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Collaboration inter-organisationnelle pour l'optimisation des chaînes d'approvisionnement en textile

Inter-organizational collaboration for optimizing textile supply chains

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Inter-Organizational Collaboration for Optimizing Textile Supply Chains

Abstract

Nowadays, as the increasing trend of customization and personalization in fashion market, the mass customization and small-series production has become more and more important in textile supply chain. However, there are still many drawbacks in existing supply chain models which are used to cope with this trend. Collaboration plays a vital role in supply chain management in past decades. However, supply chain collaboration is rarely applied in textile industry, neither in research nor in practice. Considering the potential advantages of the application of supply chain collaboration, to bridge the gap, this thesis employs multiple supply chain collaboration strategies to optimize existing textile supply chain models.

In this PhD research, a thorough investigation and literature review regarding supply chain collaboration was conducted. Several emerging supply chain collaboration paradigms and strategies were identified, which provided a theoretical foundation and research direction for the subsequent research. Consequently, three innovative supply chain models with corresponding optimization strategies were developed: (1) a novel resource sharing mechanism for optimizing garment manufacturing echelon in textile supply chain, (2) a central order processing system for optimizing demand-driven textile supply chain, and (3) a collaborative cloud service platform for optimizing make-to-order textile supply chain. Identified supply chain collaboration strategies, viz. resource sharing, information sharing, joint decision-making, profit sharing, were employed for developing the three collaborative models. Optimization heuristics were also designed for different objectives in three models respectively. The three proposed supply chain collaboration strategies were realized in three simulation models by employing discrete-event simulation technology or multi-agent simulation technology. Several experiments were conducted to demonstrate the advantages of such collaborative structure under different conditions. Based on simulation experiment results, multiple supply chain performances were improved significantly in each model under different conditions. The developed models with corresponding strategies can optimize current textile supply chain and help companies maintain competence in the trend of mass customization in textile industry.

Keywords: supply chain collaboration; mass customization; resource sharing; discrete-event simulation; multi-agent simulation; optimization heuristics; textile supply chain

Collaboration inter-organisationnelle pour l'optimisation des chaînes d'approvisionnement en textile

Résumé

Actuellement, comme la tendance croissante de personnalisation dans le marché de la mode, la demande de personnalisation de masse et la production de petites séries deviennent de plus en plus important dans la chaîne d'approvisionnement textile. Pour répondre à cette tendance, le modèle de la chaîne d'approvisionnement traditionnelle ne convient plus. Au cours des dernières années, certaines stratégies de la chaîne d'approvisionnement sont utilisées dans l'industrie textile, telles que la stratégie axée sur la demande et la stratégie de fabrication à la commande. Cependant, il existe encore de nombreux inconvénients dans les modèles de la chaîne d'approvisionnement employant ces stratégies. De nouvelles stratégies sont nécessaires pour résoudre ces problèmes et optimiser ces modèles. La collaboration dans la chaîne d'approvisionnement joue un rôle essentiel dans la gestion de la chaîne d'approvisionnement au cours des dernières décennies. Il a déjà été appliqué dans de nombreuses industries. De nombreuses entreprises utilisent des stratégies de collaboration pour poursuivre un objectif commun optimal. Cependant, la collaboration dans la chaîne d'approvisionnement est rarement appliquée dans l'industrie textile, ni dans la recherche ni dans la pratique. Considérant les avantages potentiels de l'application de la collaboration de la chaîne d'approvisionnement, pour combler le fossé, cette thèse emploie plusieurs stratégies de collaboration de la chaîne d'approvisionnement pour optimiser les modèles existants de chaîne d'approvisionnement textile.

