chain, and the collaboration requirements of the overall supply chain vary with the complexity of each activity. However, as the research has focused mostly on the activities involved in the operation stage of supply chain and in isolation from the other stages of the supply chain, it may not be helpful in achieving collaboration in the entire supply chain. Furthermore, most studies focused on the two-dimensional collaboration between supply chain activities and entities, and the different tools required to solve problems in the supply chain. The premise of supply chain collaboration is to develop an effective and efficient network that enables the various supply chain entities to interact, i.e. to design a collaborative network that embeds collaboration between the supply chain entities. However, the research on collaboration in the design stage of the supply chain is limited. Moreover, as a number of studies have evaluated the adverse effects a lack of collaboration can have on supply chain performance, collaboration in the supply chain also needs to be measured and monitored to quantify and evaluate the strength of the collaborative mechanisms. However, there are few quantitative evaluations of collaborative performance in the existing literature.

Therefore, the motivation and challenge for this study is to construct a perspective that extends the research on the operation stage to design and measurement.

From a holistic supply chain collaboration perspective, the entire supply chain is required to collaborate. Accordingly, an ideal model of a collaborative supply chain would extend collaboration to more than one activity and cover all the supply chain entities. To ensure collaboration extends to all the activities and entities, the collaboration perspective thus needs to cover the design, operation, and performance stages in the supply chain. By extending supply chain collaboration beyond the operation stage, the holistic perspective is able to provide a more real and practical impression of the supply chain, one that includes the complex interactions between upstream and downstream activities and entities.

Therefore, the design and development of the Supply Chain Collaborative (SCC) model has significance for supply chain modelling research in that it offers a holistic image of collaboration which includes the multiple stages of design, operation and measurement and applies collaboration to all the entities in the supply chain. Moreover, as the SCC model also contributes to the modelling and analysis of supply chain collaboration, the results of this study are of value to academics and industry practitioners.

2.7 THEORETICAL FRAMEWORK

The analysis of the existing literature on supply chain collaboration has identified the relationships between the activities and entities that are integral to supply chain collaboration, i.e. the three supply chain management stages of design, operation, and measurement. Accordingly, this study proposes a Supply Chain Collaboration (SCC) model that extends the operation stage traditionally studied to its two extremes, the network development and performance measurement stages of the supply chain. The theoretical framework for the model proposed in this study is illustrated in Figure 2.4.

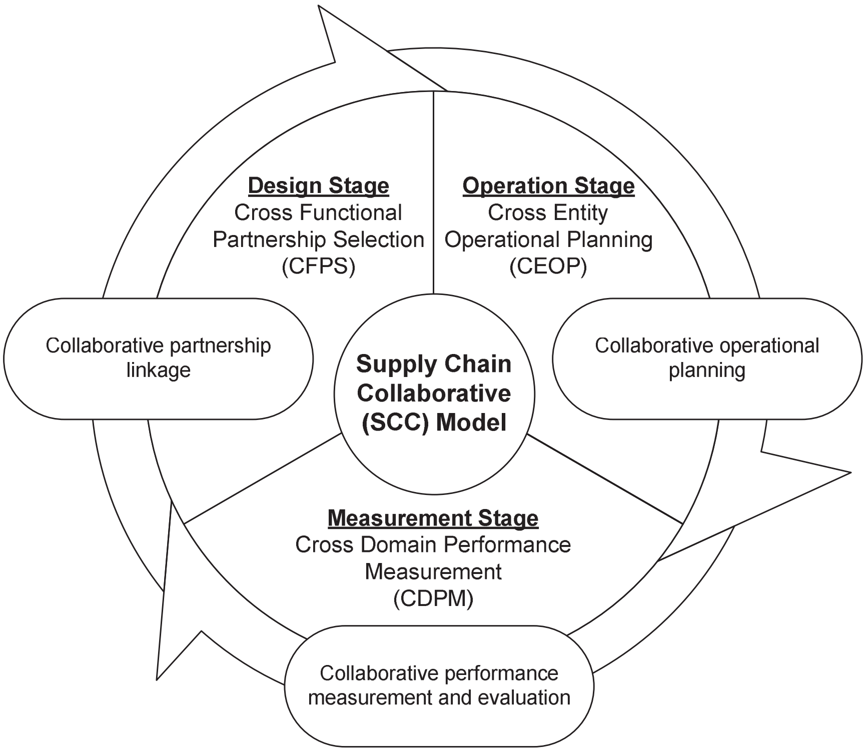


Figure 2.4 Schematic diagram of the theoretical framework of the SCC model

The design, operation, and measurement stages of the supply chain are primary dependent stages used to explain the overall collaborative performance of the SCC model. Because the model offers a perspective of the multiple stages of supply chain collaboration, it is thus able to give a more realistic picture of the supply chain by considering the complex interactions between upstream and downstream sites.

The design stage focuses on the development of the supply chain, i.e. on how the supply chain entities are selected and partnered. The design of the collaborative partnerships in the network can directly influence how the supply chain entities collaborate and perform in subsequent supply chain activities. The better the supply chain design, the better and more cohesively the relationships between the supply chain entities are able to be embedded. Next, the operation stage focuses on maintaining effective and efficient collaborative relationships between common supply chain operational activities, such as production, transportation, and inventory. The structure of the operation stage in the SCC model thus refers to the operational activities, processes, and priorities that build and sustain collaboration. The degree of collaboration during this stage influences the ability of the supply chain to fulfil customer orders and demand. Finally, the measurement stage focuses on the measurement and evaluation of the collaborative performance of the overall supply chain to provide feedback for the design and operations stages of the supply chain to further improve overall supply chain collaboration.

Network graph theory, mathematical programming, and statistical methods are applied to model the design, operation, and measurement stages of the SCC model. In the design stage, the six basic types of collaborative partnership linkages are quantified; the operation stage models a cost function to minimize the total cost incurred in the supply chain; and a time-series intervention model with quantitative performance values is proposed in the measurement stage. Detailed descriptions of the design, operation and measurement stages of the SCC model are provided in Chapters 4, 5 and 6, respectively.

On the basis of the above description of the SCC model, this study proposes that there will be a positive relationship between the overall collaborative performance of the supply chain and each of the design, operation, and measurement stages of the supply chain in the SCC model.

2.8 SUMMARY

This chapter has reviewed the research literature on supply chain management, the relationship between the supply chain and supply chain collaboration, and the perspectives, models, and theories of supply chain collaboration contained in the literature. A general analysis was carried out to identify deficiencies in the existing research on supply chain collaboration. The results show that a study of supply chain collaboration study that is conducted from a perspective and which extends the operation stage traditionally studied to the design and measurement stages will be significant and innovative contribution to the literature. A theoretical framework for the relationships between the design, operation, and measurement stages that are integral to supply chain collaboration is also constructed in this chapter. The breakdown of the theoretical framework forms the theory that underlies the SCC model and leads to the methodology for developing the SCC model, which is discussed in the following chapters.

3. DESIGN STAGE OF THE SCC MODEL

This chapter describes the design stage of the SCC model. The design stage determines the optimal network of collaborative partnership links within the supply chain by deciding how the supply chain entities are to be selected and partnered. To achieve this, a Cross Functional Partnership Selection (CFPS) sub-model is proposed, which employs a hierarchical iterative decision and evaluation process to partner and select the appropriate entities in the supply chain. The better the CFPS selects and partners entities, the better and more cohesive the relationships that can be embedded in the supply chain, which can also positively influence the collaborative performance of the supply chain. Following this, the CFPS modelling is quantified using network graph theory and, finally, the six basic types of collaborative partnership linkages between supply chain entities in CFPS are modelled for further analysis and optimization.

This chapter is organized as follows. Section 3.1 describes the role of the design stage of the SCC model. Section 3.2 introduces the CFPS sub-model for the collaborative partnership selection, and describes the significance and the theoretical processes of the approach. Section 3.3 presents a quantitative modelling approach for partnership selection, and the six basic types of collaborative partnership linkages in CFPS are proposed. Finally, Section 3.4 summarises the findings presented in this chapter.

3.1 THE ROLE OF THE DESIGN STAGE OF THE SCC MODEL

In the SCC model, the design stage focuses on the development of the design of the supply chain, i.e. on how the supply chain entities are selected and partnered. The design of the collaborative network partnerships directly influences how the supply chain entities collaborate and perform in subsequent supply chain activities, and the better the supply chain is designed, the better and more cohesive the relationships between the supply chain entities become.

Regardless of the size of the supply chain, supply chain management involves three basic types of entities, i.e. suppliers, manufacturers, customers. Customers are primarily regarded as the customer demand point (CDP) while the supply source/suppliers (SSS) support the fulfilment of the demand in the CDP, and manufacturers/distribution centres (MDC) transform the raw materials to the final-products the customers require. Relationships are established between the three basic types of entity to create material, informational and financial flows in supply chain. All of these entities and relationships play an important role as the building blocks of a supply chain, and act as integral parts of the businesses in the supply chain. Therefore, the design of the supply chain network determines how entities are structurally selected and partnered to construct the collaborative platform for the subsequent supply chain activities. The conceptual structure of the collaborative partnerships in the design stage of the SCC model is illustrated in Figure 3.1.

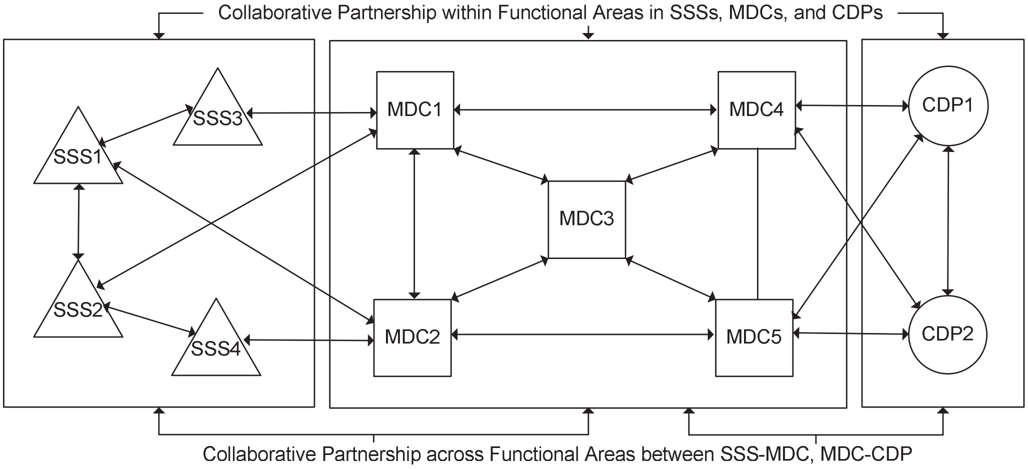


Figure 3.1 Conceptual structure of the collaborative partnerships in the design stage of the SCC model

The design stage of the SCC model proposes a hierarchical method of partnering and selecting appropriate entities in the supply chain. The design stage benefits each entity by reducing uncertainty and improving communication, increasing loyalty and establishing a common vision, and helping to enhance the overall collaborative performance of the supply chain.

3.2 COLLABORATIVE PARTNERSHIP SELECTION

Most of the studies in supply chain collaborative partnership selection focus mainly on supplier selection, i.e. the partnership between SSS-MDC. These approaches primarily employ portfolio analysis models based on the importance of purchasing and the complexity of supply market (Kraljic, 1983; Olsen & Ellram, 1997; De Boer et al., 2001).

The supplier selection and evaluation process has multiple objectives in identifying the attributes the decision-makers need to choose their suppliers.

The attributes commonly found in the research literature include quality, delivery performance and cost (Dickson, 1966; Weber et al., 1991). Some studies propose a series of stages for selecting suppliers, in which the degree of the match with a candidate supplier is first evaluated, the market potential and main competitors are then analyzed, and, finally, the worst case scenarios after the formation of the relationship are simulated (Lorange et al., 1992; Macbeth & Ferguson, 1994; Maloni & Benton, 1997).

The supplier selection and evaluation process can be divided into three categories, mathematical programming, analytic hierarchical processes, and fuzzy set analysis. Mathematical programming employs a goal-programming approach to the problem of supplier selection that is able to attain multiple results for different levels of attribute performance (Hajidimitriou & Georgiou, 2002; Ip et al., 2003; Humphreys et al., 2007). The analytic hierarchical processes rank candidate suppliers based on multiple indexes of business efficiency, such as profit and cost of partnering (Schenkerman, 1994; Saaty, 1996; Babic & Plazibat, 1998; Mikhailov, 2002; Sarkis et al., 2007). Fuzzy set analysis highlights the importance of formulating the criteria for making supplier selection decisions (Lin & Chen, 2004; Bevilacqua et al., 2006; Sarkar & Mohapatra, 2006). In addition, a number of studies also employ the heuristic approaches to resolve supplier selection problems.

3.2.1 Cross Functional Partnership Selection (CFPS)

Most of the existing research focuses only on the partnership selection between suppliers and manufacturers, i.e. the partnering between the functional areas in SSS-MDC. A limited number of studies adopt an approach to supply chain collaborative partnership selection which operates both within and across the planning functional areas between suppliers and manufacturers, i.e. the partnering between the planning functional areas in SSS-MDC and within the planning functional areas in SSS-SSS and MDC-MDC. Therefore, this study proposes a Cross Functional Partnership Selection (CFPS) sub-model to collaboratively select partners and the appropriate entities within and across planning functional areas in the design stage of the SCC model.

The CFPS selects and partners supply chain entities within and across the functional areas to develop an effective and efficient collaborative supply chain network. The hierarchical approach of partnering and selecting appropriate entities in the supply chain employed in the CPFS, is an iterative decision and evaluation process that considers the intention of the supply chain partnership, and the suitability of potential entities. The CPFS benefits the involved entities by reducing uncertainty, improving communication, increasing loyalty and establishing a common vision and helping to enhance the overall collaborative performance of the supply chain. The better entities are selected and partnered, the more cohesive the relationship between supply chain entities, which can also positively influence the performance of the supply chain. The hierarchical structure of the collaborative partnership selection in the CFPS is illustrated in Figure 3.2.

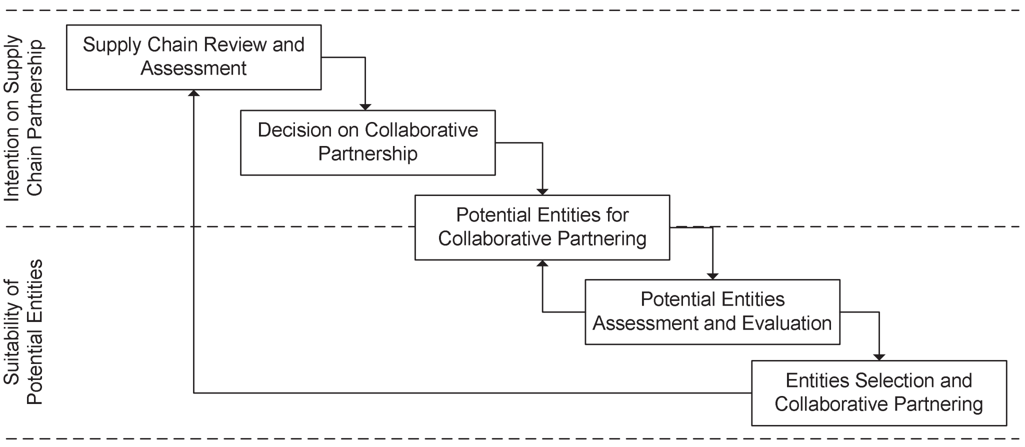


Figure 3.2 Hierarchical structure of collaborative partnership selection in the CFPS

3.2.2 Theoretical Processes of Partnership Intention in CFPS

Supply chain review and assessment are the major initiators of supply chain partnership selection in the CFPS. These are typically carried out by the key entities in the supply chain to drive the entire design stage process. The key entities review and assess the practices and collaborative performance of the supply chain according to their business objectives, and the review results may lead to the reengineering of the supply chain. During the review and assessment process, supply chain audit teams attached to the key entities provide a reengineering team with a comprehensive report on the supply chain activities, and gather essential types of information that are used throughout the entire review and assessment process. The areas covered during the review and assessment of the supply chain include business strategies, supply chain activities, the activities of key entities, strategic supply chain issues and basic business information. Therefore, the review and assessment results should include the key supply chain objectives, a profile of current supply chain activities and entities, and their position, benchmarks or targets for supply chain performance measurement, and the identification of gaps in the supply chain.

The results of the supply chain review and assessment can identify potential problems and complexities in the entire supply chain. When the decision to reengineer is related to the design of the supply chain network, or how the supply chain entities are selected and partnered, then the role of the entities to be selected and partnered needs to be decided, i.e. whether to form a collaborative partnership and what type of collaborative partnership do the entities require. For instance, if the decision involves a collaborative partnership with entities across the planning functional area of the supply chain, then the decision should focus on what type of collaborative partnership needs to be established between the supply chain and the entities. On the other hand, if the decision involves a collaborative partnership within the planning functional area of a supply chain stage, then the decision should focus on whether a collaborative partnership between the supply chain and the entities is required.

The collaborative partnership decision approach employed in the CFPS is related to the concept of “drivers” and “facilitators” proposed by Lambert, Emmelhainz, and Gardner (1996). Drivers are strategic factors that have the capacity to create a competitive advantage and to help determine the appropriate type of business relationship. Facilitators are factors that can help ensure successful supply chain collaboration. Accordingly, the drivers of CFPS in the design stage of the SCC model are the collaborative entities that influence cost efficiency, customer service, marketing advantage, and profit stability. The facilitators of CFPS are the collaborative entities that influence supply chain compatibility, management style in the supply chain, mutual commitment to collaboration formation, and fairness of supply chain involvement. Furthermore, a number of additional factors contributing to successful collaboration in supply chain may also need to be considered in CFPS, such as exclusivity, shared competitors, and shared high value customer, etc.

3.2.3 Theoretical Processes of Entity Suitability in CFPS

In CFPS, appropriate entities are selected from lists of potential entities. Potential entities are candidates that are capable of being collaboratively partnered as supply chain entities in the supply chain. This means that the key entities are required to look for potential entities according to the decisions regarding collaborative partnership requirements. The potential entities can perform various supply chain activities in the planning functional area of the decision process. For a supply chain to have core competency in any given area, it must have the necessary expertise, strategic fit, and ability to invest. Therefore, the potential entities in the list need to align with the overall requirements of the supply chain.

The assessment and evaluation of the candidates is usually based on established criteria and conducted from the lists of potential entities for collaborative partnering. The criteria for analyzing the potential entities can be qualitative or quantitative, depending on whether they are appropriate for collaborative partnering. The qualitative criteria evaluate the reputation of the potential entities, the peer review report, and the degree to which the potential entities align with the overall objectives of the supply chain. The quantitative criteria evaluate the fundamental costs and revenues associated with collaborative partnership, the partnering capabilities of the potential entities, the contribution the potential entities make to the supply chain, and the geographical parameters. Accordingly, the CFPS is a balanced approach for selecting potential entities for the supply chain.

A number of modelling tools can be used to assist the assessment and evaluation of potential entities. Modelling tools can provide considerable insight on the qualitative and quantitative criteria relating to function, as well as the cost and service effectiveness of the collaborative partnering of the various entities. Essentially, the modelling tools can simulate and optimize the collaborative partnership relations between the supply chain and the potential entities, which can assist the assessment and evaluation of the potential entities. Section 3.3 presents a detailed description of the quantitative modelling of collaborative partnership selection performed in the design stage of the SCC model.

After assessing and evaluating the potential entities, the appropriate entities are selected and partnered as supply chain entities. The selected entities are those which have strategic significance for the entire supply chain. As the selection decision follows the assessment and evaluation of the entities, it is essential that the other supply chain entities have a consistent understanding of why the decision was made and mutual expectations of what to expect from the partnership. A preliminary agreement can be created to document the partnership requirements and expectations.

3.3 QUANTITATIVE MODELING FOR PARTNERSHIP SELECTION

In the design stage of the SCC model, the CFPS links various potential entities together to assess and evaluate the appropriate entities for collaborative partnership in the supply chain. Therefore, the quantitative modelling to select partners conducted in the design stage is based on the modelling and evaluation of the collaborative partnership linkages, i.e. establish appropriate links between entities in the supply chain network.

There are many different types of collaborative partnership linkage between entities in supply chain. The linkages may be discrete events but their interactions are continuous and correlated with performance of the entire supply chain network. A collaborative partnership linkage represents the degrees of effectiveness, efficiency, and appropriateness of an entity/potential entity in a supply chain network. Despite the fact there are various types of collaborative partnership linkage, the ultimate aim is to achieve the objectives of the supply chain as a whole. Although different flows or routings of collaborative partnership linkages may directly affect the overall collaborative performance of the supply chain, there is no “standard best” linkage that a supply chain can follow, and supply chains rarely involve distinctive networks of entities. To effectively model and analyze the supply chain network, a structural approach is used to represent the partnership linkages.

In the structural quantitative modelling approach to collaborative partnership selection, the collaborative partnership linkages between entities are modelled as the network graph $G = (V, E)$, which comprises a set of vertices, $V = \{v_i \mid 1 \leq i \leq n\}$, with an n number of nodes, and a set of edges, $E = \{e_j \mid 1 \leq j \leq m\}$, with an m number of edges, such that nodes $v_i \in V$ indicates the supply chain entities in different functional areas, and edges $e_j \in E$ indicates the collaborative partnership linkages between entities. The conceptual relationships between supply chain entities and a network graph of the collaborative partnership linkages are illustrated in Figure 3.3.

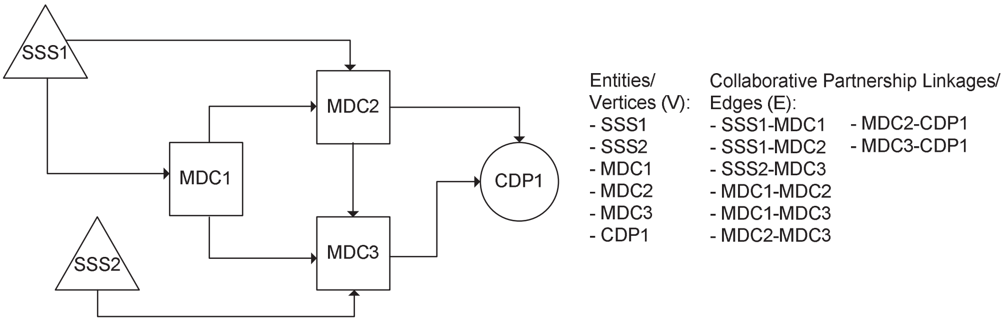


Figure 3.3 Conceptual relationships between supply chain entities and a network graph of the collaborative partnership linkages

In modelling collaborative partnership linkages, it is assumed that the network and edges have only two states, normal and failure mode, that all of the nodes are perfectly reliable, with only the edges subject to failure, and the probability of any edge being in a certain mode is known. Moreover, in the network graph

$G = (V, E)$, an associated positive real number denoted by $W = \{w_{ij} \mid w_{ij} = (v_i, v_j), \text{ and } w_{ij} > 0 \text{ and } v_i, v_j \in V\}$ represents the weighting for the collaborative partnership linkages between entities upon e_{ij}, and the in-degree and out-degree processes of the activity are represented as $\lambda_I(v_i)$ and $\lambda_O(v_i)$, respectively. Using this notation for the proposed structural quantitative modelling approach to collaborative partnership selection, the six basic types of collaborative partnership linkage between supply chain entities can then be modelled, i.e., start off linkage, serial linkage, merge linkage, split linkage, merge and split linkage, and final linkage. An example of the six basic types of collaborative partnership linkage is illustrated in Figure 3.4.