Dans cette recherche doctorale, une enquête approfondie et une revue de la littérature concernant la collaboration de la chaîne d'approvisionnement ont été menées. Plusieurs paradigmes et stratégies émergents de collaboration dans la chaîne d'approvisionnement ont été identifiés, ce qui a fourni une base théorique et une direction de recherche pour mes recherches ultérieures. En conséquence, trois modèles innovants de chaîne d'approvisionnement avec des stratégies d'optimisation correspondantes ont été développés: (1) un nouveau mécanisme de partage des ressources pour optimiser la fabrication des vêtements dans la chaîne d'approvisionnement textile; (2) un système central de traitement des commandes pour l'optimisation de la chaîne d'approvisionnement textile axée sur la demande, et (3) une plate-forme collaborative de services cloud pour l'optimisation de la chaîne d'approvisionnement textile da la fabrication à la commande. Stratégies de collaboration identifiées pour la chaîne d'approvisionnement, à savoir, le partage des ressources, le partage de l'information, la prise de décision conjointe, le partage des bénéfices, ont été utilisés pour développer les trois modèles de collaboration. Des heuristiques d'optimisation ont également été conçues pour différents objectifs dans trois modèles respectivement. Les trois stratégies collaboratives de la chaîne d'approvisionnement proposées ont été réalisées dans trois modèles de simulation en utilisant la technologie de simulation à événements discrets ou la technologie de simulation multi-agents. Plusieurs expériences ont été menées pour démontrer les avantages d'une telle structure collaborative dans différentes conditions.

Mots-clés: la collaboration de la chaîne d'approvisionnement; personnalisation de masse; partage de ressources; simulation à événement discret; simulation multi-agents; heuristique d'optimisation; chaîne d'approvisionnement textile

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Forza INTER.

Suzhou, China

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25/04/2018

Table of contents

List of tables

List of figures

General introduction

With the increasing demand for personalization and customization in today's fashion market, flexible small-series production and mass customization have become the mainstream direction for the development of textile Supply Chain (SC). In order to meet this trend, the structure of textile SC needs to be reorganized and new SC model needs to be developed. A few new SC models, e.g. demand-driven SC model, make-to-order, were adopted in textile industry to meet this trend. However, there are still many defects in existing models, so that they cannot satisfy the requirements of flexible production, small-series production in an effective way. Thus, some innovative methods are demanded to solve these issues and optimize existing SC models in textile industry.

Inter-organizational supply chain collaboration (SCC) played a vital role in SC practice and research in past decades. Many successful business models were developed based on this method. Therefore, it could be regarded as a promising direction to solve the aforementioned problems in textile SC. In order to maintain competitiveness in future textile industry, textile companies, especially SMEs, need to develop cooperative relationships with other companies and implement appropriate SCC strategies.

This thesis utilized SCC as the main research ontology. Three inter-organizational SCC strategies were proposed to solve current issues in existing textile SC models. Under different contexts, they provided optimized solutions for mass customization, flexible production, and small-series production. Optimization heuristics (a method of successively approaching the optimal solution) were designed for each model respectively. The feasibility and effectiveness of the three proposed models were verified through simulation experiments under distinct conditions. According to the outcomes of this research, textile companies, especially small and medium-sized companies, should strengthen their cooperation with other companies and change their business structure in accordance with the mechanisms and models proposed in this thesis, so that to enhance their competitiveness in the future of Industry 4.0.

The structure of this thesis and main content of each chapter is introduced as follows.

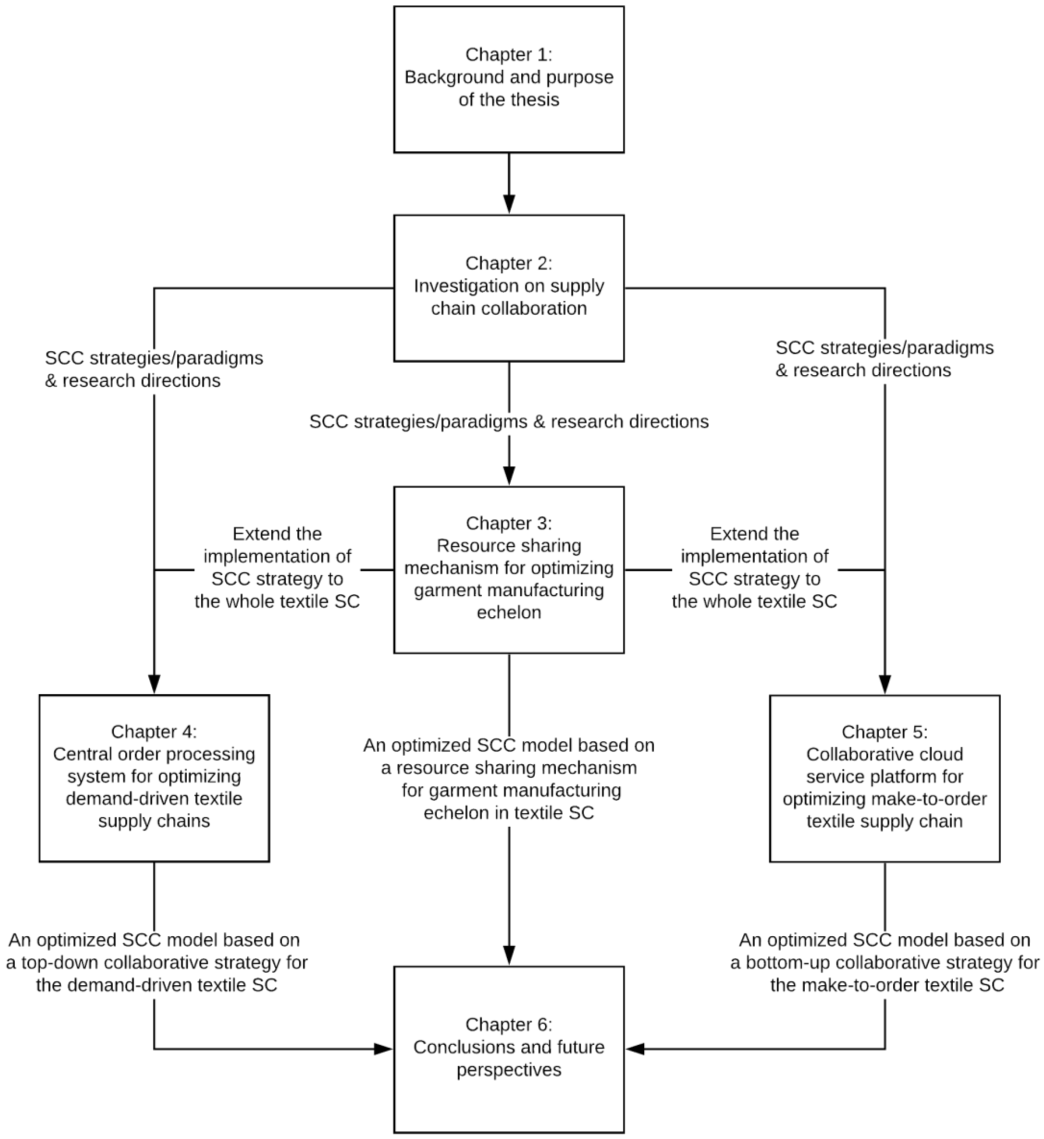


Figure 0.1 Structure of the thesis

Chapter One introduces the background of the PhD research, including a broad overview of textile industry and the trend of current textile SC. A brief introduction to the ontology of this PhD research--supply chain collaboration—is also presented. Furthermore, this chapter argues the purpose of this thesis which is pursued in this PhD research.

Chapter Two makes a systematic investigation and literature review regarding SCC. It compiles a theoretical foundation and a research direction for following research in this thesis. A cluster analysis is conducted on collected SCC articles, resulting in four clusters. Based on a thorough analysis on each cluster, a number of emerging research themes and patterns are identified and derived. It provided several SCC paradigms/strategies, e.g. resource sharing, joint decision-making, incentive alignment, information sharing strategy, for subsequent SCC models proposed in Chapter Three to Chapter Five for solving existing issues in current textile SC and attaining the purpose raised in Chapter One.

Chapter Three discusses an inter-organizational collaboration model targeting on the garment manufacturing echelon (partners in different stages of the supply chain) in textile SC. A novel mechanism on the basis of resource sharing, which is the most promising SCC research paradigm identified in Chapter Two, is proposed and implemented as the main collaborative strategy for developing the SCC model. A simulation-based heuristic is designed for obtaining the optimal solution for resource sharing. The sub-study conducts a discrete event simulation experiment for the raised research questions. The optimal resource sharing scenario under distinct conditions is attained. The positive effect of such innovative mechanism is demonstrated on the basis of the experiment results. It provides a research base for following optimized SCC models on the whole textile SC in Chapter Three and Chapter Four.