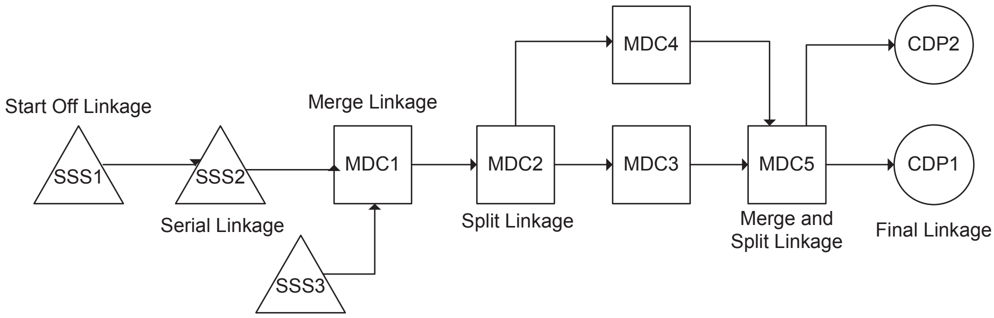


Figure 3.4 Six basic types of collaborative partnership linkage in the supply chain

The start off linkage initiates the first collaborative partnership linkage between entities in a supply chain, which leads to the development of the subsequent collaborative partnership linkages. The start off collaborative partnership linkage in the structural quantitative modelling approach to collaborative partnership selection is represented as:

$$\{v_i | \lambda_I(v_i) = 0 \ and \ \lambda_O(v_i) \geq 1\} \qquad \text{for } i = 1, 2, \ldots, n \tag{3.1}$$

Serial linkage is a straightforward serial collaborative partnership linkage between entities in a supply chain. It directly links with the single previous and single succeeding entities, and the serial collaborative partnership linkage in the structural quantitative modelling approach to collaborative partnership selection is represented as:

$$\{v_i | \lambda_I(v_i) = 1 \ and \ \lambda_O(v_i) = 1\} \qquad \text{for } i = 1, 2, \ldots, n \tag{3.2}$$

Merge linkage is a collection of collaborative partnership linkages between entities in a supply chain, in which linkages from several previous entities are merged and combined, and then processed in a single succeeding collaborative partnership linkage with an entity. The merge collaborative partnership linkage in the structural quantitative modelling approach to collaborative partnership selection is represented as:

$$\{v_i | \lambda_I(v_i) > 1 \ and \ \lambda_O(v_i) = 1\} \qquad \text{for } i = 1, 2, \ldots, n \tag{3.3}$$

Split linkage is a splitting collaborative partnership linkage between entities in a supply chain, in which a single previous linkage of an entity is split into several succeeding collaborative partnership linkages with several entities. The split collaborative partnership linkage in the structural quantitative modelling approach to collaborative partnership selection is represented as:

$$\{v_i | \lambda_I(v_i) = 1 \ and \ \lambda_O(v_i) > 1\} \qquad \text{for } i = 1, 2, \ldots, n \qquad (3.4)$$

Merge and split linkage is a combination of merge and split collaborative partnership linkages between entities in a supply chain, in which the previous collaborative partnership linkages of several entities are merged, then processed and split into the succeeding collaborative partnership linkages of several entities. The merge and split collaborative partnership linkage in the structural quantitative modelling approach to collaborative partnership selection is represented as:

$$\{v_i | \lambda_I(v_i) > 1 \ and \ \lambda_O(v_i) > 1\} \qquad \text{for } i = 1, 2, \ldots, n \qquad (3.5)$$

Final linkage ends the collaborative partnership linkage between entities in a supply chain. When the supply chain reaches the final linkage, all the supply chain processes are complete and the objectives of the enterprise have been achieved. The final collaborative partnership linkage in the structural quantitative modelling approach to collaborative partnership selection is represented as:

$$\{v_i | \lambda_I(v_i) \geq 1 \ and \ \lambda_O(v_i) = 0\} \qquad \text{for } i = 1, 2, \ldots, n \qquad (3.6)$$

Among the above six basic types of collaborative partnership linkage between entities in a supply chain, the key collaborative partnership linkage can be identified as having dense collaborative partnership linkages and connectivity, and can be represented as:

$$\{v_i | \lambda_I(v_i) \geq 2 \ and \ \lambda_O(v_i) \geq 2\} \qquad \text{for i = 1, 2, …, n} \qquad (3.7)$$

The network graph *G = (V, E)* is proposed for the structural quantitative modelling approach to collaborative partnership selection, where *V* is a set of vertices with a number of nodes as entities, and *E* is a set of edges with a number of edges as collaborative partnership linkages among the entities. The data set *V* can then simply be the status of an individual entity in the supply chain network, while the data set *E*, for the entities' relationships, can be collected and coded in the form of an experiment or investigation, and other data, such as the type and number of transactions between entities and the degree of resource sharing, can also be collected. Based on the collected and coded data, a supply chain collaborative partnership network diagram can then be constructed to represent the collaborative partnership linkages between entities/potential entities in the supply chain, such as the profit/cost of partnership, the level of integration, strength of collaboration, occurrence of subgroups, and centrality of the supply chain. Furthermore, the supply chain collaborative partnership network diagram can be made more effective by applying problem solving tools, such as Genetic Algorithms (GA), to optimize and analyze the collaborative performance of the supply chain partnerships. Examples of simple collaborative supply chain partnership network diagrams are illustrated in Figure 3.5.

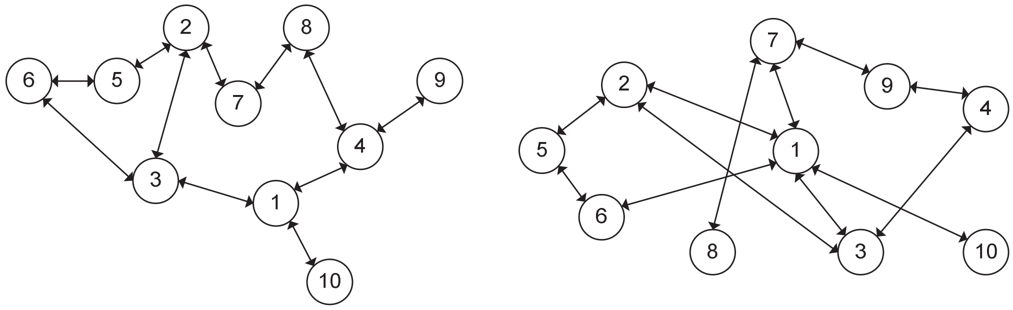


Figure 3.5 Collaborative supply chain partnership network diagrams

3.4 SUMMARY

This chapter proposed a CFPS sub-model for collaborative partnership selection in the design stage of the SCC model. The collaborative modelling of CFPS developed an effective and efficient supply chain network, in terms of how the supply chain entities are selected and partnered within and across the functional areas of the supply chain. The CPFS is a hierarchical approach for collaboratively partnering and selecting appropriate entities in the supply chain, which uses iterative decision and evaluation processes that consider the intention of supply chain partnerships, and the suitability of potential entities. For the intention of a supply chain partnership, the CFPS considers the results of business reviews and assessment of joint decisions on the needs for collaborative partnership. Similarly, to determine suitability, potential entities are assessed and evaluated to select the appropriate entities for developing a collaborative supply chain network made up of entities with the appropriate expertise, strategic fit, and ability to invest. The CPFS benefits the entities involved by reducing uncertainty, improving communication, increasing loyalty and establishing a common vision, and helping to enhance the collaborative performance of the overall supply chain. The better the entities are selected and partnered, the more cohesive the relationship embedded in the supply chain, which can also positively influence the performance of the supply chain.

Furthermore, this chapter quantified the CFPS using a network graph $G = (V, E)$, and modelled the six basic types of collaborative partnership linkages between supply chain entities in CFPS. The quantitative model for the design stage of the SCC model is illustrated in Chapter 6.

The design stage is one of the components of the SCC model. After establishing and embedding effective and efficient collaborative partnership links in the supply chain in the design stage, the operational activities of the supply chain in terms of production, transportation, and inventory can then be collaboratively planned in the operation stage of the SCC model. A detail description of the operation stage of the SCC model is presented in the next chapter.

4. OPERATION STAGE OF THE SCC MODEL

This chapter describes the operation stage of the SCC model. The operation stage enables the supply chain to develop effective collaboration between common operational activities. A Cross Entity Operational Planning (CEOP) sub-model is proposed to coordinate activities in the operation stage of the SCC model. CEOP is a mixture of vertical and horizontal planning approaches that collaboratively consider the operational planning of the entire supply chain and account for the relationships between distinct supply chain processes in the planning domains of particular entities. The CEOP model decomposes the overall operational planning process into hierarchically interrelated sub-tasks, i.e. a coherent operational plan is jointly decided and created for the activities of entities in specific planning domains in the supply chain. Operational planning is therefore based on a careful analysis of the overall decisions involved in planning operational activities. In this chapter, CEOP is quantified using mathematical programming modelling. In the operation stage of the SCC model, the objective of the quantitative model is to minimize the costs of the operational activities. The model can be used to further analyse and optimize the operation stage of the SCC model.

This chapter is organized as follows. Section 4.1 describes the role of the operation stage of the SCC model. Section 4.2 introduces the CEOP model which is based on heterarchical collaboration in operational planning for the supply chain. The significance of the operational planning tasks and activities used in the approach are also described in this section. Section 4.3 presents a quantitative modelling approach for collaborative operational planning across the planning domain entities in the supply chain. Finally, Section 4.4 summarizes the findings presented in this chapter.

4.1 THE ROLE OF THE OPERATION STAGE OF THE SCC MODEL

The operation stage of the SCC model focuses on common supply chain operational activities, e.g. production, transportation, and inventory. The operation stage is expected to establish effective collaborative relationships between entities in the supply chain. The structure of the operation stage of the SCC model thus refers to the operational activities, processes, and priorities that can be used to build and sustain collaboration. The degree of collaboration established in this stage influences the ability of the supply chain to fulfil customer orders and demand.

The interrelated operational activities in the supply chain mainly involve the entities related to suppliers, manufacturers, and customers. In the supply chain, the operation stage encompasses all of the activities involved in fulfilling customer demands, the activities associated with the flow and transformation of goods from the raw materials stage, through to the end user, and the associated flows of information and finance that start from the supplier. The role of manufacturers is to produce the final products to fulfil customer demand, and raw materials are required from the suppliers to manufacture the final products according to customers' specifications and requirements. The typical relationship between suppliers, manufactures, and customers in the supply chain is illustrated in Figure 4.1. The raw materials sent from the supplier to the manufacturer, and the final products delivered from the manufacturer to the customer, all require transportation. Moreover, the respective entities need to have certain stock levels in their inventories to effectively manage the supply chain. Therefore, to effectively and efficiently manage operations, the operation stage of the SCC model is developed based on the operational activities, such as production, transportation, and inventory, the supply chain entities require to collaboratively plan their operations to fulfil customer orders.

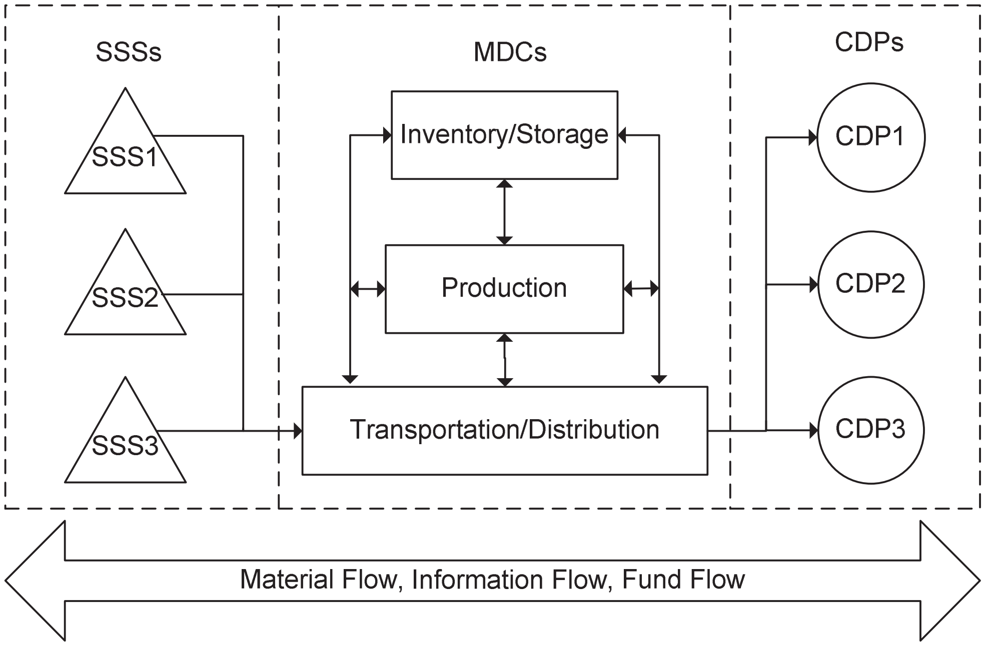


Figure 4.1 Typical relationships between suppliers, manufacturers and customers in the supply chain

4.2 COLLABORATIVE OPERATIONAL PLANNING

The core concept of supply chain management is associated with the flow of materials, information, and finance, and the related planning and control activities in the supply chain. These concepts and practices associated with the supply chain are mainly generated by the fact the final output of a supply chain actually results from the operational activities underlying the flow of manufacturing. Accordingly, manufacturing and its related activities can be regarded as the major, important activities in the supply chain, which also incur a large portion of the total costs and capital needs of the supply chain.

In the operation stage of the SCC model, the collaboration between activities is based on a structured collaborative planning decision making process that aims to determine the best objectives for a decision making situation of supply chain entities. Therefore, the aim of the operation stage is to collaboratively decide and plan the most efficient means of meeting customer demand, such as in determining the optimum ways to schedule and transport the final products to customers. The inter-relationships between operational planning and the associated activities in the operation stage of the SCC model are illustrated in Figure 4.2.

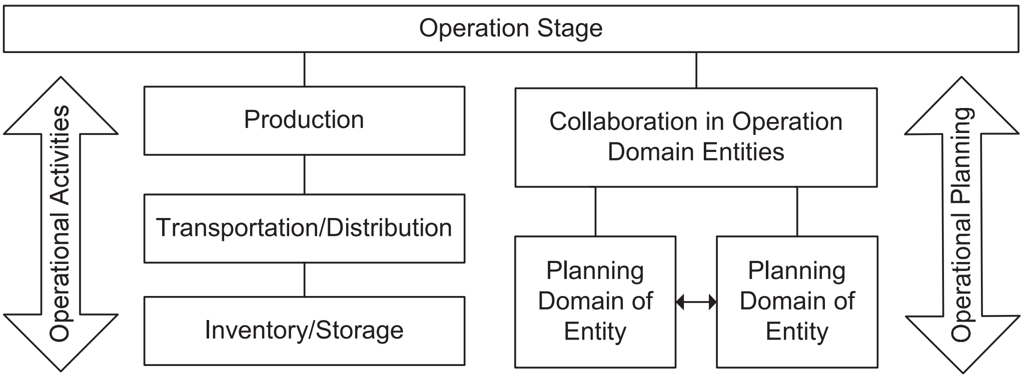


Figure 4.2 Inter-relationships between operational planning and the associated activities in the operation stage of the SCC model

4.2.1 Cross Entity Operational Planning (CEOP)

While most studies of operational planning focus on the planning and control of operation activities, they do not pay attention to either the concept of the supply chain or the collaboration between entities in the supply chain (Stevens, 1989; Hopp & Spearmanm 2001; Vollmann et al, 2005). Various successive and segregated planning approaches are commonly used in the literature, the predominant examples being Manufacturing Resources Planning (MRP II) and Enterprise Resource Planning (ERP). The planning in MRP II and ERP is based on the idea of sub-dividing the overall decision problem derived from the super-ordinate planning levels into several successive planning tasks based on the available data from local entities, which leads to a number of segregated planning processes along the supply chain. The planning approach used in MRP II and ERP is illustrated in Figure 4.3.

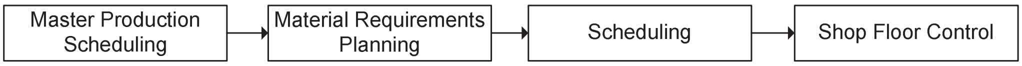


Figure 4.3 Planning approach in MRP II and ERP

As the traditional approach to planning operational activities involves a number of separate, coherent collaboration decisions, it thus lacks the ability to conduct supply chain wide planning across the supply chain. Moreover, the planning for different local entities is generated from isolated views of the item that fail to consider its interdependence with other items. To overcome the narrow scope of the traditional planning approach, this study proposes a Cross Entity

Operational Planning (CEOP) sub-model to collaborate activities in the operation stage of the SCC mode.

As in the traditional successive and segregated planning approach, CEOP decomposes overall operational planning into a variety of sub-tasks. However, the sub-tasks also interrelate in a hierarchical way. The novelty of the proposed approach is that the decomposition plays a key role in creating coherent operational planning for the manufacturer related activities and the other related domain entities in the supply chain. Therefore, the planning is based on a careful analysis of the overall planning decisions for the operational activities. Cross Entity Operational Planning is illustrated in Figure 4.4.

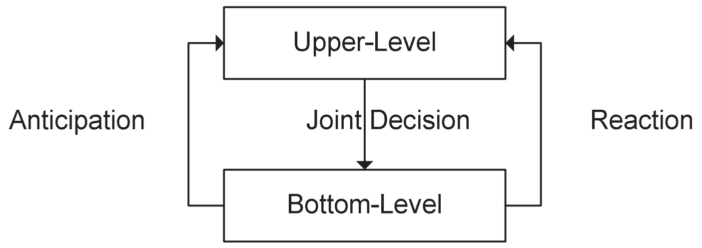


Figure 4.4 Cross Entity Operational Planning

The sub-tasks for operational activities in CEOP are defined and planned under similar time horizons, with interdependencies among the operational domain entities, and the design of the planning levels is oriented towards the structure of the supply chain entities that initiate the operational planning. For instance, the number of planning levels can correspond to the number of managerial levels. Moreover, distinct degrees of aggregation or abstraction are applied to the different planning levels to best support the respective decision making processes, i.e. the highly aggregated data is used in long-term and upper level planning, whereas detailed information is consulted for day-to-day short-term decisions.

4.2.2 Heterarchical Collaboration in CEOP

The CEOP is a mixture of vertical and horizontal planning approaches that consider the planning for the entire supply chain, and account for the interrelationships between the distinct supply chain processes of the entities.

In CEOP, the decisions made at various levels are collaborative joint decisions between entities that employ anticipation and reaction to prevent the sub-optimality of the total solution that occurs when the planning processes are decomposed into individual operational domain entities. In the multiple level or heterarchical collaboration modelled in CEOP, the upper-level decisions usually simplify the complex details of the operational planning into rough, simplified representations to provide room for the operational domain entities at the bottom level to collaborate and develop the overall operational plan of the supply chain. The joint operational planning decisions of the bottom-level operational domain entities influence upper-level decision making by anticipating demand. The corresponding reaction is realized through the reporting of the consequences of upper-level decisions once the joint decisions to act have been incorporated into the operational plan. Both the anticipation and reaction in CEOP can result in the upper-level decisions being re-evaluated or improved to achieve the collaborative aims of the joint operational decision making of entities in supply chain.

Each operational domain entity has an individual planning domain within the overall operational planning of the supply chain. For instance, the transportation stage is one of the planning domains of the operational planning of the supply chain. Because the individual planning domain of each entity in the CEOP is directly linked to other planning domains, relevant data can be exchanged between entities. As a result, the entities are able to collaborate and create a common and mutually agreed upon operational plan. The collaborative planning process between the planning domains in the CEOP is illustrated in Figure 4.5.

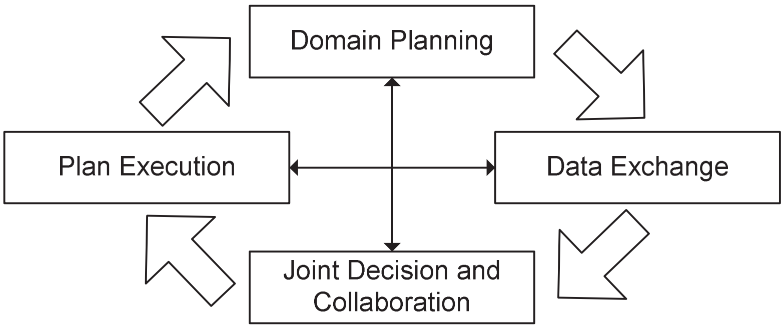


Figure 4.5 Collaborative planning process between planning domains

4.2.3 Operational Activities in the CEOP

The operational activities in the operation stage of the SCC model refer to the major operational activities. Different levels of supply chain management can build collaboration between operational activities according to the scope and depth of collaboration perspectives provided by the dynamic behaviour of the supply chain network.

Most studies of collaborative approaches to operational planning are process-oriented, such as where the manufacturer makes all the decisions relating to the factors necessary for production. Accordingly, the other supply chain entities do not have the capacity to make autonomous decisions and must follow the instructions from the manufacturer. This process-oriented approach is complicated and inflexible, and has difficultly handling the ever-changing business environment faced by modern supply chain management. Therefore, in this study, the operational activities modelled in CEOP are decision-oriented. This means that the operation stage of the SCC model is based on the joint initiative of the entities to make joint decisions on the operational activities of the supply chain. As a result of the decision-oriented approach employed in CEOP, the collaborative entities in the related planning domains are able to share resources in production, transportation, and inventory.

The decision-oriented approach used in CEOP for the operational activities in the operation stage of the SCC model can enhance the capacity for entities in related planning domains to collaborate to effectively and efficiently share resources, as the planning domain entities are required to share their business processes with other supply chain entities. A number of different levels of collaboration can be found in the literature on collaborative approaches to operational planning (Choi & Hong, 2002; Zhao et al., 2008; Bahinipati et al., 2009; Kim, 2009; Nagurney, 2009; Flynn et al., 2010; Jayaram & Tan, 2010; Nagurney, 2010). For example, the collaboration between planning domain entities can be at a strategic business level, in the form of contracts, or at an operational business level, in the form of agreements. In the SCC model developed in this study, the collaboration between entities is extended to the tactical business level of the supply chain and focuses on the specific planning details of autonomous domains. The architecture of the collaboration on operation activities in the SCC model is illustrated in Figure 4.6.

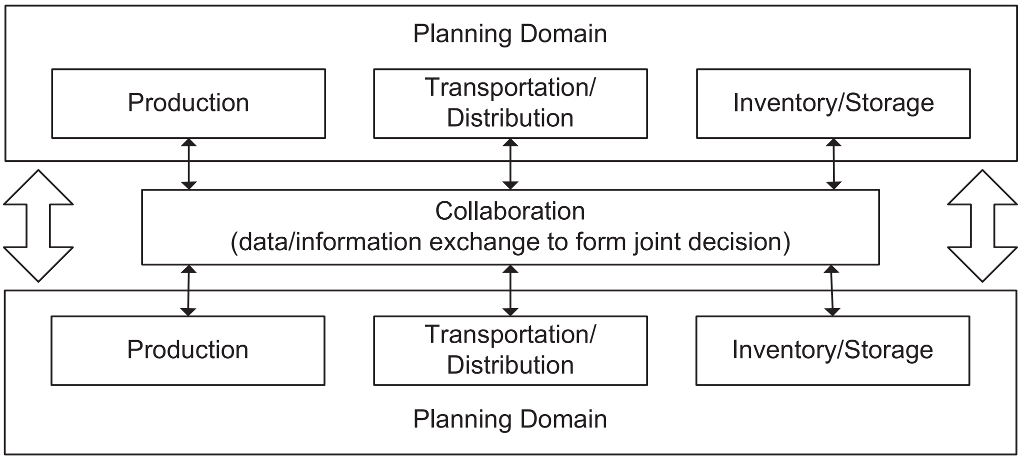


Figure 4.6 Architecture of the collaboration on operational activities in the SCC model

Production, transportation, and inventory are the common operational activities in the architecture of the supply chain depicted above. The data or information related to the operational activities can include production type, production quantities, production steps, production capacities, production planning, the number of works in process, or number of scheduled deliveries. Collaboration represents the capacity for the individual planning domain of an entity to directly connect to other planning domains to exchange relevant data and create a common and mutually agreed upon operational plan. For instance, the supply chain data or information from the manufacturer that needs to be shared is presented by production and other supply chain entities can access the shared data or information through collaboration. Any other factors from supply chain entities that may influence operational activities in the operational plan can be collected by means of collaboration. Feasible solutions (e.g. optimization in production, transportation, or inventory plans and schedules) can then be generated for the supply chain using particular modelling tools, such as genetic algorithms or mathematical programming.

Accordingly, the collaboration between autonomous operational activities is based on joint decisions between operational domain entities. Moreover, as the operation stage of the SCC model is at the tactical business level, the entities can collaborate through computer network communication channels.

4.3 QUANTITATIVE MODELING FOR COLLABORATIVE OPERATIONAL PLANNING

In the operation stage of the SCC model, the decision-oriented approach to operational planning in CEOP links various related operational domain entities in different planning domains, which enables them to collaborate and form joint decisions on the operational activities of the supply chain.

The basic operational domain entities are suppliers, manufacturers, and customers. In fulfilling customer demand, the supply chain encompasses all operational activities associated with the flow and transformation of goods from the raw materials stage through to the end user, and the associated flow of information and finance that starts from the supplier. The customer is primarily regarded as the customer demand point (CDP), supply source/supplier (SSS) supports the fulfilment of demand from the CDP, and manufacturers/distribution centre (MDC) are the entities that transform the raw materials into the final products the customer requires. Therefore, joint decisions are formed in the planning domains between SSS, MDC, and CDP. An example of the relationship between SSS, MDC, and CDP is illustrated in Figure 4.7.

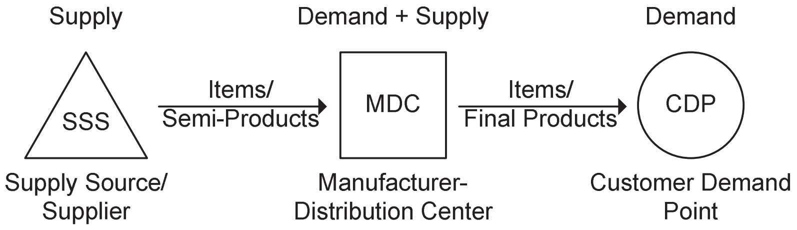


Figure 4.7 Relationship between SSS, MDC and CDP in CEOP

The operational activities begin with a customer order in CDP. The order triggers corresponding actions in MDC, such as determining the cost and number of material items required, the travelling cost and time between SSS and MDC, and the corresponding time windows. The MDC then receives the items/semi-products from the SSSs, who are upstream in the supply chain. After completing the order according to the customer’s specifications, the MDC sends the final products directly to the CDP according to the transportation route determined downstream in the supply chain.

The MDC has the role of demanding the items/semi-products from the SSSs that are required to process/assemble the final-products to fulfil the demand in CDP. All these activities involve joint decisions among the SSS, MDC and

CDP planning domains. Therefore, the modelling of the operational planning in the operation stage of the SCC model is complicated, as the modelling relationships between the SSSs and MDCs as well as the MDCs and CDPs are all “many-to-many”. The modelling relationships between the SSS, MDC, and CDP operational domain entities are illustrated in Figure 4.8.

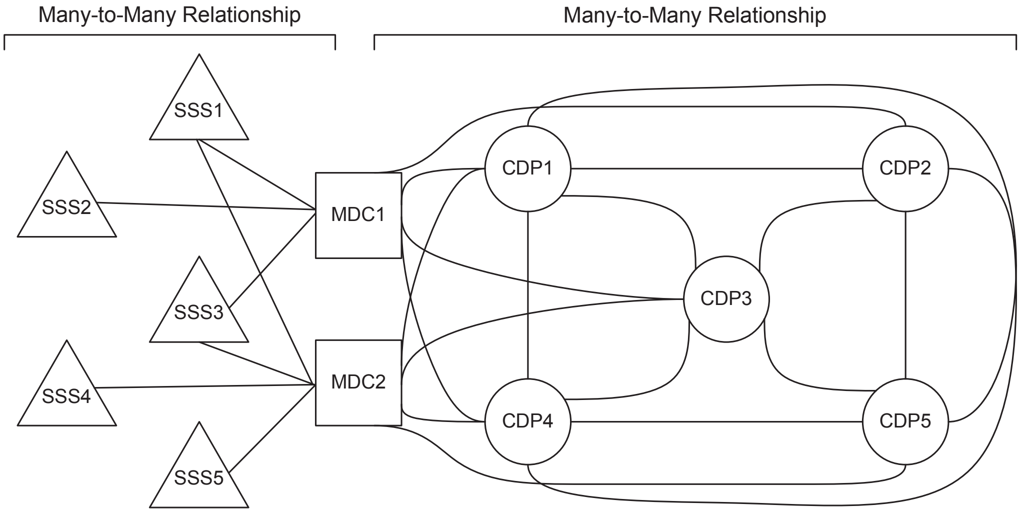


Figure 4.8 Modelling relationships between operational domain entities

The operation stage of the SCC model establishes links between the planning domain entities because each local planning situation is interactively dependent on the planning results of the other domains. A planning domain can have direct links with other planning domains in the supply chain, i.e. between SSS-SSS, SSS-MDC, MDC-MDC, and MDC-CDP. The relationships between the planning domains are illustrated in Figure 4.9.

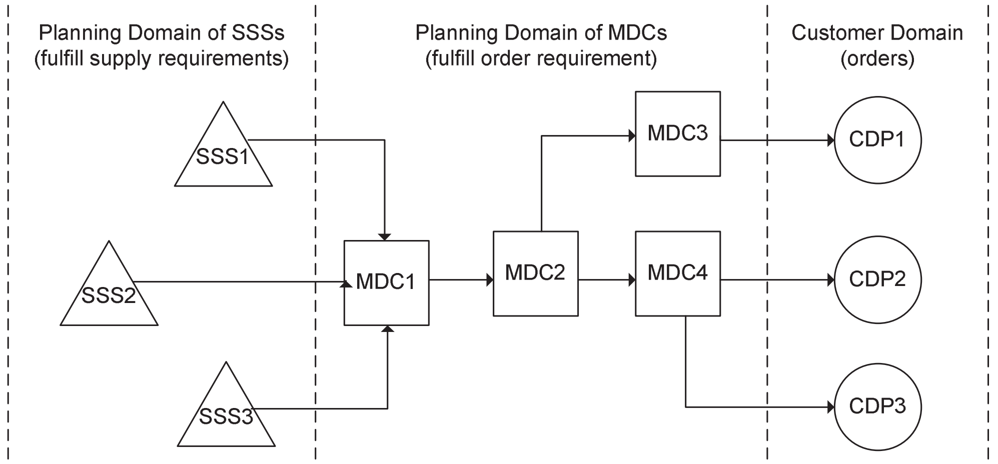


Figure 4.9 Relationships between the planning domains

Each operational activity depicted in Figure 4.9 is determined by the planning domain of the corresponding entities. The output from one planning domain may be destined for the next planning domain and its related entities can collaborate to make joint decisions until the final output reaches the customer. The customers in the CDPs are in the downstream section of the operation stage of the SCC model, referred to as the customer domain. The links with the customer domain are established by the customer order requirements sent to the MDCs. The planning domain of the MDCs is then related to the customer orders received from the CDPs in the customer domain. Furthermore, the MDCs need supplies from the SSSs in the supply domain, the planning domain of the SSSs is thus also linked with the planning domain of the MDCs. Because the links between planning domains can be at the same level or across levels, they can collaborate heterarchically as discussed in Section 4.2.2.

After modelling the relationship between the operational planning domains and their related entities using network graph theory, as discussed in Section 3.3, the following model parameters and decision variables are introduced.

Model Parameters

s	A supply source/supplier (SSS), $s \in S$
d	A manufacturer-distribution centre (MDC), $d \in D$
c	A customer demand point (CDP), $c \in C$
i	An item (semi-product/product), $i \in I$
S	Set of SSSs, $s \| s = 1, 2, \ldots, p$
D	Set of MDCs, $d \| d = 1, 2, \ldots, q$
C	Set of CDPs, $c \| c = 1, 2, \ldots, r$
I	Set of items (semi-product/product), $i \| i = 1, 2, \ldots, s$
OC_{si}	The operation cost of item i in SSS s
OC_{di}	The operation cost of item i in MDC d
OC_{ci}	The operation cost of item i in CDP c
SV_{di}	The supply of item i from MDC d to CDP c
DV_{di}	The demand of item i from CDP c to MDC d
x_{si}	The supply-demand volume of item i in SSS s
x_{di}	The supply-demand volume of item i in MDC d
x_{ci}	The demand volume of item i in CDP c
y_{sdc}	The travelling route from SSS s to CDP c via MDC c

The quantitative model for the operation stage of the SCC model is formulated below using the above notations for the parameters and variables.

$$\min \quad \{\sum_{s \in S}\sum_{i \in I} OC_{si}x_{si} + \sum_{d \in D}\sum_{i \in I} OC_{di}x_{di} + \sum_{c \in C}\sum_{i \in I} OC_{ci}x_{ci} \tag{4.1}$$

$$\text{subject to:} \quad 0 \leq \sum_{s \in S}\sum_{d \in D}\sum_{c \in C} y_{sdc} \leq 1 \qquad , for\ \forall s \in S, \forall d \in D, \forall c \in C \tag{4.2}$$

$$y_{sdc} \in \{0,1\} \qquad , for\ \forall s \in S, \forall d \in D, \forall c \in C \tag{4.3}$$

$$SV_{di} = DV_{di} \geq 0 \qquad , for\ \forall d \in D \tag{4.4}$$

$$x_{si}, x_{di}, x_{ci} \geq 0 \qquad , for\ \forall s \in S, \forall d \in D, \forall c \in C, \forall i \in I \tag{4.5}$$

The objective of the quantitative operation stage of the SCC model (4.1) is to minimize the total cost incurred from operational activities, such as the production and transportation of inventory between the operational entities in SSS, MDC, and CDP, i.e. to minimize operational costs of the SSSs, MDCs, and CDPs with respect to the supply-demand volume in each domain entity.

Constraint (4.2) ensures that a supply chain partnership linkage is constructed in the supply chain, as the items have to be transported from a supply source, SSS to CDP via MDC. According to network graph theory, mentioned in Section 3.3, here the domain entities are regarded as vertices while the partnership linkages are regarded as edges. Constraint (4.3) defines the binary decision variable on whether to travel in a possible partnership linkage constructed from a particular set of linkages, i.e. “0” for null/negative decision and “1” for positive decision. Constraint (4.4) ensures that the supply of items from the MDCs is equal to the demand from CDPs, which means all the customer demands from the CDPs are fulfilled. Constraint (4.5) defines the non-negative integer variables.

The quantitative model for the operation stage of the SCC model formulated above is a basic framework that can be further developed to apply to specific operational cases and problems. For instance, the operational costs discussed in the model can be extended to include production costs, transportation costs, inventory costs or any other cost related to the operational activities of the domain entities in the supply chain.

4.4 SUMMARY

This chapter has proposed a CEOP sub-model to develop effective collaboration between entities in forming joint decisions on the operational planning of supply chain activities. With CEOP, operational activities become decision-oriented as they are based on joint decisions that result from joint initiatives between entities. The decision-oriented approach in the CEOP is also promoted by the fact the collaborative entities in particular planning domains are able to share resources in production, transportation, and inventory. Moreover, in the operation stage of the SCC model, collaboration in operational activities is extended to the tactical business level of the supply chain, which focuses on the specific planning details of autonomous entities. In addition, the decision-oriented approach for the operational activities in CEOP can enhance the collaboration between entities in particular planning domains by enabling them to share resources and business processes with other supply chain entities.

In this chapter, the CEOP model was quantified using a mathematical programming approach. The objective of the quantitative model is to minimize the total cost incurred from operational activities. The quantitative model for the operation stage of the SCC model is illustrated in Chapter 6.

The design stage of the SCC model focuses on the development of the supply chain network through the selection and partnering of supply chain entities. The operation stage of the proposed model focuses on establishing effective collaboration between operational activities in the various planning domain of the supply chain through collaborative operational planning. The measurement stage, which follows the design and operation stages of the SCC model, measures and evaluates the overall collaborative performance of the supply chain to provide feedback for the design and operation stages to further improve overall supply chain collaboration. A detailed description of the measurement stage of the SCC model is presented in the next chapter.

5. MEASUREMENT STAGE OF THE SCC MODEL

This chapter describes the measurement stage of the SCC model. The measurement stage measures and evaluates the overall collaborative performance of the supply chain to provide feedback for the design and operation stages of the supply chain to further improve the overall supply chain collaboration. A Cross Domain Performance Measurement (CDPM) sub-model is proposed for the measurement stage of the SCC model, which uses an overall performance value to represent the collaborative performance of the entire supply chain. The CDPM sub-model for the measurement stage of the SCC model is capable of determining performance discrepancies over a period of time. This can assist management to determine the stability of the collaborations in the supply chain, and thereby gain insights into the responsiveness of the entire supply chain for continual improvement and monitoring.

This chapter is organized as follows. Section 5.1 describes the role of the measurement stage of the SCC model. Section 5.2 introduces the CDPM sub-model for measuring and evaluating the collaborative performance of the supply chain and describes the significances, performance indexes, collaborative links, and performance value employed in the approach. Finally, Section 5.3 summarizes the findings presented in this chapter.

5.1 THE ROLE OF THE MEASUREMENT STAGE OF THE SCC MODEL

The measurement stage of the SCC model focuses on the measurement and evaluation of the collaborative performance of the overall supply chain to provide feedback for the design and operation stages of the supply chain to further improve overall supply chain collaboration.

Performance measurement can influence the competitiveness and successfulness of a supply chain. The measurement and evaluation carried out in the SCC model can be regarded as a gauge for setting objectives for upper-level and bottom-level entities to understand how their supply chains are performing, to evaluate their collaborative performance, to enable them to make informed decisions, and to take appropriate actions, or determine future courses of action, to improve their collaborative performance to sustain competitive advantage.

Collaborative performance measurement involves a performance measure, a performance indicator, and performance measurement data. The performance measure, also known as performance metrics, refers to the nature of the measurement; the performance indicator describes the unit of measurement; and performance measurement data refers to the results of the performance measure and performance indicator (Browne et al., 1997; Hatry, 1999).

The collaborative performance measurement employed in the measurement stage of the SCC model includes individual measures and grouped performance measures, which means the measurement covers the individual planning domains and the cross planning domains of entities in the supply chain.

Therefore, to effectively measure collaborative performance, a perspective is developed to measure the performance of the entire supply chain. By effectively measuring and reviewing the supply chain, the measurement stage of the SCC model can help maintain and improve the performance stability of the supply chain, leading to continual improvement in supply chain collaboration. The relationship between domain entities in the measurement stage of the SCC model is illustrated in Figure 5.1.

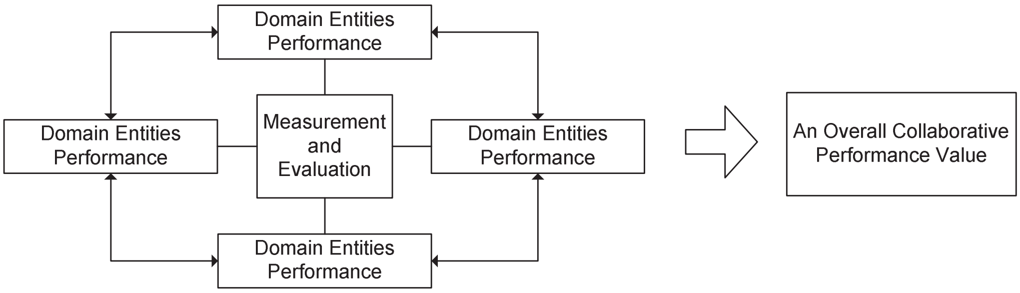


Figure 5.1 Relationship between domain entities in the measurement stage of the SCC model

5.2 COLLABORATIVE PERFORMANCE MEASUREMENT

Continual improvement in supply chain collaboration and the development of cohesive relationships within the supply chain are strategic and crucial prerequisites to modern supply chain management.

The objectives of the measurement stage of the SCC model are to assess the overall collaborative performance of the supply chain and to study its stability and responsiveness. By taking advantage of the measurement stage of the proposed model, organizations can effectively measure and evaluate the performance of their supply chains, and thereby improve their collaborative performance and derive better supply chain management solutions.

5.2.1 Cross Domain Performance Measurement (CDPM)

As Beamon (1999) points out, performance measurement is one of the most important aspects of efficient supply chain management. It is even regarded as one of the cornerstones of business excellence (Neely et al., 1995; Lim & Lee, 2005). Collaborative performance measurement represents a monitoring stage, and a performance assessment tool in a supply chain network (Kittelson & Associates, 2003). In addition to evaluating the effectiveness of a supply chain, collaborative performance measurement is an important instrument for diagnosing potential problems, monitoring performance, enhancing motivation, improving communications, and enriching the supply chain (Beamon, 1999; Brewer & Speh, 2000; Holmberg, 2000; Lau et al., 2001; Morash, 2001; Bullinger et al., 2002; Tan et al., 2002; Otto & Kotzab, 2003; Gunasekaran et al., 2004). Collaborative performance measurement can also be used to quantify the efficiency and the effectiveness of actions. In fact, encouraging collaborative performance measurement over a period of time can determine performance trends, by enabling past or existing collaborative performances to be evaluated with respect to the business objectives or performance objectives of an individual entity or all the entities in a supply chain network.

Collaborative performance measurement can also be used as a benchmark for driving excellence.

Numerous academics and industry practitioners have made efforts to measure supply chain collaborative performance. However, limited research has been published on inter-organizational or cross domain collaborative performance measurement. Moreover, a comprehensive supply chain collaborative performance measurement is perhaps more an ideal than a reality. Little empirical research has been conducted on supply chain collaborative performance measurement that covers multi-stages the supply chain, as most studies focus on individual, rather than systems measures. As a result, most research is based on the collaborative performance measurement of individual planning domains, rather than performance measurements of entities across planning domains in the supply chain.

To broaden the scope of the research on collaborative performance measurement, a Cross Domain Performance Measurement (CDPM) sub-model is proposed for the measurement stage of the SCC model to measure and evaluate the collaborative performance of the supply chain.

To measure the performance of the entire supply chain, the CDPM sub-model integrates the key performance indexes of each entity in the supply chain into hierarchical levels and then aggregates the indicators to calculate an overall performance value. As a result, the collaborative performance of a supply chain can be numerically represented by a performance value and any performance discrepancies over a period of time can be determined by comparing this result with the ideal performance. The collaborative performance of the supply chain is represented and indicated by various key performance indexes, which are defined according to the business and performance objective of each entity in the supply chain. The defined key performance index can then be further evaluated by the specific evaluation criteria set by the decision maker or upper-level management. The structure of the CDPM model is illustrated in Figure 5.2.

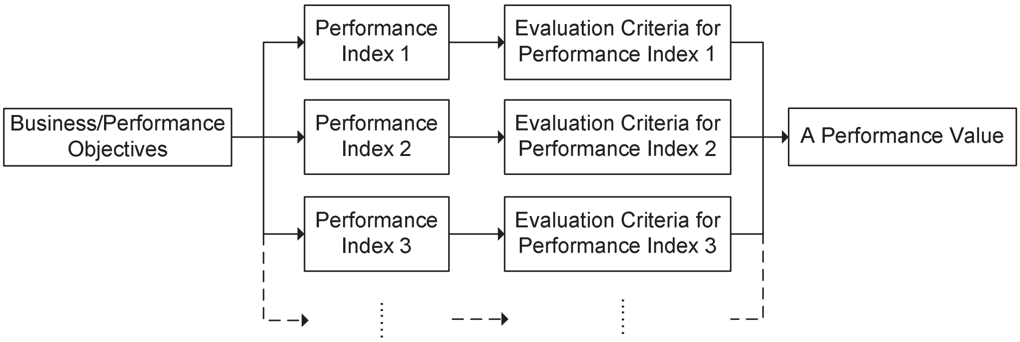


Figure 5.2 Structure of the CDPM model for collaborative performance measurement

As collaborative performance measurement in the CDPM is established across planning domains and the customer domain in the supply chain, it can thus help entities understand the supply chain's strengths, weaknesses, current performance, and the gap between strategic intent and current status. This also enables the entities to make joint decisions and to gain insights about the appropriate actions to take to improve the efficiency and effectiveness of their overall collaborative performance and to sustain competitive advantage through interoperability. The CDPM is also able to compare individual performance indexes within a supply chain and determine the best collaborative linkages.

5.2.2 Performance Indexes and Collaborative Linkages in CDPM

The SCC model enhances collaboration in the supply chain and establishes various collaborative partnership links between the SSS, MDC, and CDP entities in the supply chain, which means the links can be within and across the entities' planning domains, for instance between SSS-SSS, SSS-MDC, MDC-MDC, and MDC-CDP. As these collaborations are directional, various collaborative paths can then be traced within a supply chain from SSS to CDP. Therefore, in representing the overall collaborative performance of a supply chain, the performance value generated by the CDPM measures the performance of the entire supply chain by hierarchically integrating the key performance indexes of all entities with respect to the collaborative partnership linkages in the supply chain.

The measurement and evaluation of the overall collaborative performance of a supply chain in the CDPM is based on the integration of the performance indexes and the collaborative partnership linkages. The main characteristic of this approach is that it can evaluate the overall collaborative performance of a supply chain and compare the performances of the collaborative linkages. Figure 5.3 shows a representation of the CDPM in the measurement stage of the SCC model.

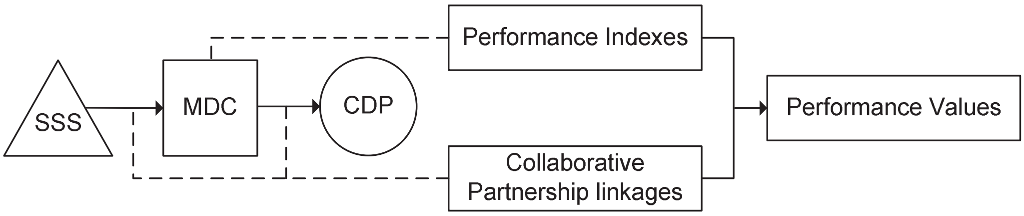


Figure 5.3 Representation of the CDPM in the measurement stage of the SCC model

According to the structure of the CDPM as depicted above, the overall collaborative performance of a supply chain is determined by the relationship between the performance of the collaborative flow in the supply chain and its performance indexes. In the measurement stage of the SCC model, the performance indexes and the collaborative partnership linkages are correlated to the measurement and evaluation of performance.

Performance indexes are the indicators used to measure and evaluate the performance of a supply chain. The performance indexes can be quantified and documented, and can interact with and contribute to each other in achieving the overall performance objectives of the supply chain. The performance indexes are measured and evaluated in a hierarchical manner. The most common performance indexes are cost, quality, delivery, and flexibility. The performance indexes are assumed to be equally weighted in determining the performance value. The relationships between the overall performance objectives and examples of performance indexes of a supply chain are presented in Figure 5.4.

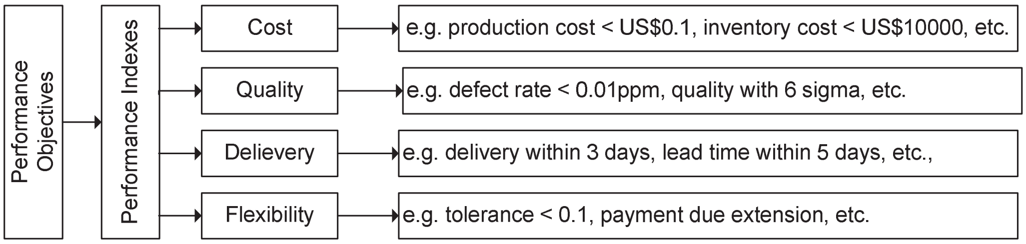


Figure 5.4 Relationships between the performance objectives and performance indexes of a supply chain

The performance indexes highlight the preferences and changes that result from business factors, such as technological advances, profit margins, cooperation strength, and environmental restrictions. They can be positive or negative, and can directly lead to future changes in the collaborative performance of the supply chain. Moreover, the collaborative partnership linkages are industry-specific, which usually depends on the design stage of the SCC model. The collaborative partnership linkages represent the major supply chain routes between entities. An example of collaborative partnership linkages between entities is illustrated in Figure 5.5.