The implementation of SCC strategy is extended to the whole textile SC in Chapter Four. A novel collaborative textile SC model is proposed for optimizing the entire demand-driven textile SC on the basis of a top-down collaborative strategy (joint-decision in a centralized system and then implementation at individual company level). Besides the resource sharing mechanism that is proposed in Chapter Three, information sharing, incentive alignment, joint decision-making strategy (identified in Chapter Two) are also applied by designing and developing a central order processing system. Both vertical collaboration and horizontal collaboration are realized in this innovative SCC model. This sub-study uses discrete-event simulation technique to experiment the new collaborative models under different conditions. Based on the results of simulation experiments, the advantages of this new model are demonstrated. Further its performance under distinct conditions, e.g. application under different workload, application on different textile SC echelons, is also examined.

Chapter Five presents another collaborative textile supply chain model for optimizing make-to-order textile SC on the basis of a bottom-up collaborative strategy (operation and decision-making in each individual company and then joint decision-making in a centralized cloud platform). A collaborative cloud service platform is developed to realize resource sharing strategy (proposed in Chapter Three), information sharing, joint decision-making strategy (identified in Chapter Two). The sub-study designs a heuristic for the selection of optimal service provider corresponding to the various demands received by the cloud platform. In this sub-study, multi-agent simulation technology is utilized to implement the innovative model and the corresponding cloud service platform. An experiment is conducted based on the multi-agent model as well. The new model with cloud service platform is compared to two existing make-to-order textile supply chain models, namely the traditional model and the outsourcing model. Based on the simulation experiment, the superiority of the new model is demonstrated, which the collaborative cloud service platform can bring significant benefits to textile SMEs.

On the basis of results of Chapter Two to Chapter Five, a list of conclusions of the thesis is derived in Chapter Six. It summarizes the contributions of this research from various aspects. This chapter also provides perspectives for future research in this domain.

1. Introduction of the thesis

This chapter starts with the introduction of textile Supply Chain (SC), which presents the background of this research. The focus is on the manufacturing sector and SC aspects. The concept of Supply Chain Collaboration (SCC) is then presented to illustrate main direction of methodology. On the basis of background and general concepts introduction, the motivation of the research and main contents are elaborated.

1.1 An overview of textile supply chain

Historically, textile industry typically refers to the design and production of yarn, silk, fabric and garment. As one of the oldest industry in the world, textile industry has extremely complex structure as its development along history. Different types of companies with specific expertise, e.g. dyeing workshop, fabric manufacturer and garment manufacturer, play distinct roles in textile industry. Several typical sectors in textile industry include pre-production (product design, product development, material management, and sourcing), manufacturing, distribution and logistics, and retailing (Keiser & Garner 2012). In this thesis, manufacturing and SC aspect is the main focus of this research, thus different types of manufacturers in textile industry are introduced in detail. A general structure of manufacturer classification in textile industry is illustrated in Figure1.1.