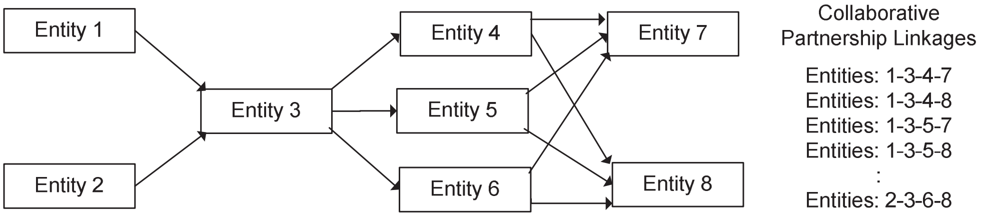


Figure 5.5 Collaborative partnership linkages between entities in the supply chain

5.2.3 Performance Value in CDPM

The CDPM measures and evaluates the collaborative performance of a supply chain using a multi-attribute analytical and hierarchical method. This method accounts for and relates to the various interdependent performance indexes that result in a single performance value. In this process, the overall performance objective of a supply chain is decomposed into different corresponding performance indexes with equal weighing. Accordingly, CDPM attempts to evaluate the overall collaborative performance, as well as each major performance index of the supply chain, and a performance value is then used to describe the collaborative performance of the entire supply chain.

Individual performance data are collected in the hierarchical structure of the CDPM. This process is cumulative, which considers all the outputs of the preceding performance data under different performance indexes and collaborative linkages. Figure 5.6 shows an example of the aggregation of the performance data towards the performance indexes in the CDPM.

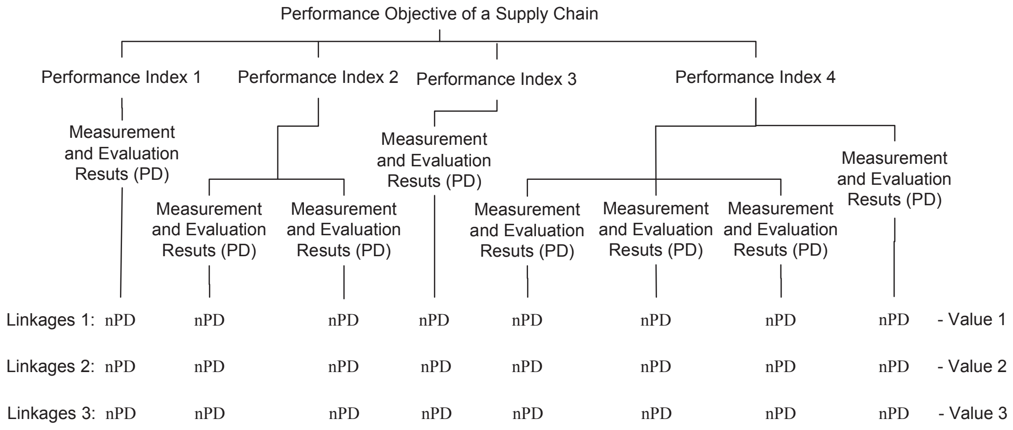


Figure 5.6 Aggregation of the performance data in CDPM

The individual performance data are made up of the data that represent the results of the performance indexes. To evaluate the overall performance of a supply chain, as well as its collaborative partnership linkages, the performance data need to be normalized. Under normalization, the performance data and the performance of different collaborative partnership linkages can be compared on the same basis. The data can also be integrated to measure and evaluate the overall collaborative performance of the supply chain in terms of a single performance value. The normalization of the performance data is processed by determining the proportion of the value of the individual performance data (PD) in relation to the overall value of the performance data, such that the normalized performance data (nPD) is determined as follows.

$$\begin{array}{l} Value\ of\ Normailized \\ Performance\ Data\ (nPD) \end{array} \qquad (5.1)$$

$$= \frac{Value\ of\ Individual\ Performance\ Data\ (PD)}{Total\ Value\ of\ Performance\ Data\ (\sum PD)}$$

Once the performance data has been normalized, the performance indexes can then be determined by accumulating the normalized performance data. A collaborative performance measurement table can be determined using the various performance indexes that result across a period of time. An example of a collaborative performance measurement table with nPD is illustrated in Table 5.1.

Table 5.1 Collaborative performance measurement table

Performance indexes	Period 1	Period 2	Period 3	Period 4	. .	n
A - Indicator a	0.32	0.40	0.33	0.35	. .	. .
A - Indicator b	0.91	0.90	0.95	0.99	. .	. .
A - Indicator c	0.62	0.60	0.65	0.67	. .	. .
B - Indicator d	0.12	0.15	0.10	0.16	. .	. .
B - Indicator e	0.23	0.28	0.29	0.21	. .	. .
B - Indicator f	0.17	0.19	0.11	0.14	. .	. .
C - Indicator g	0.64	0.61	0.70	0.69	. .	. .
C - Indicator h	0.45	0.49	0.46	0.43	. .	. .
C - Indicator i	0.96	0.91	0.94	0.92	. .	. .
:	:	:	:	:		
m	:	:	:	:		

Based on the hierarchical performance measurement of entities' performance indexes contained in the performance measurement table, the overall collaborative performance of a supply chain can be represented in terms of a performance value. The performance of the supply chain over a period of time ($n \geq 1$) can be determined by comparing its actual performance with the best or ideal performance value of the supply chain. In determining the performance value for a collaborative supply chain, it needs to be assumed that all the performance indexes in a performance measurement are in the same performance measurement periods. Therefore, the performance value in a supply chain over n periods with m performance indexes of x planning domain entities can be represented as follows:

$$Performance\ Value = \frac{\sum_{n \in N} \sum_{m \in M} \sum_{x \in X} nPD_{nmx}}{max(m, x) \times n} \tag{5.2}$$

The larger the computed performance value, or the closer the computed performance value is to the ideal pre-defined performance value of the collaborative supply chain, the better the collaborative performance of the supply chain. The performance value is a single value that provides a clear index to represent the overall collaborative performance of the entire supply chain. This helps upper-level management and all the planning domain entities to understand how their supply chain performs. By comparing various performance values of the supply chain in different periods, a collaborative performance trend can be determined to study its performance stability.

5.3 SUMMARY

This chapter proposed a CDPM sub-model to measure and evaluate the collaborative performance of the overall supply chain in the measurement stage of the SCC model. In the CDPM, the measurement and evaluation of the overall performance of collaboration in a supply chain is based on the relation between the performance indexes and the collaborative partnership linkages. The performance indexes highlight the preferences and changes that result from business factors, while the collaborative partnership linkages represent the major routes between entities in the supply chain. As the performance indexes and the collaborative partnership linkages are interdependent in CDPM, the overall collaborative performance of the supply chain can then be measured and evaluated using a multi-attribute analytical and hierarchical method. This method accounts for, and relates to various interdependent hierarchical performance indexes, and then aggregates the indicators to calculate an overall performance value. Thus, the performance value obtained from the CDPM can be used to represent the overall collaborative performance of a supply chain. The proposed CDPM sub-model in the measurement stage of the SCC model enables the performance discrepancies to be determined over a period of time. The CDPM sub-model can also provide feedback for the design and operation stage of the supply chain to further improve overall supply chain collaboration.

The design, operation, and measurement stages are the three components of the SCC model proposed in this study. The design stage provides a means of selecting supply chain partnerships, the operation stage provides a collaborative operational planning approach based on the established partnership linkages that result from the design stage, and the measurement stage provides a tool to measure and evaluate the collaborative performance of the overall supply chain that has resulted from the design and operation stages. Moreover, the measurement stage also provides feedback to the design and operation stages for the continual improvement of supply chain collaboration. All three stages are interrelated, such that one stage influences another stage and the collaborative performance of the entire supply chain. Therefore, the SCC model has a significant influence on the positive performance of the supply chain. To illustrate the three stages of the SCC theoretical model, the model is further developed and illustrated in an industrial case study. A detailed illustration of the proposed model in an industrial case study is presented in the next chapter.

6. CASE STUDY OF THE SCC MODEL

This chapter reports a case study of a Hong Kong based company to illustrate the CFPS, CEOP, and CDPM sub-models for the design, operation, and measurement stages of the SCC model. The studied company (hereafter, the company) is a world leader in the manufacturing, testing, and measurement of made-to-order high frequency quartz crystal products. The case study was carried out during a period when the company reengineered its supply chain. In the design stage of the case study, the main objective is to reengineer the company's supply chain network using the CFPS sub-model to determine the best partnering of entities to reduce redundant looping activities and process flows in terms of operational cost and processing time. The operation stage of the case study employs the CEOP sub-model to coordinate the company's transportation activities, which is the primary operational activity the company wants to improve to minimize existing high transportation costs. In the measurement stage of the case study, the performance values are calculated by the CDPM sub-model to determine the degree of intervention effect on the performance of the supply chain. The results of the measurement and evaluation also reflect the collaborative performance of the supply chain before and after the reengineering is completed. After illustrating the CFPS, CEOP, and CDPM sub-models for the design, operation, and measurement stages of the SCC model in the case study, the SCC model is then further validated using statistical methods.

This chapter is organized as follows. Section 6.1 presents the background of the studied company and its supply chain. Sections 6.2, 6.3, and 6.4 illustrate the CFPS, CEOP, and CDPM sub-models of the SCC model in the design, operation, and measurement stages of the studied company, respectively. The modelling approaches and the optimal results and solutions are also presented. Section 6.5 validates the SCC model using the statistical methods of analysis of variance (ANOVA), trend line, and effect size. Finally, Section 6.6 summarizes the findings presented in this chapter.

6.1 BACKGROUND OF THE STUDIED COMPANY AND ITS SUPPLY CHAIN

The SCC model is illustrated in a case study of company participating in the Teaching Company Scheme (TCS). A detailed description of the scheme is presented in Appendix I. The company manufactures high frequency quartz crystal products for the OEM electronic and automotive industry and was established in 1983.

The company studied in this chapter is a world leading manufacturer of made-to-order high frequency quartz crystal products, such as KHz crystals, MHz crystals, crystal resonators, crystal clock oscillators, piezoelectrics, and ceramic resonators. These quartz crystal products are widely used in the automotive, industrial telecommunications, and consumer electronic industries, and sell for between USD0.085 and USD0.750 per unit. The company’s 5 factories are located in Hong Kong, Shenzhen, Fujian, Qingdao, and Zibo. Examples of the various quartz crystal products manufactured by the company are shown in Figure 6.1.

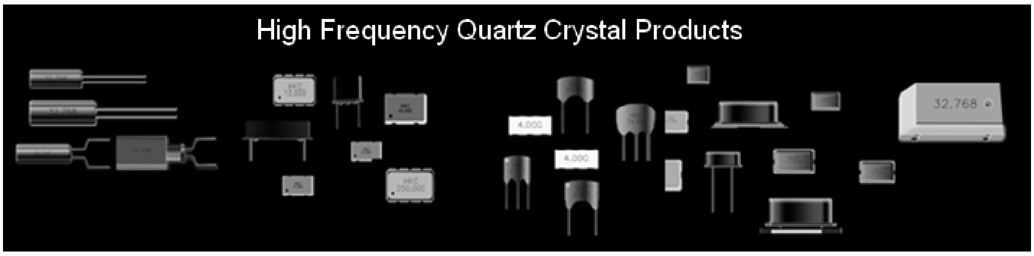


Figure 6.1 Examples of the quartz crystals produced by the studied company

In early 2005 the company began to reengineer its supply chain. The primary task involved the implementation of a new enterprise information system (EIS) to maintain the daily operation of supply chain activities. The EIS is capable of standardizing the majority of most of the activities within the supply chain. At the time, the majority of the company's supply chain activities were manually handled and decision making was highly dependent on staff experience. Prior to implementing the EIS, the company's business practices and the efficiency and effectiveness of the supply chain activities of the factories were completely analyzed and reviewed to identify potential problems and inefficiencies.

An efficient and effective supply chain is essential for the success of the company. This company's supply chain is dedicated to manufacturing products that are used in most of the electronic equipment produced by many of the major industry brands, such as digital cameras, watches, visual and audio equipment, telecommunications, and automobile acceleration and braking systems. Therefore, an efficient and effective supply chain would not only make the company more successful, it would also directly affect the related industries it supplies.

The problems that the company faced were mainly in the design, operation, and measurement stages of its supply chain. Customer satisfaction with regard to the existing supply chain network was low. There were internal complains about redundant looping activities and process flows and external complaints arising from long processing times. Accordingly, the design stage of the SCC model was applied to determine the ways to partner entities to reduce redundant looping activities and the operational costs and processing times of the process flows. The operational activity within the supply chain that was of most concern to the company was transportation. The existing practices resulted in extremely high overall transportation costs and became the major operational problem for the management team. The operation stage of the SCC model was thus applied to improve and enhance collaboration and to minimize the company's high transportation costs. In reengineering the supply chain, the management team redefined their business objectives towards standardizing practices and activities to streamline and improve the efficiency and effectiveness of the supply chain. Hence, the measurement stage of the SCC model was applied to measure and evaluate the overall collaborative performance of the supply chain and to provide feedback for the design and operation stages to further improve supply chain collaboration.

The proposed modelling approaches presented in this thesis mainly evolved from observations of the participating company, such as the review and analysis of internal and external business documents and process flows, the redesign of the operational practices, and the implementation of new systems and databases. The data to illustrate and validate the SCC model were then collected from the database of the participating company in the periods before and after the supply chain reengineering. The timeline for collecting the data to illustrate the CFPS, CEOP and CDPM sub-models for the design, operation, and measurement stages of the SCC model is presented in Figure 6.2.

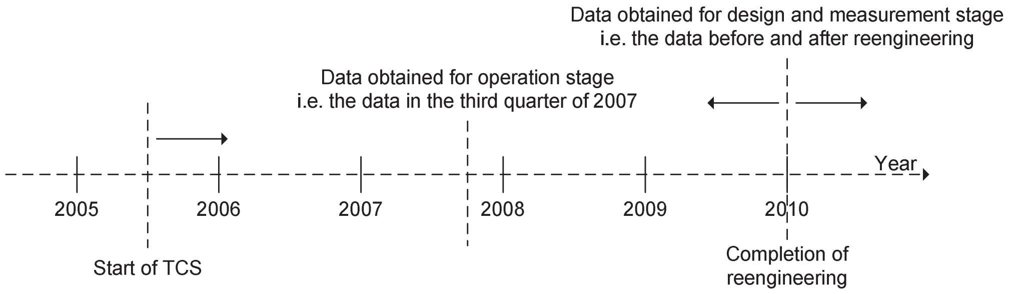


Figure 6.2 Data collection timeline for the case study

6.1.1 The Organizational Structure of the Studied Company

The company has 5 factories, with the headquarters located in the Hong Kong factory. The Hong Kong factory is also regarded as the leader of the other 4 factories, as it operates as a trading company while the other four factories, which are situated in mainland China, operate as manufacturing companies. Although each of the 5 factories is a separate legal entity, they all operate under the control of the studied company in Hong Kong. The structure of the company and its factories is presented in Figure 6.3.

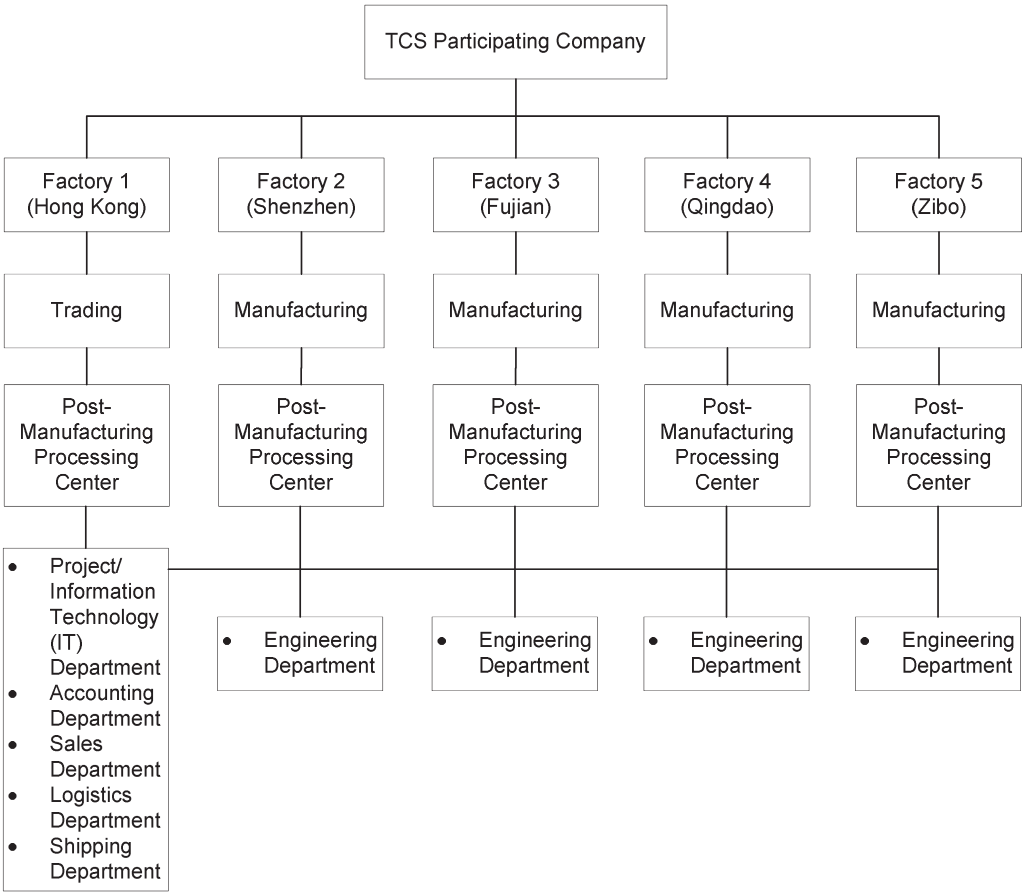


Figure 6.3 Structure of the studied company and its factories

The Hong Kong factory contains 5 major departmental units which oversee the daily business operations of the company: the project/information technology (IT) department, accounting department, sales department, logistics department, and shipping department. The organizational structure of the Hong Kong factory is presented in Figure 6.4.

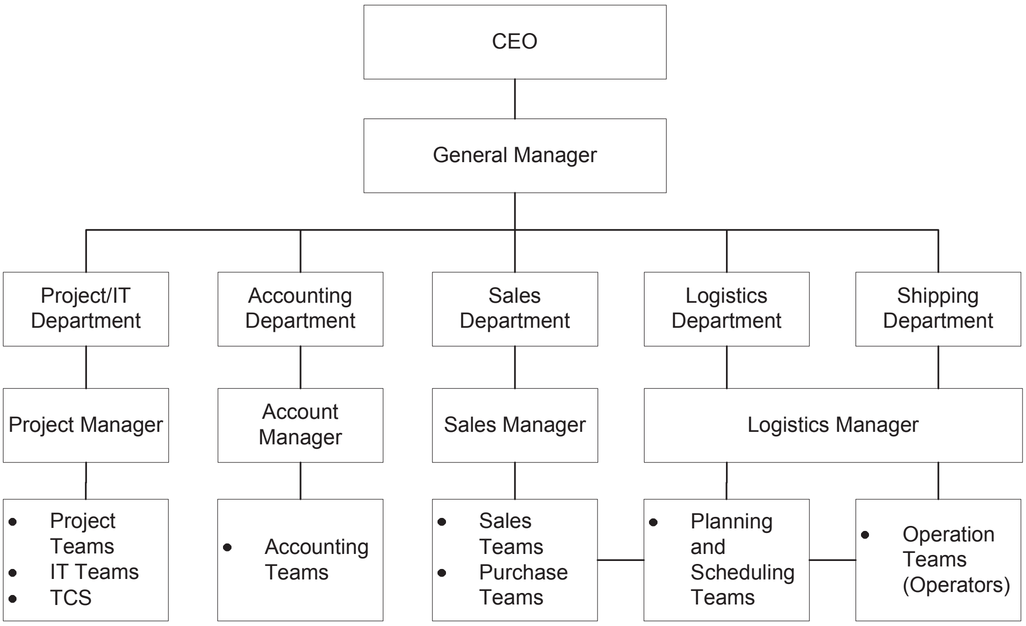


Figure 6.4 Organizational structure of the studied company

The research for this thesis was co-supervised by the project manager of the project/IT department of the company. The project manager and a team in the project/IT department, supported by the IT teams and assisted by the TCS, oversaw the reengineering of the supply chain and the implementation of the EIS. All the relevant information and data used or required for the case study have been obtained through the project manager of the company. The information and data for the design and development of the SCC model, the partnership evaluation and selection in the design stage, and the performance measurement in the measurement stage of the case study, were collected from the sales department of the company. The information and data for the optimization conducted in the operation stage of the case study, were collected from the company's logistics department. Finally, all of the cost related information and data were collected from the accounting department.

6.1.2 The Operation Flows of the Studied Company

The studied company is a made-to-order manufacturing business. The operational flow of the company is structured such that the factory in Hong Kong mainly operates as a trading company with limited manufacturing capability, mainly post-manufacturing processes, and the four factories in China are manufacturing companies. Customers place purchase orders with the Hong Kong factory and the factories in China produce the finished goods. Buy and sell relationships are maintained between the respective trading and manufacturing companies to enable the goods made in China to be sold to the factory in Hong Kong.

Each factory has its own post-manufacturing processing centre responsible for post-manufacturing processes, such as tagging, packaging, secondary quality assurance, and quality control. These processing centres also serve as logistics and consignment centres for the transportation of finished goods (FG) or work-in-process (WIP) items between factories or the transportation of finished goods to customers through the factory in Hong Kong. The operational flows and relationships between the 5 factories are illustrated in Figure 6.5.

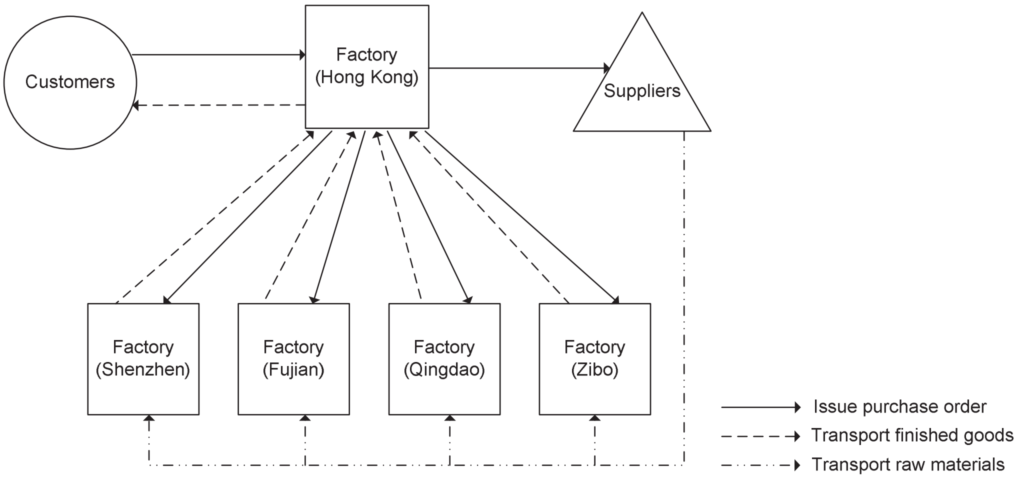


Figure 6.5 Operational flows and relationships between the factories of the studied company

Basic daily business operations are mainly controlled by the project/information technology (IT), accounting, sales, logistics, and shipping departments in Hong Kong. Simply put, the factory in Hong Kong receives a purchase order from a customer, evaluates the order, and then generates a sales order for manufacturing if the customer purchase order is accepted. Accordingly, the sales orders from the factory in Hong Kong become purchase orders for quartz crystal products from the factories in China to fulfil customer purchase orders.