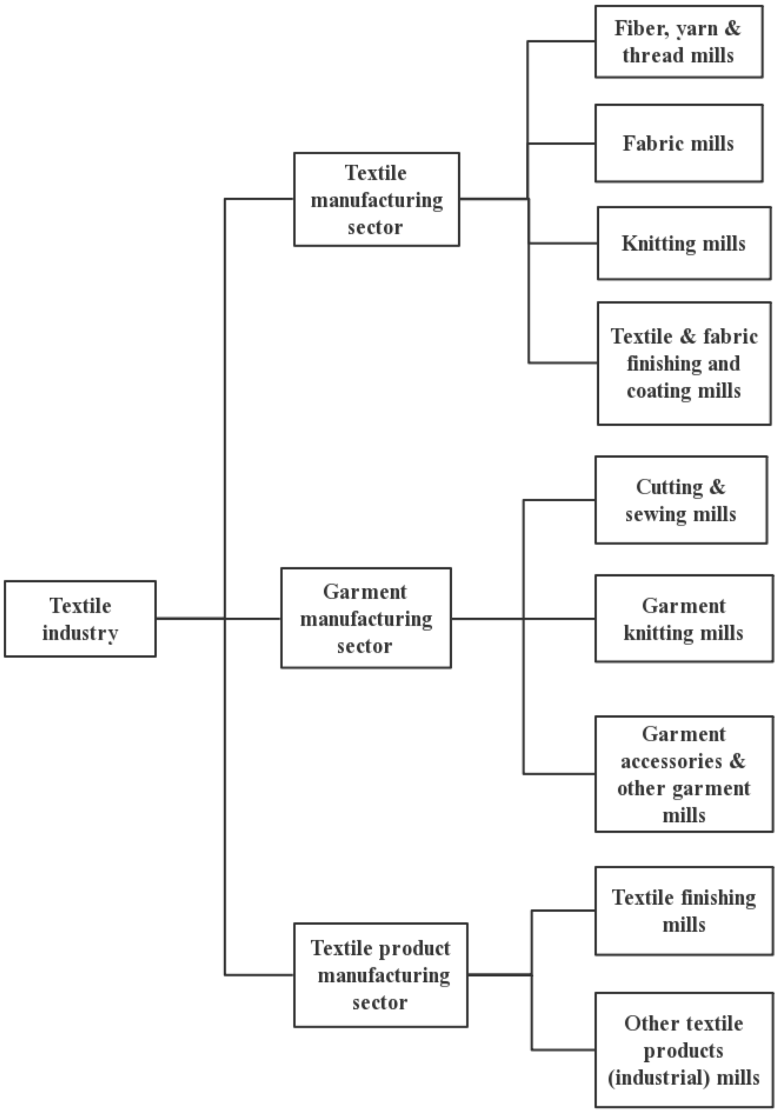


Figure 1.1 Structure of manufacturer classification in textile industry

As the development of customization and personalization is increasing in recent years, to meet the demand of customers and catch up with the latest fashion, companies in textile industry have much less time for product development (including design, sampling, production, distribution) now. As shown in Figure 1.2, the calendar from concept to final product consists of 54 weeks in past times, while today's calendar is 35 weeks for basic garment and fast fashion calendar only has 17 weeks (Keiser & Garner 2012). The current textile industry now is more flexible than before, and is also more flexible compared to other industries. In general, among the total cycle for product development, eight to ten weeks are needed for basic garment production, while around five weeks for fast fashion garment production. Both basic and fashion garments generally need around five weeks for logistics. It is clear to see that the 45 percent time reduction (17 weeks) between basic garment and fast fashion garment in product development is mainly due to the time reduction in preproduction process, such as trend analysis for each product line and product design. In production and logistics process, there is not too much difference in timetables between basic product and fast fashion product.

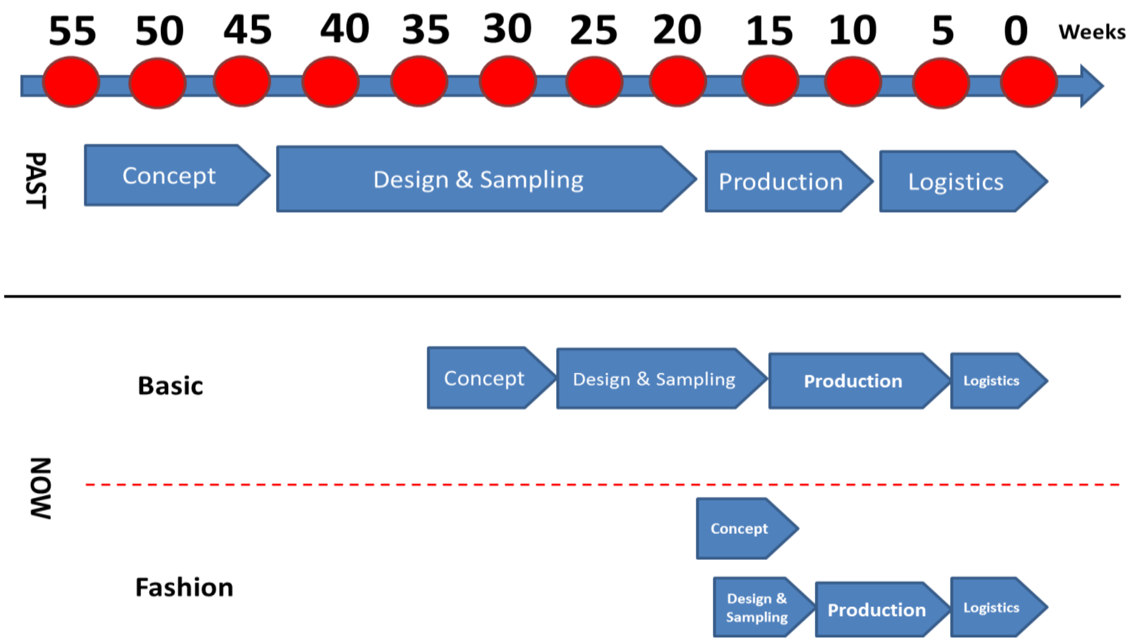


Figure 1.2 Example of product development calendars in garment industry

As the increasing complexity in manufacturer classification of modern textile industry, textile SC also became more complex in past decades. In a traditional linear textile SC, the role of each echelon is distinct, each with its own product and customer (Keiser & Garner 2012), as Figure 1.3 shows. However, today's textile SC is demanded to be more flexible than the traditional linear model. More actors are involved in the SC, and with proper communication, the expertise of each SC player or sourcing partner contributes to the entire chain and increases the value of the final products. Activities from several SC echelons could be integrated and be completed by one company, while a SC echelon could be divided into several parts and be completed by different companies with distinct and specific expertise.

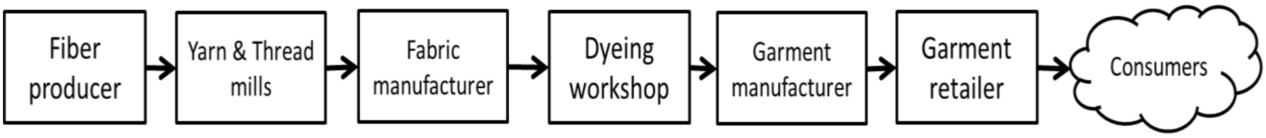


Figure 1.3 A typical traditional linear textile supply chain

A typical textile SC can be divided into two parts, textile manufacturing and garment manufacturing. Textile manufacturing generally consists of four echelons, viz. fiber processing, yarn spinning, fabric production or fabrication, dyeing and finishing. The four echelons could be processed in one big manufacturer or in multiple manufacturers respectively. Garment manufacturing generally has three main steps, viz. fabric cutting, sewing and finishing. The production of textile product could be domestic (developed countries) production, offshore (developing countries) production or a combination of the two options. Meanwhile, some textile companies own production facility themselves while others utilize contractor production. The advantages and disadvantages of these four options are shown in Table 1.1 and Table 1.2 (Burns & Bryant 2002). Offshore production and contractor production are more common than their alternatives, whereas domestic production and company-owned facility production are also important for the sake of quick response. An important issue in textile SC is the resource allocation, the amount of resources required for garment production varies according to certain factors, such as different styles, volume and delivery schedules. The complexity of the garment industry increases the difficulties in achieving effective resource allocation.(Lee et al. 2014). With additional pressure brought about by the trend of mass customization and fast fashion in today's textile industry, garment manufacturers are being urged to achieve effective and efficient production resource allocation for their survival in the competitive industry (Lee et al. 2013).

Table 1.1: Comparison between domestic production and offshore production in textile supply chain

	Advantages	**Disadvantages**
Domestic production	Easier for quality control and product customization; Lower shipping time and costs; Known culture; Supported by consumers who prefer products "made in Europe";	Labour costs may be higher than in other countries; Some types of fabrics may not be readily available
Offshore production	Labour costs may be lower than Europe; Can take advantage of trade agreement incentives; Some types of fabrics are more readily available	Differences in cultural norms; Monetary/currency differences; Language barriers; Possible trade barriers

Table 1.2: Comparison between company-owned facility production and contractor production

	Advantages	**Disadvantages**
Company-owned facility production	Greater quality control; Greater control over production timing; Communication with textile suppliers and retailers optimized	Financial requirements associated with facility and human resource; Need to ensure continuous production; Higher labour costs
Contractor production	Greater flexibility of changing equipment or production needs; No investment in factories, equipment, or training needed	Less control over quality or production timing