Before releasing purchase orders to the factories in China, the sales and logistics departments in Hong Kong co-evaluate the capability of each factory, such as their existing number of manufacturing orders, and the availability of machines, labour, and raw material, to determine the optimal factory/factories in China to fulfil the orders. Moreover, the manufacture of the quartz crystal products is monitored by the engineering department in each factory according to the specifications and requirements provided by the sales department in Hong

Kong. The raw materials for manufacturing are also determined and purchased from suppliers through the sales department in Hong Kong, which means all the purchasing tasks are centralized in Hong Kong. When the purchase orders are completed by the factories in China, the factory in Hong Kong will receive the finished quartz crystal products, and apply any necessary post-manufacturing processes. The finished and finalized quartz crystal products are then shipped to customers from the Hong Kong factory. The general operation flow of the company is illustrated in Figure 6.6.

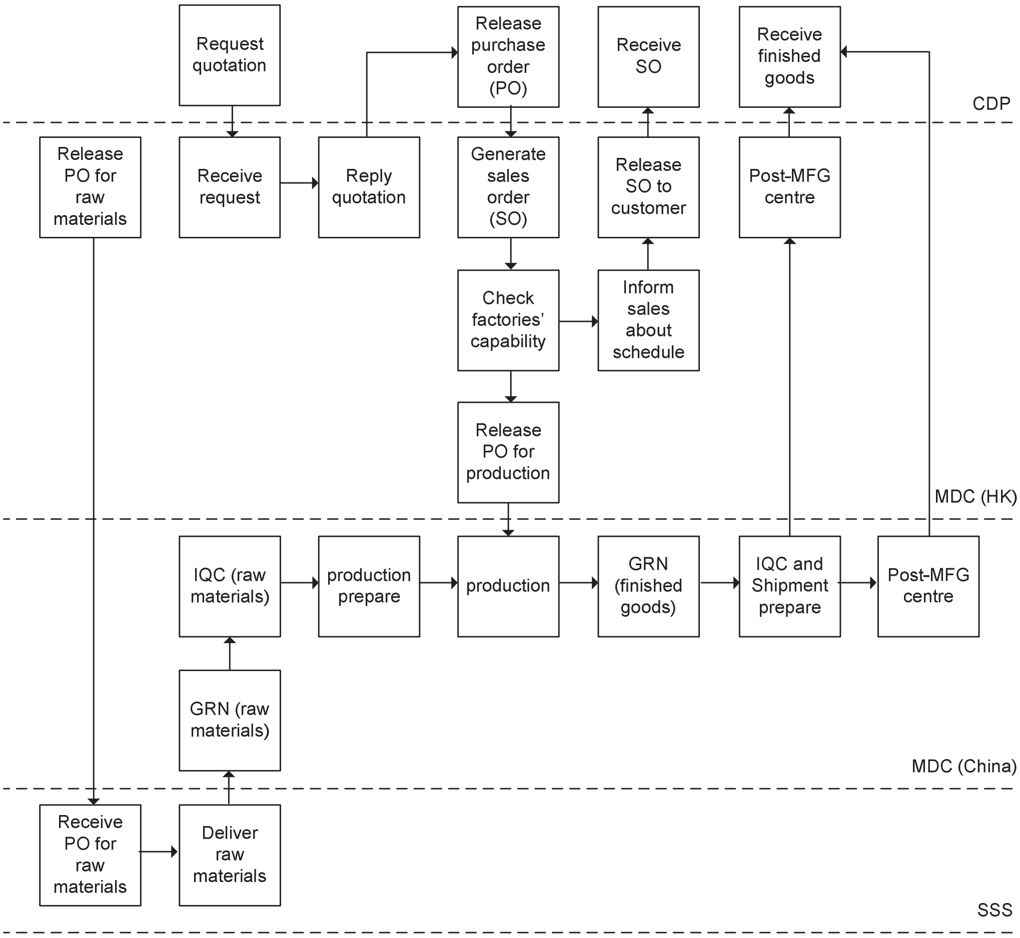


Figure 6.6 General operational flow of the studied company

6.1.3 The Manufacturing Processes for the Quartz Crystal Product

Except for the frequency values and any post-manufacturing requirements specified by the customer, the quartz crystal products are manufactured using a number of common standard processes. A quartz crystal made up of three basic parts, a blank, a base, and a lid. The blank is the most important and critical part, as it possess the pre-defined frequency value necessary to activate the quartz crystal, for which the base and lid can be considered protective casings. To attain a high quality quartz crystal, the blank needs to be perfectly mounted onto the base and completely sealed by the lid, and the frequency values tested after the sealing process must be within the tolerance values specified by the customer.

Dust and dirt are the main contaminants that can cause the quartz crystal products to malfunction. Therefore, quartz crystal must be manufactured in a clean room with a controlled standalone ventilation system capable of filtering over 95% of the dust and dirt. The standard manufacturing processes carried out in the clean room start with the cleaning and plating of the base. The base is first washed with running distilled water, and dried at room temperature to remove dust and dirt. The base is then plated with silver wire to conduct electricity, and conductivity is further enhanced through silver electrode baking. The base plating is sample inspection checked and any defects are either scrapped or reworked.

After the sample inspection checking of the base plating has been completed, the blank is mounted onto the base and cemented with silver epoxy. The bases with cemented blanks then undergo a curing process that stabilizes the component through baking at between 45℃ and 130℃, depending on the type of quartz crystal. The components are sample inspection checked and any defects are either scrapped or reworked.

After the sample inspection checking, the component then undergoes a final plating and high drive cleansing process. This process can further enhance the conductivity and purity of the component. After the component is baked a second time to further enhance stability, the lid is seam sealed to protect the blank inside. Further sample inspection checking is conducted and, at this stage, most defects will be scrapped as only limited types of finished quartz crystal can be reworked.

Several tests and measurements are conducted on the finished components depending on the type of quartz crystal, such as leak tests, aging tests, and thermal shock tests. The tests and measurements are conducted primarily through sample inspection, and the results are filed for customer reference. Post-manufacturing processes may also be applied to the finished quartz crystals in accordance with customer requirements, such as tagging with a company logo or name, and specific packaging. A detail description of the common manufacturing processes used to produce the quartz crystal components is presented in Appendix III.

6.2 DESIGN STAGE OF THE COMPANY

In the design stage of the SCC model, the proposed Cross Functional Partnership Selection (CFPS) sub-model is employed to select and partner entities to determine the optimal network of collaborative partnership linkages in the supply chain. The CFPS sub-model is then quantified using a network graph $G = (V, E)$, which comprises a set of vertices, $V = \{v_i \mid 1 \leq i \leq n\}$, with an n number of nodes and a set of edges, $E = \{e_j \mid 1 \leq j \leq m\}$, with an m number of edges, such that nodes $v_i \in V$ indicate the supply chain entities in different functional areas, and edges $e_j \in E$ indicate the collaborative partnership linkages between the entities.

Customer satisfaction with regard to the company's existing supply chain network was low. There were internal complains about numerous redundant looping activities and process flows leading to high daily operational costs, and external complaints arising from long processing times.

To increase customer satisfaction and the competitiveness of the supply chain network, the upper-level management of the company decided that one of the reengineering tasks would be to analyse and redesign the partnerships in the supply chain. Ten entities and their associated partnership linkages were identified as pilot reengineering functional areas to be modelled through CFPS.

The ten entities identified were 2 salespersons, 5 suppliers, and 3 warehouse operators. These ten were selected because they are representative of the main entities in the supply chain. The 2 salespersons are the top 2 salespersons in the company and accounted for nearly half of the sales of the company. The 5 suppliers are the suppliers most frequently selected by the company, and they have extensive connections with the 2 salespersons. The 3 warehouse operators were identified because their associated factories are the 3 most productive factories in the company. These ten entities are mainly involved in the daily operations of the company's supply chain, and the pilot analysis and redesign of their partnerships is of significant relevance to the reengineering of the supply chain. The roles and descriptions of the ten entities modelled by CFPS are presented in Table 6.1, and the existing supply chain collaborative network among the ten entities is shown in Figure 6.7.

Table 6.1 Roles and descriptions of the ten entities modelled by CFPS

Entities	Roles	Descriptions
1	Sales team	Sales team in Hong Kong factories
2	Sales team	Senior sales team in Hong Kong factories
3	Supplier	Supplier in China for the base/lid
4	Supplier	Supplier in China for the base/lid
5	Supplier	Supplier in China for the blank/base/lid
6	Supplier	Supplier in China for the base/lid
7	Supplier	Supplier in China for the blank/base/lid
8	Warehouse operators	Warehouse operators in Shenzhen factories
9	Warehouse operators	Warehouse operators in Fujian factories
10	Warehouse operators	Warehouse operators in Qingdao factories

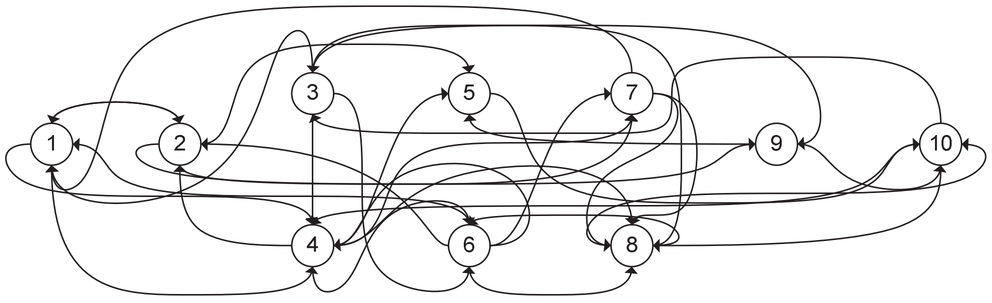


Figure 6.7 The existing supply chain collaborative network among the ten entities

In the supply chain collaborative network depicted in Figure 6.7, the interactions or connections between the entities are represented by directional lines. For instance, entity 1 and entity 2 represent the two sales teams in Hong Kong, which need to interact with each other to exchange sales information, and report sales progress to the senior sales team, etc. Therefore, the existing collaboration between the two sales teams (entity 1 and entity 2) is represented as a bi-directional line. The representation of the existing supply chain collaborative network evolved from the review and analysis of internal and external business documents and process flows in the sales and logistics departments, as well as observation of their daily practices.

6.2.1 SCC Model Treatment – CFPS

To quantify the CFPS, a network graph $G = (V, E)$ is proposed. In elaborating the data sets of V and E, V is a set of vertices, $V = \{v_i \mid 1 \leq i \leq n\}$, and E is a set of edges, $E = \{e_j \mid 1 \leq j \leq m\}$. Therefore, according to the partnership linkages between the ten entities shown in Figure 6.7, the set of vertices $V = \{v_1, v_2, v_3,$

$v_4, v_5, v_6, v_7, v_8, v_9, v_{10}\}$, and the set of edges $E = \{(1, 2), (1, 4), (1, 8), (2, 1), (2, 5), (2, 7), (2, 10), (3, 4), (3, 6), (3, 9), (4, 2), (4, 5), (4, 7), (4, 8), (5, 10), (6, 1), (6, 2), (6, 4), (6, 8), (7, 1), (7, 8), (8, 3), (8, 6), (8, 10), (9, 5), (10, 1), (10, 4), (10, 8)\}$.

The main objective in reengineering the company's supply chain network is to reduce operational costs and processing times of the redundant looping activities and process flows. As the performance of the supply chain collaborative network also depends on how the entities are partnered with each other, an associated positive real number, denoted by $W = \{w_{ij} \mid w_{ij} = (v_i, v_j), \text{ and } w_{ij} > 0 \text{ and } v_i, v_j \in V\}$, represents the cost weighting for the interactions between entities upon e_{ij}. Furthermore, in the modelling of the supply chain collaborative network based on the quantification of CFPS, it is assumed that the cost weighting of entity partnership is bi-directionally the same, i.e. $w_{ij} = w_{ji}$ for all $v_j \in V$, and that the cost weighting is the aggregated sum of the multiple interactions involving the entities.

The cost weighting is determined by the ratio of cost and time spent on an interaction or connection between entities in the supply chain collaborative network within the data collection timeline period of the case study.

The cost weighting is first determined using a basic cost (in dollars) provided by the accounting department which represents the average cost for the entity to operate in the company. For instance, the cost for sales team A is determined by the average expenditure on the salespersons in team A (i.e. the average salary of a team member in a month) and the basic cost is calculated in terms of minutes, i.e. the cost per minute for the entity (in dollars per minute). As the time of interaction and connection between entities equals the time (in minutes) required to complete the interaction and connection, the time is determined by the number of minutes the entities spend interacting or connecting with each other, for instance, the time it takes sales team B to report sales information to sales team A. The time is recorded and provided by the entity during the data collection timeline period. The cost weighing is thus the results of the basic cost (in dollars per minute) multiplied by the processing time (in minutes)

Therefore, for instance, the cost weighting for the entity-partnership between the sales team and the senior sales team (entity 1 and entity 2) is $40, which means the interaction between the two teams requires $40 to be completed in a specific amount of time. The cost weightings for the entity-partnerships between the ten identified entities are shown in Table 6.2.

Table 6.2 Cost weightings (in dollars) for the entity-partnerships between the ten identified entities

i	1	2	3	4	5	6	7	8	9	10
1	00	40	00	30	00	00	00	80	00	00
2	40	00	00	00	50	00	70	00	00	40
3	00	00	00	10	00	60	00	00	60	00
4	00	30	00	00	90	00	90	70	00	00
5	00	00	00	00	00	00	00	00	00	30
6	20	10	00	30	00	00	00	20	00	00
7	50	00	00	00	00	00	00	10	00	00
8	00	00	40	00	00	20	00	00	00	50
9	00	00	00	00	10	00	00	00	00	00
10	10	00	00	50	00	00	00	50	00	00

According to the data set of vertices (V), edges (E), and the cost weightings for the entity-partnerships, a supply chain collaborative network for the case study can then be modelled with the objective of minimizing the set of partnerships in *E* that connects all the entities in *V*. This enables at least one possible partnership to be found in the supply chain that meets the objective of reengineering the supply chain to reduce the operational costs and processing times of the redundant looping activities and process flows.

Therefore, an objective function of minimizing Z can then be used to represent the supply chain collaborative network with the minimal total cost/time ratio of partnerships. Z can thus be formulated as $Z = \min_Z \sum_{e_{ij} \in E} w_{ij}$, where Z is a set of possible partnerships between entities in the supply chain collaborative network, subject to deterministic constraints, such as some entities needing to be processed before others.

The degree of entity partnership in the supply chain collaborative network can be measured by the number of partnerships that occur in a particular entity. The degree of entity partnership is generally two when the entity is partnered with two of its direct neighbourhood entities, but it can also be one when the entity is partnered to only one entity. This implies that the more entities a particular entity is partnered to, the higher the degree of entity partnership of the collaborative network.

To reengineer the supply chain network of the studied company using CFPS, a genetic algorithm (GA) is adopted as a tool for determining the optimal supply chain collaborative network based on the objective function of minimizing *Z*. A detail description of the modelling approach of GA is presented in Appendix IV.

6.2.2 SCC Model Treatment – CFPS Optimal Results

To minimize the objective function *Z*, the parameters for GA modelling are as follows: population size = 50; crossover rate = 0.9; mutation rate = 0.01; generation gap = 0.98; and the termination condition is the best fitness unchanged after 500 generations. In running the GA, the number of generations required before arriving at the minimum best fitness value of 74 is around 205 cycles, which is the optimal minimum total cost/time ratio solution for GA. The corresponding supply chain collaborative network for the ten identified entities is depicted in Figure 6.8.

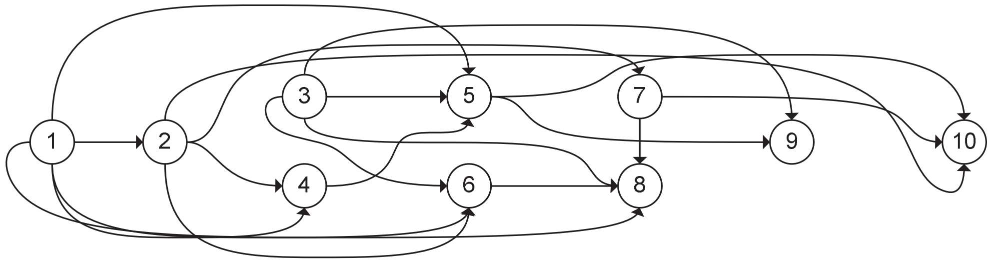


Figure 6.8 Supply chain collaborative network based on the GA optimal results for the ten identified entities

In comparing the supply chain collaborative networks in Figures 6.7 and Figures 6.8, the supply chain collaborative network in Figure 6.8 appears less “netted” and most of the redundant activities and process flows have been eliminated. However, the network is still able to maintain the same basic daily operational functions as the supply chain collaborative network in Figure 6.7. In addition to the visual analysis of the network diagram, performance data before and after adopted the CFPS were obtained from the company's EIS, including the average processing time per order and the average operating cost per order, that enable the effectiveness and efficiency of CFPS to be determined. The processing time and cost represents the average time and cost for the company to process a customer purchase order (including order evaluation time) and then issue a purchase order to the factories in China for the manufactured item. The processing time and cost per order for each entity thus refers to the average time and cost that a particular entity spent on an order. The performance data for each entity before and after CFPS was adopted were directly generated from the company's EIS without further data processing. The performance data for CFPS are summarized in Table 6.3.

Table 6.3 Performance data of the studied company

	Processing time (minute) per order		Processing cost (dollar) per order	
Entities	Before CFPS	After CFPS	Before CFPS	After CFPS
1	16.9	13.8	123.23	106.91
2	31.7	13.9	823.69	292.19
3	191.1	83.9	7,767.58	4,388.21
4	107.9	47.4	1,403.01	1,287.76
5	69.8	30.6	2,836.42	1,946.75
6	118.1	114.8	10,939.36	6,956.29
7	51.6	22.7	2,099.41	1,128.76
8	151.7	66.6	6,167.77	4,665.82
9	5.1	2.2	685.03	431.33
10	7.4	6.0	559.97	167.42
Total	751.3 minutes	401.9 minutes	$33,405.47	$21,371.44

Table 6.3 shows that the average processing time per order after adopting CFPS is around 45% lower than the original value, while the average operating cost

per order is around 35% lower. Therefore, the CFPS sub-model of the SCC model significant increased the efficiency and effectiveness of the supply chain collaborative network in the case study by reducing the operational costs and processing times of the redundant looping activities and process flows in the design stage of the supply chain.

6.3 OPERATION STAGE OF THE COMPANY

The operation stage of the SCC model employs the proposed Cross Entity Operational Planning (CEOP) sub-model to achieve effective and efficient collaboration between the common supply chain operational activities. The CEOP sub-model is then quantified using a mathematical programming modelling approach. The objective of the quantitative model in the operation stage of the SCC model is to minimize the costs incurred from operational activities.

The primary operational activity the company wished to improve its transportation activities within the supply chain. As the company carried out extensive transportation between its factories and of finished goods to customers, transportation activities had a critical impact on the performance of the entire supply chain.

The company’s manufacturing and distribution roles are structured by a typical three-stage supply chain, where items are transported between suppliers, manufacturers/distribution centres, and customers, i.e. the factories of the studied company act as MDCs, its suppliers as SSSs, and its customers as CDPs.

With the company's current supply chain, transportation is predetermined in the logistics department of the Hong Kong factory, and finished goods are transported to customers only from the factory in Hong Kong. The logistics department organizes the transportation of finished quartz crystal products from the supply source of a factory or factories in China to the factory in Hong Kong, and the goods are then transported to the final customers directly and immediately without any decisions being made on travel routing or the grouping of finished goods with other orders. This practice has lead to extremely high overall transportation costs in the company. Because one-to-one transportation between the factory in Hong Kong and each customer is carried out without item grouping or routing, the maximum capacity and resources of the transportation fleet are employed to fulfil just a single order The high transportation cost is the major operational problem arising from current practice, and has drawn the attention and concern of the management team.

After extensive discussion with the management team, it was decided that the transportation rules should be redesigned to enable the finished quartz crystal products to be transported from the factories in China directly to the customers without using the factory in Hong Kong as an intermediary hub. Moreover, to protect confidential customer information and company records, an employee from the logistics department in Hong Kong is required to stay in each of the factories in China to execute the corresponding transportation instructions from Hong Kong to transport the finished goods to the customers directly from the factories in China. This approach has the advantage of clearer custom declarations and facilitates efficient and effective transportation in the supply chain. The proposed new relationships between the 5 factories and the customers are illustrated in Figure 6.9.

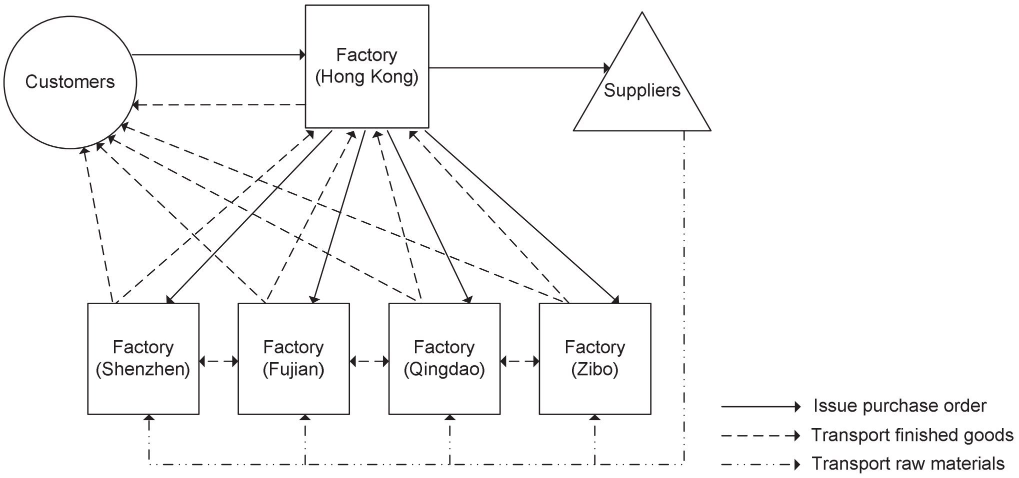


Figure 6.9 Proposed new relationships between the factories and customers

6.3.1 SCC Model Treatment – CEOP

The data sets from two customer orders are used to illustrate the CEOP sub-model of the SCC model in this case study. The information and data are the de facto historical data obtained from the sales and logistics departments and have not been adapted by any special modelling approach. Accordingly, the de facto data set can be compared with the same data set under CEOP for the operational activities in transportation.

Customer orders from two customers (denoted as CDP2 and CDP5) were received by the factory in Hong Kong (denoted as MDC1) in the first quarter of 2009. The volumes demanded by CDP2 and CDP5 were 600 and 900 units of quartz crystal, respectively. After evaluating the orders, MDC1 accepted the orders and issued the purchase orders to factory in Shenzhen (denoted as

MDC2). This triggered a corresponding purchase of raw materials from suppliers according to the bill of materials for the quartz crystal products. In line with the company's existing practices, after MDC2 finished manufacturing the quartz crystals according to customer specifications, the finished quartz crystals were transported to the factory in Hong Kong and then on to the designated CDPs. The transportation network between the factories in Hong Kong and Shenzhen is illustrated in Figure 6.10, and the roles and descriptions of the entities in the transportation network are presented in Table 6.4.