1.2 Current challenges and trends in textile supply chain

The recent changes in the trend of globalization and new technological innovations have lead to a series of changes in the textile supply chain, e.g. fade of mass production, modified SC structural characteristics. Textile industry faced many challenges in response to those changes (Macchion et al. 2015). The increased competition forced textile companies to desire low cost, small quantity and flexibility in design, production and delivery (Bhardwaj & Fairhurst 2010), making the competition increasingly fierce in this industry (Brun & Castelli 2008). The demand of customization and personalization is growing in fashion market in recent years as well, leading to the increase of stochastic demands from customer in fashion market. According to Yeung & Choi (2011), mass customization, which refers to producing customised products or services for satisfying individuals with an efficiency similar to mass production, plays a significant role in meeting this trend. Mass customization starts to become the mainstream in textile industry, it changes textile SC structure, requiring small-series production and high diversity in production extremely. Under such circumstances, textile SC structure becomes more complex and characterized by short product life cycles, volatile and unpredictable demand, and tremendous product variety (Şen 2008). It becomes more and more difficult for textile manufacturers to produce garments and related materials (fabric, yarn, silk etc.) based on traditional production mode. Traditional SC strategy (e.g. forecast-based strategy, make-to-stock strategy) for ready-to-wear products is not feasible anymore. New SC strategy and corresponding optimization method are urgently demanded in textile industry.

To cope with aforementioned trend in textile SC, demand driven strategy and make-to-order strategy have been adopted by the textile industry. According to Verdouw et al. (2011), a demand-driven SC can be defined as a supply chain in which all actors involved are sensitive and responsive to demand information of the end customer and meet those varied demands in a timely and cost-effective manner. In a demand-driven SC, only products and services corresponding to customers' demands are produced and it forces stakeholders in the SC to collaborate with each other (Hadaya & Cassivi 2007). The demand-driven strategy can also bring many other benefits to textile companies, e.g. an increased variety of garments, zero inventory, reduced return from customers, minimized risk of production based on forecasts. Although the concept of demand-driven SC seems to be simple, it is very complicated to achieve it (Selen & Soliman 2002), as it involves many aspects which are differs from traditional forecast-based SC. Although demand-driven has many advantages in its current form, this model still has several defects, such as long lead-time, very high cost, unsmooth production flow, long delay between two echelons Therefore, there are a lot of potentials to improve it.

Demand driven strategy is one way for textile companies to cope with changes in textile industry, another one is the make-to-order strategy. Make-to-order strategy means that manufacturers starts production only after receiving a customer's order, production and distribution processes in the SC are all triggered by customer orders (Meisel & Bierwirth 2014). Besides advantages such as meeting the desire for customization and reducing risk of forecast-based production, make-to-order strategy can also help companies avoid inventory of semi-finished products and final products which are unavoidable in make-to-stock strategy (Olhager & Östlund 1990). Same as the characteristic of demand-driven strategy, production activity is only triggered by orders received in each company applied make-to-order strategy. Therefore, there is no inventory of final product in a make-to-order SC. However, unlike the structure of a demand-driven SC (every SC activity, e.g. production, order placement, is totally driven by orders.), only the activity of production is driven by orders in a make-to-order SC, while other activities are according to each individual company's criteria. For example, order for replenishing raw materials is based on current inventory level and re-order point set by each company. Companies of a make-to-order SC hold raw material inventory, while companies of a demand-driven SC have no raw material inventory at all. Make-to-order strategy incurs many additional issues as well, such as long lead time (Ioannou & Dimitriou 2012), high cost (Morikawa et al. 2014) and unbalanced capacity. Currently, in a make-to-order textile SC, retailers need to place an order to garment manufacturer several months in advance for production. The order size should be also big enough per order. Under such circumstance, late delivery still often occurs due to insufficient raw material or insufficient production capacity. Companies who can satisfy due dates set by customers and can shorten lead times could have a great competitive advantage.