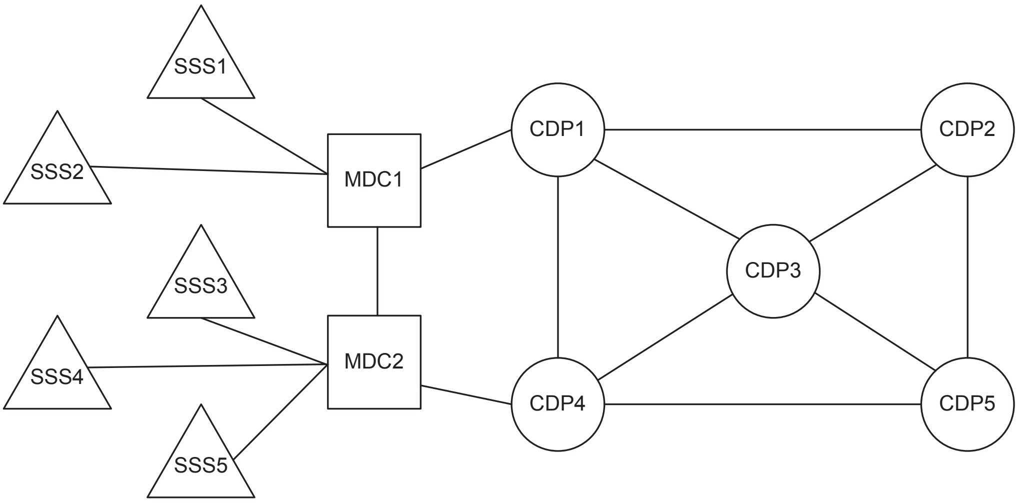


Figure 6.10 Transportation network between the factories in Hong Kong and Shenzhen

Table 6.4 Roles and descriptions of the entities in the transportation network

Entities	Roles	Descriptions
SSS1	Supplier	Supplier in Hong Kong for tagging materials
SSS2	Supplier	Supplier in Hong Kong for packages materials
SSS3	Supplier	Supplier in China for the blank
SSS4	Supplier	Supplier in China for the base
SSS5	Supplier	Supplier in China for the lid
MDC1	Factory	Factory in Hong Kong (trading company)
MDC2	Factory	Factory in Shenzhen (manufacturing company)
CDP1	Customer	Customer demand point
CDP2	Customer	Customer demand point with order size 600 units
CDP3	Customer	Customer demand point
CDP4	Customer	Customer demand point
CDP5	Customer	Customer demand point with order size 900 units

Because the main objective of the company is to reduce transportation costs in the operational activities of the supply chain, the total operational costs incurred are then referred to the transportation costs among the operational activities, i.e. operation cost = transportation cost ($OC = TC$). Therefore, the quantitative model for the operation stage of the SCC model proposed in Chapter 4 (4.1) is then furthered developed and elaborated as in (6.1) below. The data set obtained from the company database on transportation costs (in dollars) is presented in Tables 6.5 and 6.6.

$$\min \ Z = \quad \{\sum_{s \in S} \sum_{i \in I} TC_{si} x_{si} \quad + \sum_{d \in D} \sum_{i \in I} TC_{di} x_{di} \ + \sum_{c \in C} \sum_{i \in I} TC_{ci} x_{ci} \tag{6.1}$$

Table 6.5 Transportation costs between SSSs and MDCs

TC	MDC1	MDC2	SSS1	SSS2	SSS3	SSS4	SSS5
MDC1	0000	0000	2,500	2,500	0000	0000	0000
MDC2	0000	0000	0000	0000	2,000	1,200	1,800

Table 6.6 Transportation costs between MDCs and CDPs

TC	MDC1	MDC2	CDP1	CDP2	CDP3	CDP4	CDP5
MDC1	0000	3,300	3,600	0000	0000	0000	0000
MDC2	3,200	0000	0000	0000	0000	3,200	0000
CDP1	3,700	0000	0000	2,800	3,900	3,200	0000
CDP2	0000	0000	2,900	0000	3,800	0000	3,200
CDP3	0000	0000	3,100	3,900	0000	3,000	3,200
CDP4	0000	2,700	3,800	0000	3,300	0000	3,300
CDP5	0000	0000	0000	3,500	2,900	3,200	0000

The transportation costs (in dollars) between entities in the transportation network were obtained from the logistics department's historical records on transportation with the associated entities. For example, the transportation cost between SSS1-MDC1 of $2500 is the average cost spent on the route between SSS1 and MDC1 in the historical record for the customer orders for the 600 and 900 units of quartz crystal.

To minimize the operational costs of the company using CEOP, a genetic algorithm (GA) is also adopted as a tool for determining the optimal supply chain collaborative transportation routing decision, based on the objective of minimizing transportation costs. A detailed description of the modelling approach of GA is presented in Appendix IV.

6.3.2 SCC Model Treatment – CEOP Optimal Results

For minimizing the objective function Z, the parameters for the GA modelling are as follows: population size = 50; crossover rate = 0.8; mutation rate = 0.01; generation gap = 0.98; and the termination condition is the best fitness unchanged after 500 generations. In running the GA, the number of generations required before arriving at the minimum best fitness value of 21100 is around 75 cycles, which is the optimal minimum transportation cost solution from GA. A summary of the results is presented in Table 6.7, and the corresponding transportation routing results are presented in Figure 6.11.

Table 6.7 Summary of the results for the transportation costs under CEOP

Transportation cost between SSS3/SSS4/SSS5-MDC2	\$5,000
Transportation cost between MDC2-CDP2 and MDC2-CDP5	\$16,100
Overall transportation cost	\$21,100

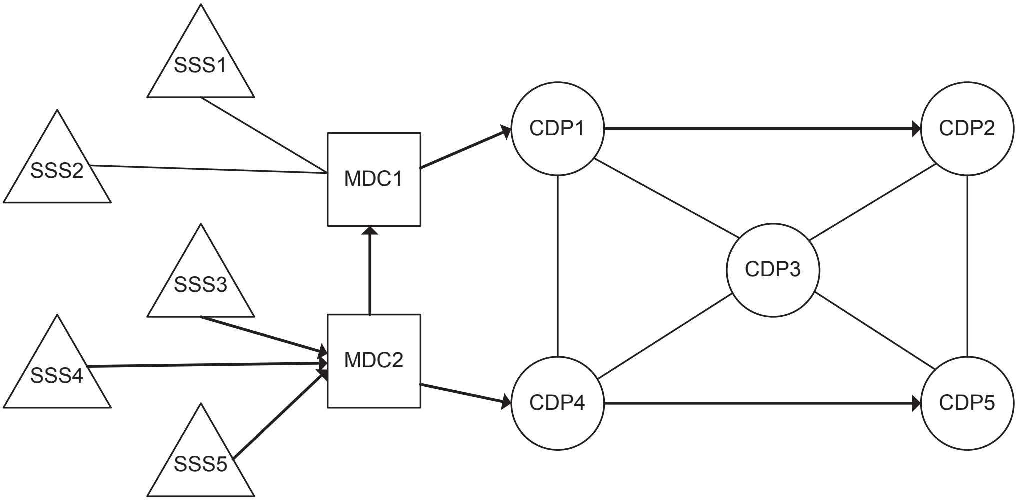


Figure 6.11 Optimal transportation routing results from GA

The transportation cost is the cost of transporting raw materials from SSSs to MDC2, and then transporting the finished quartz crystal products from MDC2 directly to CDP2/CDP5 via other CDPs. As there are three SSSs supplying items/semi-products to MDC2, the transportation routing decisions from SSSs to MDC2 in the CEOP are the same as the original routing decision without applying the CEOP. On the other hand, from the results of the quantified CEOP, it is optimal to have two routes for transporting the finished quartz crystal products from MDC2 to CDP2 and CDP5. Also, in this case the transportation costs for two separate routes for these two customer orders are less than for grouping the orders and transporting along a single route.

The two optimal routings are Route1-SSS3/SSS4/SSS5-MDC2-MDC1-CDP1-CDP2 for the customer order for 600 units of quartz crystal, and Route2-SSS3/SSS4/SSS5-MDC2-CDP4-CDP5 for the customer order for 900 units of quartz crystal. The optimized routing decisions under the CEOP sub-model of the SCC model are illustrated in Figures 6.12 and 6.13.

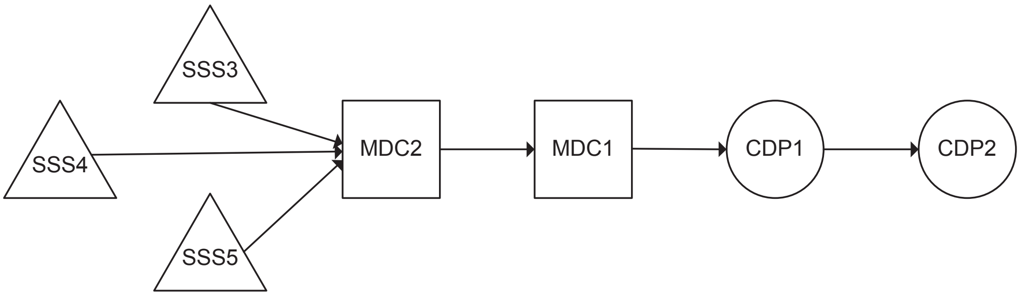


Figure 6.12 Optimal route for fulfilling the customer order for CDP2

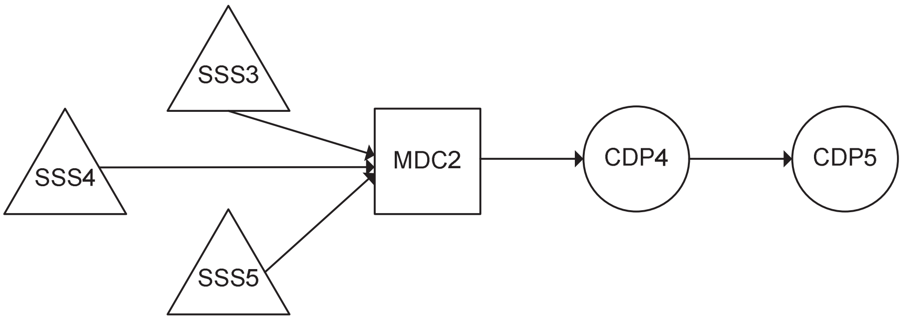


Figure 6.13 Optimal route for fulfilling the customer order for CDP5

Route1-SSS3/SSS4/SSS5-MDC2-MDC1-CDP1-CDP2 starts from the SSSs to MDC2 (i.e. the factory in Shenzhen). After the factory in Shenzhen finished manufacturing the quartz crystals, the finished products were transported to MDC1 (i.e. the factory in Hong Kong) as one of the routing vertices, and then travelled via the factory in Hong Kong before finally reaching the designated vertex of CDP2. This transportation route is the same as the existing practice, where the factory in Hong Kong acts as an intermediary hub. In contrast, Route2- SSS3/SSS4/SSS5-MDC2-CDP4-CDP5 also starts from the SSSs to MDC2. After the factory in Shenzhen finished manufacturing the quartz crystals, the finished products were then directly transported to the designated vertex of CDP5 via CDP4. This routing decision by the proposed CEOP approach is different from the original practice, where all the finished goods must be transported to the factory in Hong Kong before reaching the final destination.

According to the results of the optimization, for the 2 customer orders received from CDP2 and CDP5, one customer order is still transported via the factory in Hong Kong while the other customer order is directly transported from the factory in Shenzhen to the customer. Table 6.8 presents the comparison between the overall transportation costs with and without CEOP (i.e. the existing and the proposed transportation practices) in fulfilling the customer order demands for CDP2 and CDP5.

Table 6.8 Comparison between the overall transportation costs with and without CEOP in fulfilling the customer order demands for CDP2 and CDP5

Overall transportation cost with CEOP approach	\$21,100
Overall transportation cost without CEOP approach	\$27,400
Difference	\$6,300

The overall transportation cost with the CEOP approach is determined by the optimization model in (6.1). The overall transportation cost without the CEOP approach is the transportation cost that was spent in fulfilling the customer orders, as this was directly obtained from the accounting department without further data processing. The routing for the transportation without the CEOP approach follows the original practice where all the finished goods must be transported to the final designated customer via the factory in Hong Kong. Therefore, the routes in fulfilling customer orders in CDP2 and CDP5 were Route1-SSS3/SSS4/SSS5-MDC2-MDC1-CDP1-CDP2, and Route2-SSS3/SSS4/SSS5-MDC2-MDC1-CDP1-CDP2-CDP5,

Table 6.8 clearly shows that the transportation cost is lower with CEOP, which is mainly due to the heterarchical approach of the CEOP in enabling joint decisions to be made across the planning domains of MDC2 and MDC1 in regards to the transportation approaches to fulfilling customer order demands. Therefore, the CEOP sub-model of the SCC model significantly in increased the efficiency and effectiveness of the supply chain collaborative network in the case study by reducing transportation costs in the operation stage of the supply chain.

6.4 MEASUREMENT STAGE OF THE COMPANY

The measurement stage of the SCC model employs the proposed Cross Domain Performance Measurement (CDPM) sub-model to measure and evaluate the overall collaborative performance of the supply chain to provide feedback for the design and operation stages to further improve overall supply chain collaboration. The CDPM sub-model provides a quantitative performance value for the overall collaborative performance of the supply chain for analyzing intervention changes and variation in supply chain collaboration.

The performance value in CDPM is determined by the performance indexes induced from the business and performance objectives. The management team of the studied company redefined the business objective for reengineering the supply chain as to standardize most practices to streamline, and improve the efficiency and effectiveness of the supply chain, to satisfy their customers and maintain competitiveness. The updated business objectives of the company and its supply chain, together with the mapped performance objectives and performance indexes are presented in Table 6.9.

Table 6.9 Mapping of the performance indexes with the business/performance objectives of the studied company

Business Objectives	Performance Objectives	Performance Indexes
1. To manufacture reliable high frequency quartz crystal products	• Quality • Dependability	• Quality (return rate) • Effectiveness (defect rate)
2. To provide pertinent support and service to its customers in terms of prompt and accurate delivery, and prompt response to customers	• Quality • Speed • Dependability	• Efficiency (on-time delivery) • Quality (return rate, number of customer complaints) • Productivity • Effectiveness (customer fulfilment)
3. To promote a profitable and growing company that can offer employee fulfilment, enable new product development and provide better services	• Flexibility • Quality • Cost	• Productivity • Profitability • Effectiveness (employee fulfilment, customer fulfilment) • Efficiency (profit growth, working efficiency) • Innovation (number of new products developed)
4. To achieve cost cutting by continual process improvement and work efficiency	• Speed • Cost	• Profitability • Efficiency (working efficiency)

Table 6.9 reveals that the performance indexes of “efficiency” and “effectiveness” are comparatively significant to the company’s supply chain. As

the performance indexes of efficiency and effectiveness refer to a mixture of business and performance objectives, they are further divided into 6 performance indicators to truly reflect the objectives, and determine the performance value of the supply chain. In regard to effectiveness, the performance indicators are (a) defect rate, (b) employee fulfilment, and (c) customer fulfilment. Concerning the performance index of efficiency, the indicators include (d) on-time delivery, (e) growth rate, and (f) working efficiency. The six key performance indicators are designed to measure the performance of the supply chain network of the company in terms of its effectiveness and efficiency. Their corresponding evaluation criteria are defined and presented in Table 6.10.

Table 6.10 Key performance indicators and evaluation criteria for the studied company and its supply chain

Performance Indicators	Evaluation Criteria
Effectiveness-Product Reliability	Acceptable when the weekly average defect rate ≤ 200 parts per million
Effectiveness-Employee Fulfilment	Acceptable when the weekly employee feedback questionnaire average rating ≥ 5
Effectiveness-Customer Fulfilment	Acceptable when the weekly customer feedback questionnaire average rating ≥ 5
Efficiency-On Time Delivery	Acceptable when the weekly average on-time delivery rate ≥ 98%
Efficiency-Profit Growth	Acceptable when the weekly revenue ≥ 12%
Efficiency-Working Efficiency	Acceptable when the weekly average order fulfilment rate ≥ 95%

6.4.1 SCC Model Treatment – Performance Value in CDPM

To determine the performance value of the company and its supply chain using the above mentioned performance indexes and indicators, the corresponding data and information were collected internally and obtained from the company database for a period of 70 weeks. The performance data and information were provided by the sales department, which first collected the statistical data from the engineering department of each factory and then filed the data for quality control and internal and external auditing purposes. The data and information were then normalized according to Chapter 5 (5.1). The 70 weeks of data included two sets of 30 weeks of data before and after the completion of the reengineering of the supply chain, and the 10 weeks data between the two 30 week data sets are later removed from the output analysis to eliminate the warm-up period effect/nuisance effect from the initiation of supply chain reengineering. The two sets of data differ in that the second set was obtained after the supply chain reengineering period, in which the performance data underwent modelling by the CFPS and CEOP of the SCC model, while the first set are the original data without the modelling approaches of the SCC model.

Table 6.10 shows two equally weighted critical performance indexes with six specified indicators and corresponding evaluation criteria from four identified planning domain entities in the supply chain of the studied company, which means $n = 1, 2, 3, \ldots, 30$; $m = 1, 2, 3, 4, 5, 6$; and $x = 1, 2, 3, 4$ with respect to Chapter 5 (5.2). A collaborative performance measurement table with normalized nPD for the case study with the CDPM is presented in Tables 6.11

and 6.12. A detailed description of the types of performance data obtained from the studied company is presented in Appendix V.

Table 6.11 Collaborative performance measurement table for weeks 1-30 of the case study with CDPM

Performance indexes\ Week	1	2	3	. .	29	30
Effectiveness-Product Reliability	1.47	1.47	1.69	. .	0.87	1.01
Effectiveness-Employee Fulfilment	1.08	1.04	1.20	. .	0.79	1.32
Effectiveness-Customer Fulfilment	0.96	0.84	0.90	. .	1.12	0.95
Efficiency-On Time Delivery	0.98	1.04	1.02	. .	1.34	1.38
Efficiency-Profit Growth	0.97	0.79	0.96	. .	1.33	0.84
Efficiency-Working Efficiency	1.13	1.07	1.06	. .	0.59	1.50

Table 6.12 Collaborative performance measurement table for weeks 41-70 of the case study with CDPM

Performance indexes\ Week	41	42	43	. .	69	70
Effectiveness-Product Reliability	3.04	0.46	1.37	. .	3.42	1.39
Effectiveness-Employee Fulfilment	2.54	0.63	1.32	. .	3.56	0.78
Effectiveness-Customer Fulfilment	2.57	0.70	1.97	. .	3.80	1.30
Efficiency-On Time Delivery	2.68	0.49	1.30	. .	3.91	1.07
Efficiency-Profit Growth	3.16	0.71	1.50	. .	3.78	0.80
Efficiency-Working Efficiency	2.62	0.68	2.03	. .	3.58	0.49

The performance data and information in Tables 6.11 and 6.12 show the performance values for the collaborative performance of the supply chain before and after reengineering, and the performance values are summarized in Table 6.13. The larger the computed performance value, or the closer the computed performance value is to the ideal pre-defined performance value of the collaborative supply chain, the better the collaborative performance of the supply chain. Therefore, comparing the numerical value of the performance values explicitly shows that the collaborative performance of the supply chain improved in terms of effectiveness and efficiency after the supply chain was reengineered.

Table 6.13 Performance values for the collaborative performance of the supply chain before and after reengineering

Performance value for weeks 1-30	1.09
Performance value for weeks 41-70	1.75
Difference	+ 0.66

The CDPM sub-model of the SCC model quantitatively accounts for, and relates to various interdependent performance indexes in a hierarchical level, and then aggregates the indicators to calculate an overall performance value. The collaborative performance of the supply chain can then be represented in a performance value, which is a practical and easy method of interpretation, and can enable management to save much time and work in effectively monitoring, communicating, driving excellence, and supporting decision making along the supply chain. Therefore, the CDPM sub-model of the SCC model has significant value in measuring and evaluating the collaborative performance of supply chain in terms of the effectiveness and efficiency.

6.5 SCC MODEL TREATMENT ANALYSIS

The CFPS, CEOP, and CDPM sub-models for the design, operation, and measurement stages of the SCC model in the studied company are illustrated in Sections 6.2 to 6.4. The SCC model is then validated using the statistical methods of analysis of variance (ANOVA), trend line and effect size, and the feasibility and usefulness of the SCC model for supply chain collaboration can then be statistically analyzed.

6.5.1 Analysis of Variance (ANOVA)

To validate the SCC model for collaboration in supply chain, the performance data obtained from the company are further analyzed using the statistical analysis of variance (ANOVA) to diagnose the significance underlying the relationship between the SCC model and supply chain collaboration.

The CFPS, CEOP, and CDPM sub-models of the SCC model proposed for the reengineering of the supply chain were adopted by the company. Therefore, the supply chain performance after the completion of the supply chain reengineering process contains the treatment results and effects of the SCC model.

After the company completed its supply chain reengineering on January 4 2010, the operational data for the ANOVA testing were collected internally and obtained from the company database for 7 consecutive months. This included the data for the 3 months before and after the completion of the supply chain reengineering, and the 1 month between the two data sets of the 3 month periods were later removed from the output analysis to eliminate the warm-up period effect/nuisance effect from the initiation of the supply chain reengineering.

In the ANOVA testing, the percentage of order fulfilment is used as the dependent variable. This is the major variable considered in the testing because the numerical value represents the results of supply chain collaboration in fulfilling customer orders. Moreover, the company's management team commonly use the order fulfilment percentage to evaluate the success of their company and the supply chain. Order fulfilment is determined as the percentage of the number of orders completed and orders received across a time period, and it is represented as:

$$Order\ Fulfillment\ Percentage\ (OFP) = \frac{Orders\ Completed}{Orders\ Received} \times 100\% \qquad (6.4)$$

The data time period for the ANOVA testing is half-monthly, i.e. the number of orders completed and the number of orders received are in a half-monthly time periods. The information and data on orders completed and received were obtained from the sales department. The data were obtained for 7 consecutive months across three-quarters of the business year of the company. To minimize the seasonal factors that may incur in the number of orders received from customers during the data collection period, the average number of orders received from customers during the period is used to determine the OFP. As the data are exposed under the same processing basis and methods used to determine the OFR, contaminating factors are expected to have been controlled and minimized, thus allowing the effect of the SCC model and its internal validity to be determined. The half-monthly period data for the ANOVA testing are presented in Table 6.14.

Table 6.14 Half-monthly period data for the ANOVA testing

Periods	OFP	Periods	OFP
01-15 Oct 2009	34	01-14 Feb 2010	55
16-31 Oct 2009	17	15-28 Feb 2010	56
01-15 Nov 2009	42	01-15 Mar 2010	72
16-30 Nov2009	64	16-31 Mar 2010	98
01-15 Dec 2009	54	01-15 Apr 2010	96
16-31 Dec 2009	52	16-30 Apr 2010	98

The data collected for one way ANOVA testing are analyzed using the SPSS statistical package. The descriptive results are presented in Table 6.15. After testing the assumption of equal variance in ANOVA, i.e. $H_0: \sigma_1^2 = \sigma_2^2 \ and \ H_1: variance \ is \ not \ equal$, the results presented in Table 6.16 show that the value is at 0.258 significance, which means there is no evidence against *H₀*, and the assumption holds at 5% level of significance.

Table 6.15 Descriptive results from ANOVA testing

					95% Conf. Interval			
	N	Mean	Std. Dev	Std. Err	Lower	Upper	Min	Max
Before	6	43.833	16.714	6.824	26.293	61.374	17.0	64.0
After	6	79.167	20.808	8.495	57.330	101.00	55.0	98.0
Total	12	61.500	25.774	7.440	45.124	77.876	17.0	98.0

Table 6.16 Results of test of homogeneity of variances

Leven Statistics	df1	df2	Sig.
1.438	1	10	0.258

Furthermore, in testing if differences exist in the collaborative performance of the supply chain in different the periods, i.e.

$H_0: \mu_1 = \mu_2 \ and \ H_1: mean \ is \ not \ equal$, the results of the F-test for the equality of means is presented in Table 6.17, and yield 0.009 significance. As the analysis shows $p < 0.05$, and H_0 is thus rejected, there is also significant difference among the means. This means the collaborative performance of the supply chain is not the same before and after the reengineering of the supply chain. In turn, this means the SCC model does have an effect on the collaborative performance of the supply chain.

Table 6.17 Results of one way ANOVA testing

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3745.333	1	3745.333	10.516	.009
Within Groups	3561.667	10	356.167		
Total	7307.000	11			

6.5.2 Trend Line and Effect Size Analysis

In determining the effect the SCC model has on supply chain collaboration, the collaborative performance is plotted in terms of the OFP values performed by the company and its supply chain. The plotting of the OFP values in the trend line is presented in Figure 6.14.

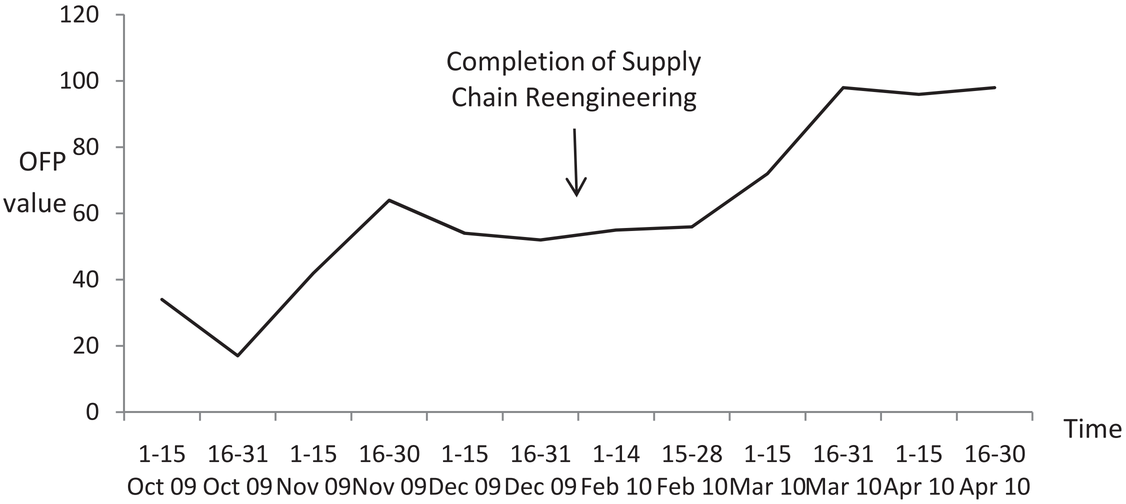


Figure 6.14 Trend line for supply chain collaborative performance in terms of the OFP values

As from Figure 6.14, the collaborative performance of the studied company and its supply chain performed better after adopting the SCC model, and the OFP values are steadily higher than in the period without the SCC model. Moreover, in determining the effect of the SCC model on supply chain collaboration, the statistical method of "effect size" is used. Effect size is a statistical method for comparing data with meaningful interpretation with standard deviation, and is calculated as:

$$Effect\ Size = \frac{(Mean - Norm\ Mean)}{Standard\ Deviation} \tag{6.5}$$

In applying the effect size method in the case study with the SCC model, the mean of the OFP values before the reengineering of the supply chain are used as the norm mean to compare the mean of the OFP values after the supply chain was reengineered. The effect size of the SCC model is presented in Table 6.18, which shows that the SCC model has a positive effect size of 2.3157 on supply chain collaboration, as well as improving the collaborative performance of the supply chain.

Table 6.18 Effect size of the SCC model in the case study

	OFP Mean (After)	OFP Mean (Before)	Standard Deviation	Effect Size
The SCC model for the supply chain collaboration	79.1667	43.8333	15.2580	2.3157

6.6 SUMMARY

This chapter has employed a case study to illustrate the CFPS, CEOP, and CDPM sub-models for the design, operation, and measurement stages of the SCC model and validated the effect of the SCC model on supply chain collaboration using statistical methods.

In the design stage of the company, the CFPS sub-model enhanced the efficiency and effectiveness of the supply chain collaborative network by reducing redundant looping activities and process flows in terms of operational cost and processing time. In the operation stage of the company, the CEOP sub-models reduced the operational cost of transportation activities by implementing joint decision making for transportation routing across the planning domains to fulfil customer order demands. In the measurement stage of the company, the CDPM sub-model provided an overview of the collaborative performance of supply chain in terms of a performance value that estimates the form and magnitude of the effect of intervention in the collaborative performance of the supply chain. In the case study, the CFPS, CEOP, and CDPM sub-models of the SCC model had significant value in the design, operation, and measurement stages of the company.

ANOVA, trend line, and effect size statistical methods were applied to validate the SCC model. The ANOVA testing was used to diagnose the significance underlying the relationship between the SCC model and supply chain collaboration by hypothesis testing, and provided the significance level of effect. The order fulfilment percentage (OFP) was used as the dependent variable in the testing, and the data collected for one way ANOVA testing was analyzed using the SPSS statistical package. The analysis results of ANOVA show that there is a significant difference among the means of testing hypothesis, which means the SCC model does have an effect on the collaborative performance of the supply chain in the case study. Furthermore, in determining the effect of the SCC model on supply chain collaboration, a positive and steady high supply chain collaborative performance trend line was plotted in terms of the OFP values of the company and its supply chain. Moreover, in applying the method of effect size, the results show that the SCC model has a positive effect size of 2.3157 on supply chain collaboration, as well as improving the collaborative performance of the supply chain in the case study. Therefore, the results analysis demonstrates the SCC model had a significant and positive effect on supply chain collaboration.

In the next chapter, the academic and industrial contributions of the SCC model in this research study are discussed based on the illustration and validation of the SCC model in the case study in this chapter, as well as the modelling of the CFPS, CEOP, and CDPM sub-models for the design, operation, and measurement stages of the SCC model in the previous chapters. Furthermore, the next chapter outlines the limitations of this study and recommendations for further research and provides an overall summary of the findings presented in this thesis.

7. DISSCUSSION AND CONCLUSION

As an aid to the reader, this final chapter summarizes the research presented in this thesis, and reviews the principle methods employed. In addition, the contributions this thesis makes to the literature, the limitations of the study and recommendations for further research are discussed.

This chapter is organized as follows. Section 7.1 presents a summary of the research project. Section 7.2 discusses potential contributions to the literature. Section 7.3 outlines the limitations of the research. Finally, Section 7.4 suggests further research relating to this study and concludes the thesis.

7.1 SUMMARY OF THE RESEARCH

As discussed in Chapter 2, to date most of the research on supply chain collaboration has focused on the operation stage of the supply chain, where problems are restricted to finding different ways of implementing different tools. However, the design and measurement stages are also essential to the successful operation of the supply chain as a whole. The design stage selects and partners appropriate entities, while the measurement stage evaluates the collaborative performance of the overall supply chain. Nonetheless, few studies focus on these two stages of the supply chain or view collaboration from a holistic perspective. The research presented in this thesis is intended to fill these gaps in the existing literature by studying supply chain collaboration from a fully perspective that extends the traditional focus on the operation stage to the design and measurement stages. Accordingly, this study proposes a Supply

Chain Collaborative (SCC) model to integrate the design, operation and performance measurement stages of the supply chain.

The design and development of the SCC model is based on a perspective that covers the multiple stages of the design, operation and measurement of supply chain. Network graph theory, mathematical programming and statistical methods are used to model the design, operation and measurement stages of the SCC model. A Cross Functional Partnership Selection (CFPS) sub-model is proposed for the design stage of the SCC model to select and partner supply chain entities. A Cross Entity Operational Planning (CEOP) sub-model is proposed for the operation stage to develop effective and efficient collaboration among common supply chain operational activities. Finally, a Cross Domain Performance Measurement (CDPM) sub-model is proposed to measure and evaluate the performance of the entire supply chain.

A case study of the SCC model was conducted under the auspices of the Teaching Company Scheme (TCS) offered by the Hong Kong Polytechnic University and a participating company. This study was a specific research and development project directly related to the business needs and environment of the participating company. Heuristic methods using genetic algorithms were adopted to analyse different scenarios of the company’s supply chain. In applying the SCC model, the CFPS sub-model employed in the design stage was found to enhance the efficiency and effectiveness of the company’s supply chain collaborative network, by reducing the operational costs and processing times related to redundant looping activities and process flows. In the operation stage, the CEOP sub-model reduced the operational costs arising from transportation by implementing joint decision making for transportation routing across the company's various planning domains to fulfil customer order demand. Finally, in the measurement stage, the CDPM sub-model provided an overview of the collaborative performance of the overall supply chain by calculating a performance value to estimate the form and magnitude of the effects of the intervention in the design and operation of the supply chain of the studied company. Overall, the CFPS, CEOP and CDPM sub-models of the SCC model were of significant value to the design, operation and measurement stages of the participating company and its supply chain.

Furthermore, the statistical methods of analysis of variance (ANOVA), trend line and effect size were used to validate the feasibility and usefulness of the proposed model in improving supply chain collaboration using data sets obtained from the participating company. The results of the ANOVA tests showed that there was a significant difference between the means of testing hypothesis on the order fulfilment percentage (OFP), which means the SCC model did affect the collaborative performance of the supply chain. In addition, a positive and steady high collaborative performance trend line was plotted in terms of the OFP values of the studied company and its supply chain. Moreover, the results of the effect size analysis showed that the SCC model had a positive effect on collaboration and improved the collaborative performance of the supply chain of the company participating in the case study.

Therefore, the results of the analysis to illustrate and validate the case study demonstrate the potential significance of the SCC model and its ability to positively effect supply chain collaboration.

7.2 POTENTIAL CONTRIBUTIONS AND IMPLICATIONS OF THE RESEARCH

This thesis designed and developed a Supply Chain Collaborative (SCC) model for achieving collaboration among the various activities and entities in a supply chain.

The primary academic contribution of this study is the capacity of the SCC model to model collaboration across the entire supply chain. The multiple stage, design, operation and measurement modelling approach employed in this study is an original and innovative contribution to the existing literature on supply chain collaboration. Accordingly, the research presented in this thesis has filled the gaps in the existing literature identified and stated in Chapter 2, namely, that studies of supply chain collaboration focus mostly on the operation stage and on isolated aspects of the supply chain.

The SCC model developed in this study extends the traditional study of the operation stage to its two extremes of the design and measurement stages. In the design stage, the CFPS sub-model provides a hierarchical approach of selecting and partnering appropriate entities to develop and embed collaboration within the supply chain network. In the operation stage, the CEOP sub-model provides a heterarchical collaboration approach for developing effective and efficient collaboration among the operational activities in the supply chain. In the measurement stage, the CDPM sub-model provides quantitative approaches for measuring and evaluating collaboration to provide feedback on the collaborative performance of the entire supply chain for the design and operation stages. The multiple stages modelling approach developed in this study has been demonstrated to be an effective alternative for modelling and analysing supply chain collaboration.

The original and innovative multi-stage modelling approach employed in the SCC model developed in this study can be used as a reference for other academics to develop further models or theories of holistic supply chain collaboration and to contribute to the sustainable development of the supply chain management domain as a whole.

The contribution of this research for industry is that the SCC model provides significant modelling approaches for improving and enhancing supply chain collaboration in the design, operation and measurement stages of the supply chain. The SCC approaches are distinctive as all the supply chain entities are involved in improving and enhancing the performance of the supply chain. Thus, the SCC model provides the basis for developing holistic and company/supply chain wide practices.

The SCC model provides detailed approaches for the management team to achieve collaboration through the design, operation and measurement stages of their supply chain. In the design stage, the CFPS can enable the management team to easily identify and select the appropriate entities for supply chain partnership. In the operation stage, the management team can employ the CEOP sub-model to develop effective and efficient joint-decision operational planning between different entities. In the measurement stage, the management team can determine the performance stability of the supply chain in collaboration using CDPM, thereby gaining insights into the responsiveness of the entire supply chain for the purposes of continual improvement and monitoring. With the SCC model, the management team can also use the quantitative data and optimal results gained from the proposed model for decision making, as they are consistent upon reliable data input. As a result, mistakes arising from human error can be minimized. Moreover, as the modelling approaches of the SCC model are based on the business and performance objectives of the company and its supply chain, the management team is required to constantly review the quantitative data and optimal results provided by the SCC model to ensure the collaborative performance of the supply chain is aligned with those objectives. This can benefit the growth of the company.

As the perspective of the SCC model covers the multiple stages of design, operation and measurement the management team can focus on collaboration along the entire supply chain. This multi-stage perspective increases the coherence of the relationships between supply chain activities and entities, as each entity no longer focuses solely on its own individual activity. Each entity along the supply chain has to collaborate with the others, and contribute to the development of the overall supply chain to leverage with others, achieve mutual benefits and increase the competitiveness of the supply chain.

The SCC model has been applied in an industrial case study, and real data and information from the participating company were used to illustrate and validate the SCC model. The results show that the SCC model has a demonstrated significant and positive effect on supply chain collaboration. Therefore, the SCC model can be used as a reference for other practitioners from the same or other industries in enhancing or improving their supply chain collaboration.

7.3 LIMITATIONS OF THE RESEARCH

The SCC model has only been illustrated and validated in a single case study of a specific research and development project directly related to the needs of a company in the made-to-order manufacturing industry. Accordingly, the modelling approach employed in the SCC model may reflect the background and nature of the participating company and its supply chain. Due to a number of restrictions and agreements relating to this study, it was difficult to obtain data sets from other companies or supply chain partners to further illustrate and validate the SCC model. Therefore, the SCC model needs to be reviewed before being applied to different types of companies and supply chains.

As the SCC model considers multiple stages of the supply chain, the number and complexity of the associated modelling parameters may exponentially increase as the supply chain becomes extremely complicated. For instance, if there are too many complicated selection criteria for partnerships in the design stage, too many associated direct or indirect operational costs need to be considered in the operation stage, or there are too many qualitative or objective indicators in the measurement stage, then a large number of modelling parameters are likely to be required, and a complicated formulation of the SCC model will result.

The modelling approaches of the SCC model are based on the business objectives of the company and its supply chain. As a result, the performance objectives of the supply chain need to be clearly definable, measurable and achievable. If the business and performance objectives of the supply chain are not clearly defined, errors will arise in the measurement and evaluation of the supply chain performance in the CDPM sub-model. Furthermore, as the measurement stage provides feedback to the design and operation stages, syntax errors may arise in CFPS and CEOP, i.e. errors spreading to the entire SCC model. Similarly, the use of modelling parameters needs to be concise and accurate in each of the sub-model stages, as the design, operation and measurement stages are inter-related in the SCC model.

7.4 FURTHER WORK

As the SCC model provides a perspective on supply chain collaboration, the concept of resilience and friability can possibly be further incorporated into the model. Any disconnection in the interrelationships between supply chain entities can affect collaboration within the overall supply chain. For instance, when one or two supply chain entities suddenly fail to operate or provide services in the supply chain, the subsequent emergency actions the other entities need to execute to compensate for the failure becomes a critical issue. Resilience and friability can then provide an efficient way of analyzing the ability of a supply chain network to return to a stable state following a disruption arising from a failure in the collaboration between entities. As the collaborative or survival ability of a pair of entities in a supply chain depends on the number of effective and efficient interrelated connections there are between them, the resilience of an entity can be evaluated by the weighted average number of reliable collaborations with all other entities in the network, and the network resilience can then be calculated by the weighted sum of all entity resilience. Moreover, the friability of the supply chain can be determined by the total resilience decline after removing particular collaborations between entities. Therefore, under certain predefined constraints in a network with known collaboration, the stochastic impact scenarios for the supply chain entities can be further evaluated, analyzed and optimized to maximize overall supply chain collaboration. Resilience and friability can be integrated into the SCC model to enhance the sensitivity and robustness of supply chain collaboration.

In the design stage of the SCC model, simulation software can be further used to analyse the selection and partnership of supply chain entities and the overall workflow of the entire supply chain. Simulation software is a convenient tool for simulating and analyzing supply chain situations. The operation stage of the SCC model can also be further developed into a model for making decisions about running new factories. By incorporating other projected cost parameters into the operation stage, such as the projected investment costs for new factories, and projected operation costs, the impacts or effects of the new factories on the existing operations in the supply chain can be determined. In the measurement stage of the SCC model, different weighting can be further applied to different performance indexes to determine the performance value for supply chain collaboration, because different companies may require different performance indexes.

Information system architecture can also be further developed on the basis of the SCC model to develop computer systems or networks to assist collaboration in the supply chain. The modelling parameters, quantitative data and optimal results relating to performance can be efficiently and effectively shared among supply chain entities, and real-time data and information can assist decision making processes. Similarly, the modelling approach of the SCC model can also be integrated with existing information and management systems, such as the Enterprise Information System (EIS), Enterprise Resources Planning (ERP), and Customer Relationship Management (CRM). Therefore, the SCC model can increase the functional diversity of existing systems, while concise and accurate data from the systems can also be used in the SCC model to maintain consistent decision making.

Since the SCC model is illustrated in this research study in a company in the made-to-order manufacturing industry, the proposed model can further be developed and illustrated in the made-to-stock manufacturing industry. Made-to-order is a production approach that products are built once a confirmed customer order is received. Made-to-stock is another production approach that products are build-ahead a confirmed customer order, and the production may be based upon sales forecast or historical demand. The different in the roadmap for the made-to-order and made-to-stock approach in the SCC model is mainly in the design stage of the model. In the made-to-order industry, the selection and partnering criteria for the suitable supply chain entities in the design stage of the SCC model depends on the order requirements given by the customer, such as different customer orders may require different materials, different raw materials for production may thus require from different supply chain entities for different customer orders. On the other hand, since products are comparatively more standardized in the made-to-stock industry, the selection and partnering of the supply chain entities may not be carried out as frequent as in the made-to-order industry. The selection and partnering criteria for the supply chain entities in the made-to-stock approach may then highly follow the business objectives and the production specifications of the standardized product. Therefore, the business objectives and production specification of production in the made-to-stock approach may firstly need to well-defined in the design stage of the SCC model. Once the selection and partnering criteria are defined, suitable supply chain entities and their partnership linkages can then be determined as well as the subsequent operational activities can be executed. Measurement stage of the SCC model can then also be applied in the made-to-stock approach to measure and evaluate the collaborative performance of the supply chain and to provide feedback to the design and operation stages so as to further improve the overall collaborative performance of the supply chain.

The SCC model is an effective tool for the modelling of supply chains which can cover the multiple stages of design, operation and measurement and has strategic importance for the success of a supply chain. Furthermore, it provides a useful basis for further study by academics and industrial practitioners and the research results are applicable to other industries and supply chains. Such applications can further illustrate and validate the modelling approach of the SCC model in achieving supply chain collaboration in different scenarios.

APPENDIX I. TEACHING COMPANY SCHEME

Teaching Company Scheme (TCS) is offered by the Hong Kong Polytechnic University (PolyU) and a participating company, and the scheme is also supported by the Hong Kong Special Administrative Region Government's Innovation and Teaching Commission.

The Scheme is one of the University-Industry Collaboration Programmes (UICP). The Scheme provides high-calibre MPhil or PhD students with an opportunity to work on advanced level research topics that directly related to the needs of participating companies with a finite duration. Students will work under the joint supervision of a PolyU staff member and a representative of the company.

All parties under the TCS can attain maximum benefits under the framework of partnership between the academia and the commercial and industrial sectors. For participating companies, their gain is the research deliverables while students acquire practical research experience in a genuine business environment. The university faculties also benefit from the close links established with industry.

The Teaching Company Scheme Programme is designed and conducted by the PolyU in support of industry and business aiming to bring ideas through research activities to results that can be used by companies to support their growth and development; and through close collaboration in the spirit of partnership, the PolyU and the Partner jointly develop a Teaching Company

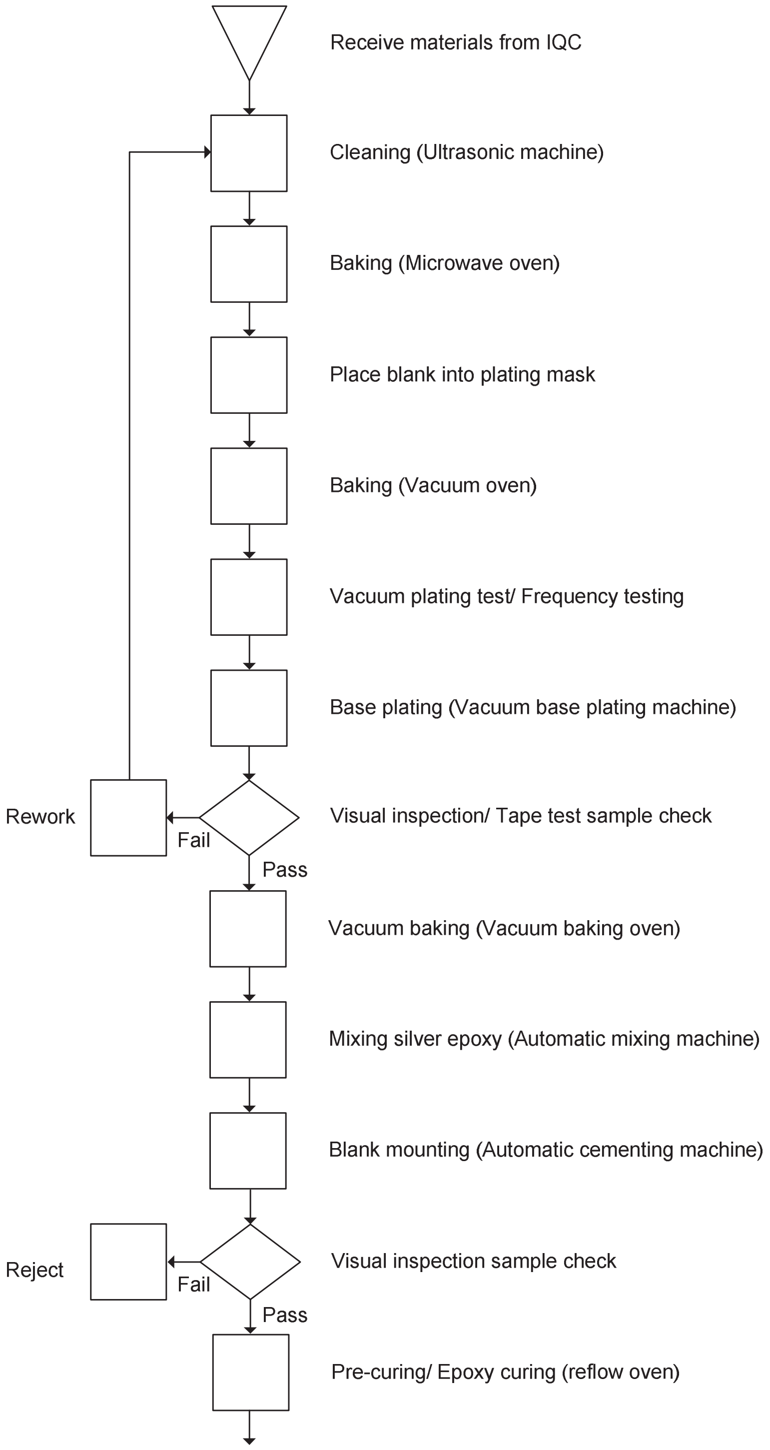
Scheme ("TCS") and provide guidance to the * appointed / recruited researcher, known as the Teaching Company Associate ("TCA"), in a research project of high intellectual content and of application value to the Partner according to agreed upon plan and objectives. Upon completion of the project, subject to the production of a thesis and applicable regulations of the PolyU for the Degree of Doctor of Philosophy offered by the PolyU, the TCA may be conferred a postgraduate degree.

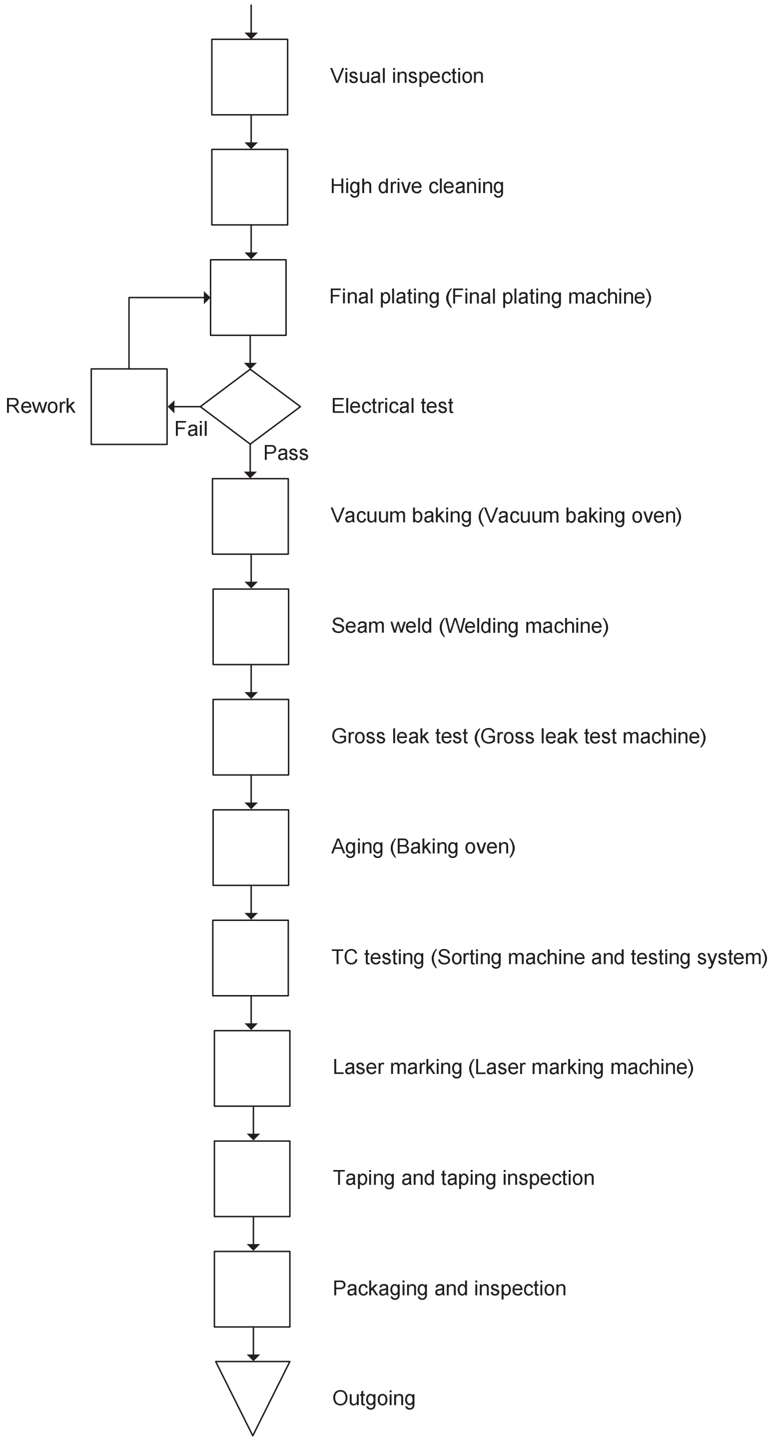
APPENDIX II. RESEARCH TIMETABLE

Description	Duration
Preparation Phase • Literature review • Analyze the potential for supply chain collaboration • Identify the research gap, and the motivation and significance of the research • Confirm the project team for the TCS in the university and company • Write up the scope, objectives, and plan of the project	1 year (2005-2006)
Phase 1 – Development of the SCC model • Study and analyze the company's existing supply chain practices • Identify problems and map the supply chain and business requirements of the company • Design and develop the company's supply chain practices using the design, operation and measurement stages of the SCC model • Evaluate and pilot test the SCC model in the company • Write up the research results/papers	2 years (2006-2008)
Phase 2 – Illustration and Validation of the SCC model • Identify the types of data used for the illustration • Collect the data and convert it into a readable format • Use the data from the company to illustrate the design, operation and measurement stages of the SCC model • Validate the SCC model using the ANOVA, trend line, and effect size statistical tools • Write up the research results/papers	1.5 years (2008-2009)
Finalization Phase • Finalize the research • Write up the research results/papers • Write up the research report for the company • Write up the academic research thesis	0.5 year (2009-2010)

APPENDIX III. MANUFACTURING PROCESSES FOR QUARTZ CRYSTAL PRODUCTS

Notes: Common manufacturing processes for product types: 9S, SMD




Visual inspection
High drive cleaning
Final plating (Final plating machine)
Rework
Fail
Electrical test
Pass
Vacuum baking (Vacuum baking oven)
Seam weld (Welding machine)
Gross leak test (Gross leak test machine)
Aging (Baking oven)
TC testing (Sorting machine and testing system)
Laser marking (Laser marking machine)
Taping and taping inspection
Packaging and inspection
Outgoing

APPENDIX IV. GENETIC ALGORITHMS

Genetic algorithms are the most widely known type of meta-heuristic algorithm. They have received considerable attention regarding their potential as an optimization technique for complex problems and have been successfully applied in many supply chain problems (Berger et al., 2003; Lam et al., 2008; Saez et al., 2008; Liu et al., 2009; Zhao et al., 2009; Marinakis & Marinaki, 2010)

1 GENERAL STRUCTURE OF GENETIC ALGORITHMS

The Genetic Algorithm (GA) was invented and developed by J. Holland and his associates in the early 1970s (Holland, 1975). GAs are a stochastic search technique based on the evolutionary processes of natural selection and genetic fitness. The basic form of GA was described by Goldberg (1989).

Unlike conventional search techniques, a GA starts with an initial set of random solutions called a population. Each individual element, or chromosome, in a population represents a possible solution to a problem. A chromosome is a string of symbols, usually a binary bit/number string that evolves through successive iterations, called generations. In each generation, the chromosomes are evaluated according to a number of measures of fitness. To create the next generation, new chromosomes, called offspring, are formed by either (i) merging two chromosomes from the current generation using a crossover operator, or (ii) modifying a chromosome using a mutation operator. A new generation is then formed by (i) selecting some of the parents and offspring according to the fitness values, and (ii) rejecting others to keep the population size constant. Fitter chromosomes have a higher probability of being selected. After several generations, the algorithms converge towards the best chromosome, which represents the optimum, or a suboptimal solution to the problem (Davis, 1991; Mitchell, 1996; Chambers, 1999; Gen & Cheng, 2000).

Encoding

In Holland's work, encoding is carried out using binary strings. Similarly, the encoding scheme used in this study is generated from binary strings of random 0s and 1s. This encoding scheme has the advantage of eliminating the offspring feasibility problem and is robust to problem structure. In terms of GAs, this general form of chromosome encoding is denoted as K_p, which represents the *p-th* chromosome, and k_{ij} is the corresponding decision variable for whether the route/possible route is feasible in the encoding.

Initialization

The initialization of the population of chromosomes is done by randomly generating as many NP chromosomes as desired for the population size. Each chromosome is represented in a general form that represents a feasible route, and genetic operations are then performed on the population of chromosomes. The generation procedure of the initial population size is illustrated by the following pseudo-code:

Procedure: INITIALIZATION

```
BEGIN
    $\pi \leftarrow \{1, 2, ..., sc\}$;
    Repeat
        select a random number r from set $\pi$;
        calculate corresponding row and column;
        $i \leftarrow (r - 1)/c + 1$;
        $j \leftarrow (r - 1)\ ,mod\ c + 1$;
        assign available amount of units to $k_{ij}$;
        $k_{ij} \leftarrow min\ \{a_i, b_j\}$;
        update data;
        $a_i \leftarrow a_i - k_{ik}$;
        $b_j \leftarrow b_j - k_{ij}$;
        $\pi \leftarrow \pi / \{r\}$;
    until ($\pi$ becomes empty)
END
```

The basic idea of the procedure is to (i) select random decision variables from the allocation route, (ii) assign as many k_{ij} available units as required, and (iii) update the data of supply and demand to guarantee balance condition.

Evaluation

GA chromosomes contain information that needs to be evaluated by a number of fitness measurements. The fitness values indicate the relative superiority of the chromosomes, which is necessary for conducting subsequent procedures, including the selection and reproduction operations.

For the CFPS and CEOP stages of the SCC model, the fitness function for the GA evaluation is formulated in equations (IV.1) and (IV.2).

$$\mathrm{eval}(\mathrm{K}_{\mathrm{p1}}) = \sum_{e_{ij} \in E} w_{ij} \qquad \text{(IV.1)}$$

where $W = \{w_{ij} \mid w_{ij} = (v_i, v_j), \text{ and } w_{ij} > 0 \text{ and } v_i, v_j \in V\}$ represents the weighting for the collaborative partnership linkages between entities upon e_{ij}, $V = \{v_i \mid 1 \leq i \leq n\}$ represents a set of vertices with a number of n nodes; $E = \{e_j \mid 1 \leq j \leq m\}$ represents a set of edges with a number of m edges, such that nodes $v_i \in V$ indicate the supply chain entities in different functional areas, and edges $e_j \in E$ indicate the collaborative partnership linkages between the entities.

$$\mathrm{eval}(\mathrm{K}_{\mathrm{p2}}) = \sum_{s \in S} \sum_{i \in I} TC_{si} x_{si} + \sum_{d \in D} \sum_{i \in I} TC_{di} x_{di} + \sum_{c \in C} \sum_{i \in I} TC_{ci} x_{ci} \qquad \text{(IV.2)}$$

where

s	A supply source/supplier (SSS), $s \in S$
d	A manufacturer-distribution center (MDC), $d \in D$
c	A customer demand point (CDP), $c \in C$
i	An item (semi-product/product), $i \in I$
S	Set of SSSs, $s \mid s=1,2,\ldots,p$
D	Set of MDCs, $d \mid d=1,2,\ldots,q$
C	Set of CDPs, $c \mid c=1,2,\ldots,r$
I	Set of items (semi-product/product), $i \mid i=1,2,\ldots,s$

TC_{si}	The operation cost of item *i* in SSS *s*
TC_{di}	The operation cost of item *i* in MDC *d*
TC_{ci}	The operation cost of item *i* in CDP *c*
x_{si}	The supply-demand volume of item *i* in SSS *s*
x_{di}	The supply-demand volume of item *i* in MDC *d*
x_{ci}	The demand volume of item *i* in CDP *c*

Supposing that the population size equals *pop_size*, the evaluation procedure can then be described as follows:

Procedure: EVALUATION

Step 1: *Convert the chromosome's genetype to its phenotype into relative real values* $K_p = (x_{sdi}, y_{dci})$*, for* $p = 1, 2, \ldots,$ *pop_size.*

Step 2: *Evaluate the objective function* $f(x_{sdi}, y_{dci})$.

Step 3: *Convert the value of objective function into fitness.*

Selection

The roulette wheel approach (Goldberg, 1989; Gen & Cheng, 2000) is adopted for selecting the chromosomes to conduct the genetic operations. In the roulette wheel approach, the probability of selecting a chromosome is determined by its fitness, where the chromosomes with larger fitness values are more likely to be selected. Although the roulette wheel mechanism selects the chromosomes probabilistically, it is certain that on average a chromosome will be selected with a probability proportional to its fitness. The selection procedure is described as follows:

Procedure: SELECTION

Step 1: *Calculate the fitness value eval* (K_p) *for each chromosome* K_p.

Step 2: *Calculate the total fitness for the population.*

Step 3: *Calculate the selection probability* p_p *for each chromosome* K_p.

$$p_p = \frac{eval(K_p)}{F} \qquad , for\ p = 1, 2, \dots, pop\_size$$

Step 4: *Calculate the cumulative probability* q_p *for each chromosome* K_p.

$$q_p = \sum_{j=1}^{p} p_j \qquad , for\ p = 1, 2, \dots, pop\_size$$

Step 5: *Generate a random number r from the range [0, 1] .*

Step 6: *If* $r \le q_p$, *then select the first chromosome* K_1; *otherwise, select the chromosome* K_p *such that* $q_{p-1} < r \le q_p$.

Genetic Operations

Various genetic operations can be used in GAs. The genetic operations adopted in this study are crossover and mutation, which have proven to be very robust in computational tests (Bean, 1994; Hadj-Alouane, 1997). The number of chromosomes selected for the crossover and mutation operations are denoted as N_c and N_m, respectively, such that $N_c + N_m = pop\_size$.

The crossover operation chooses two chromosomes as parents from the current generation according to the selection scheme. Assuming that two chromosome matrices, $K_1 = k_{sc}^1$ *and* $K_2 = k_{sc}^2$, are selected as parents for the crossover operation, the crossover procedure is then performed as follows:

Procedure: GENETIC OPERATION – CROSSOVER

Step 1: *Create two temporary matrices* $A = a_{ij} = \left(k_{ij}^1 + k_{ij}^2\right)/2$ *and* $B = b_{ij} = \left(k_{ij}^1 + k_{ij}^2\right) \, mod \; 2$.

Matrix A keeps rounded average values from both parents, and matrix B keeps track of whether any rounding is necessary. The relationship between these two matrices describes two properties: (i) the number of "1"s in each row and each column is even, i.e. the marginal sums of rows and columns are even integers, and (ii) the values of row marginal sums of matrix B equal twice the difference between row marginal sums of matrix A and corresponding supplies, and the values of column marginal sums of matrix B equal twice the difference between column marginal sums of matrix A and corresponding demands.

Step 2: *Divide matrix B into two matrices* $B^1 = b_{ij}^1$ *and* $B^2 = b_{ij}^2$, *such that* $B = B^1 + B^2$..

Step 3: *Two offspring of of* $K_1^{'}$ *and* $K_2^{'}$ *are produced as follows:*

$K_1^{'} = A + B^1$, $K_2^{'} = A + B^2$

The chromosome mutation is implemented by randomly generating one (or more) entirely new chromosome(s) from the same distribution as the original generation and then including them in the next generations. Mutation plays an important role in preventing premature convergence of the population (Bean, 1994; Hadj-Alouane, 1997). The mutation procedure is performed as follows:

Procedure: GENETIC OPERATION – MUTATION

Step 1: *Make a sub-matrix from a parent matrix. Randomly select {i_1, ..., i_c} rows and {j_1, ..., j_c} columns to create a (s x c) sub-matrix Y =* y_{ij}*, where it takes the value of the element in the crossing position of selected row i and column j in the parent matrix.*

Step 2: *Reallocate a commodity for the sub-matrix. The available amounts of commodity* a_i^y *and* b_j^y*.*

$$a_i^y = \sum_{j \in \{j_1,\ldots,j_s\}} y_{ij} \qquad , for\ i = i_1, i_2, \ldots, i_c$$

$$b_j^y = \sum_{j \in \{i_1,\ldots,j_c\}} y_{ij} \qquad , for\ j = j_1, j_2, \ldots, j_s$$

Step 3: *Replace the appropriate elements of the parent matrix with new elements from the reallocated sub-matrix Y.*

2 THE MODELLING AND OPTIMIZATION PROCEDURES IN GA

The modelling and optimization of the SCC model in this study follows the GA solution approach shown in Figure IV.1.

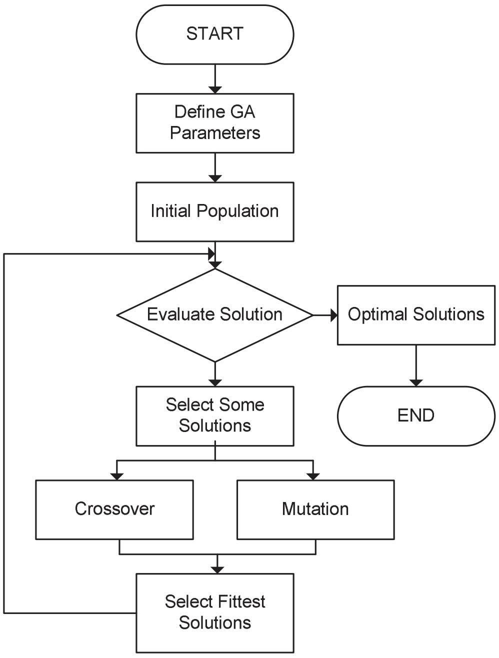


Figure IV.1 Modelling and optimization of the SCC model using a GA-based meta-heuristic method

For the GA used in the SCC model, a number of parameters, including maximum generation, population size, crossover rate, and mutation rate, need to be defined before the GA creates an initial set of random solutions. Each potential solution in the search space is represented in the form of a chromosome, and then all the obtained chromosomes are evaluated using the fitness measurement, i.e. $eval(K_p)$. On the basis of the fitness values, two genetic operations, i.e. crossover and mutation, are executed to produce a new set of chromosomes (offspring) to prevent premature convergence of the population. The steps are iterated, and the evaluation is performed again to start the next iteration until the maximum generation is reached or the algorithm converges to the best solution. The overall GA procedure is described as follows:

Procedure: GA FOR SCC MODEL

Step 1: *Define the GA parameters, including the maximum generation (gen_no), the population size (pop_size), the crossover rate (*Cr_r*), and the mutation rate (*Mu_r*).*

Step 2: *Generate initial pop_size chromosomes according to the encoding*

Step 3: *Evaluate the fitness value of all chromosomes in the population*

Step 4: *Perform the chromosome crossover*

Step 5: *Perform the chromosome mutation*

Step 6: *Iterate Steps 3 – 5 until the maximum generation is reached.*

APPENDIX V. PERFORMANCE DATA

Notes:

The performance data for each period include:

- [PI-1] Effectiveness-Product Reliability: determined by the average defect rate.
- [PI-2] Effectiveness-Employee Fulfilment: determined by the average employee feedback rate from questionnaire.
- [PI-3] Effectiveness-Customer Fulfilment: determined by the average customer feedback rate from questionnaire.
- [PI-4] Efficiency-On Time Delivery: determined by the average on time delivery rate.
- [PI-5] Efficiency-Profit Growth: determined by the average revenue balance.
- [PI-6] Efficiency-Working Efficiency: determined by the average production time.

Table V.1 Collaborative performance measurement table for weeks 1-7

Week	1	2	3	4	5	6	7
PI-1	1.47296	1.46665	1.69329	1.00026	2.06532	1.39646	0.00000
PI-2	1.08192	1.03945	1.20470	0.92644	1.81385	1.12301	0.36505
PI-3	0.95775	0.84486	0.90469	0.83992	1.13438	1.47069	0.00000
PI-4	0.98392	1.03600	1.01593	0.88775	1.23027	0.81929	0.00000
PI-5	0.97263	0.78777	0.95923	0.80618	1.32214	1.32007	0.33571
PI-6	1.13170	1.07481	1.05782	0.92539	1.36712	1.08180	0.48354

Table V.2 Collaborative performance measurement table for weeks 8-14

Week	8	9	10	11	12	13	14
PI-1	1.14375	0.46552	0.76790	2.83111	0.22843	0.94659	1.37388
PI-2	1.92563	0.67185	1.05535	2.68156	0.48409	1.30449	1.49797
PI-3	1.36873	0.24986	0.64627	2.49381	0.91683	1.11406	1.48296
PI-4	1.43428	0.81771	0.81759	2.60128	0.81033	1.21649	1.51842
PI-5	2.05771	0.25010	1.51011	2.73515	0.19319	0.66694	1.02502
PI-6	1.58001	0.48001	1.42517	3.11565	0.16447	1.07562	0.81760

Table V.3 Collaborative performance measurement table for weeks 15-21

Week	15	16	17	18	19	20	21
PI-1	0.97579	0.74338	1.41749	1.57146	0.45326	0.28967	1.88615
PI-2	0.83807	0.75360	0.88097	1.64132	0.75983	0.82881	2.35738
PI-3	1.11367	1.22553	1.40302	1.45804	0.58454	0.96724	2.57326
PI-4	1.09530	1.31951	1.54139	1.41138	0.07622	0.65689	2.17071
PI-5	0.70998	0.72008	1.55213	1.44065	0.93322	0.71554	2.05895
PI-6	1.06351	0.83943	0.99080	1.86710	0.24043	0.64820	2.49081

Table V.4 Collaborative performance measurement table for weeks 22-28

Week	22	23	24	25	26	27	28
PI-1	0.50917	0.08671	0.72937	0.78480	0.73438	1.08058	1.43462
PI-2	0.09072	0.92706	0.94243	1.58356	0.79600	0.93715	1.60637
PI-3	0.67563	0.97816	1.08761	1.51181	0.58667	1.55956	1.79388
PI-4	0.44348	0.00421	1.16971	1.27300	0.88642	0.68517	1.61915
PI-5	0.44854	0.40130	1.20204	1.26907	1.43977	0.72734	1.93342
PI-6	0.86833	0.01879	0.93523	0.97155	0.90433	1.17565	1.45248

Table V.5 Collaborative performance measurement table for weeks 29-35

Week	29	30	31	32	33	34	35
PI-1	0.87291	1.00679	2.33769	1.69733	2.25672	0.54619	3.42546
PI-2	0.78617	1.31758	1.48991	2.37976	1.68522	1.01807	2.77527
PI-3	1.11864	0.94520	1.62835	2.21107	1.86404	1.10340	3.28521
PI-4	1.33815	1.37796	2.19462	2.40652	1.82752	1.40293	3.46923
PI-5	1.33372	0.84097	1.68805	1.66144	2.17411	0.89037	3.05088
PI-6	0.59281	1.50121	2.21596	1.64602	1.56042	0.69665	3.00957

Table V.6 Collaborative performance measurement table for weeks 36-42

Week	36	37	38	39	40	41	42
PI-1	0.58336	1.53761	2.20533	1.27513	1.25854	3.04175	0.45590
PI-2	0.76141	1.36577	1.96013	1.24809	1.59589	2.54376	0.62981
PI-3	0.55316	1.35104	2.02247	1.39126	1.79931	2.56524	0.70484
PI-4	0.65297	0.94471	2.00838	1.49729	1.68565	2.68051	0.49487
PI-5	1.10888	1.06305	2.36462	0.99601	1.45008	3.15555	0.70774
PI-6	1.45240	0.79961	2.13383	1.60130	1.80143	2.62439	0.67940

Table V.7 Collaborative performance measurement table for weeks 43-49

Week	43	44	45	46	47	48	49
PI-1	1.37277	2.14467	0.39772	3.27878	0.51000	2.76817	0.90465
PI-2	1.31676	2.93382	1.18220	2.51791	1.25596	2.65925	1.26673
PI-3	1.97142	3.05171	0.30235	2.62461	1.23399	2.53549	0.71451
PI-4	1.30133	2.50226	0.88908	3.31899	1.12709	2.44931	1.11622
PI-5	1.50264	2.64254	0.84307	2.98365	0.76820	2.26885	0.98652
PI-6	2.02825	2.76528	0.51404	2.93022	1.24040	2.63100	0.80668

Table V.8 Collaborative performance measurement table for weeks 50-56

Week	50	51	52	53	54	55	56
PI-1	0.69598	3.84452	0.53711	0.26491	1.95675	1.69373	1.42113
PI-2	0.94147	3.71046	1.27259	0.28570	2.32372	1.63110	1.81994
PI-3	1.05689	3.78479	0.94114	0.35562	1.64376	1.89897	1.08636
PI-4	0.52388	3.79578	1.44361	0.11519	1.79896	1.91931	1.22347
PI-5	0.53253	4.02972	1.40062	0.51007	1.45524	2.46793	1.24027
PI-6	0.58320	3.88043	1.23503	0.55431	1.87661	2.37728	1.62948

Table V.9 Collaborative performance measurement table for weeks 57-63

Week	57	58	59	60	61	62	63
PI-1	2.94105	0.79649	3.92693	1.65675	1.45277	2.76768	0.71692
PI-2	2.44709	0.15019	3.76807	2.03765	1.28674	2.65701	0.97539
PI-3	2.21516	0.24152	3.34533	1.85646	1.68125	2.53478	0.83073
PI-4	2.67415	0.68349	3.51439	2.18341	1.31711	2.62866	0.39835
PI-5	2.59700	1.07873	3.35562	1.90528	1.25141	2.25993	0.08628
PI-6	2.55568	0.75000	3.65068	1.67999	1.50390	2.19222	0.93910

Table V.10 Collaborative performance measurement table for weeks 64-70

Week	64	65	66	67	68	69	70
PI-1	3.00075	0.98912	1.74539	0.48154	0.50411	3.41616	1.38919
PI-2	3.29436	0.77246	2.44635	0.49994	0.55050	3.55546	0.77623
PI-3	2.76208	0.66082	2.32782	1.02187	0.64780	3.80449	1.30283
PI-4	2.69542	0.71701	2.64300	0.88376	0.67756	3.91243	1.06856
PI-5	2.51796	1.05554	2.51459	0.99767	0.12905	3.78178	0.79838
PI-6	2.38359	0.94069	2.63492	0.91052	0.90447	3.57538	0.49490

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