1.3 **Supply chain collaboration**

To stay competitive in the current challenging business environment, more and more companies develop collaborative relationships with partners and they employ collaborative strategies. It can take place in various forms, these include inter- and intra- organizational collaboration. Intra-organizational collaboration means the relationship internally between departments and divisions of one organization (Mena et al. 2009). Inter-organizational collaboration depicts relationship between two or several organizations in which the participating parties agree to invest resources, mutually achieve goals, share information, resources, rewards and responsibilities, as well as jointly make decisions and solve problems (Chan and Prakash, 2012). According to (Cao & Zhang 2011), Supply Chain Collaboration (SCC) is defined as two or more autonomous firms working jointly to plan and execute SC operations. It can be classified into two main categories: vertical collaboration and horizontal collaboration (Figure 1.4). Vertical collaboration is “the collaboration when two or more organizations from different levels or stages in SC share their responsibilities, resources, and performance information to serve relatively similar end customers” (Chan & Prakash 2012). Horizontal collaboration is “a business agreement between two or more companies at the same level in the SC or network in order to allow greater ease of work and cooperation towards achieving a common objective" (Bahinipati et al. 2009). The majority of the research on SCC focuses on inter-organizational collaboration and there is no indication that this focus will change. Thus, the emphasis, in this thesis, hereon is on inter-organizational collaboration unless otherwise specified.

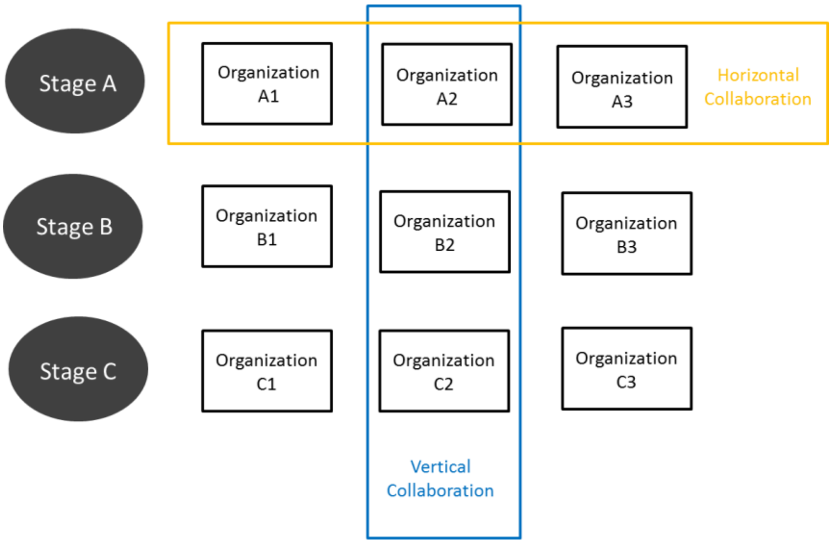


Figure 1.4 Illustration of horizontal collaboration and vertical collaboration

Research regarding inter-organizational collaboration has a wide scope. It cover diverse topics, e.g. new collaborative business models (Holm et al., 2013, Rohrbeck et al., 2013, Chesbrough, 2007), joint innovation (Romero and Molina, 2011, Howarth, 1994), collaborative communication and information exchange platforms (Romero and Molina, 2010, Chituc et al., 2009, Rossignoli et al., 2009). On the other hand, for the specific area of SC, the literature is relatively narrow and the studies tend to focus on specific aspects of SC, e.g. influence of certain collaborative contract type on SC performance (Inderfurth and Clemens, 2014, Kunter, 2012, Xu et al., 2014), or the impact of certain information sharing method on SC (Inderfurth et al., 2013, Ozer et al., 2011) or efficiency improvement of SC through collaborative replenishment or production planning (Ben-Daya et al., 2013, Chaharsooghi and Heydari, 2010, Pibernik and Sucky, 2007).

Besides collaboration, there are several other concepts in use that implicate an interest in collaborative relationships in SC, e.g. *coordination, cooperation, alliance* and *joint venture*. These may connote a collaborative relationship however they tend to represent different levels or perspectives of collaborations. For example, Weaver (2012)'s study on comparing between 3Cs (coordination, cooperation and collaboration) along SC activities (e.g. planning and forecasting). It showed that coordinative demand planning and forecasting was conducted mainly by the downstream partners with errors thus having minor effects on the upstream partner, while cooperative planning was conducted by the downstream partners with subsequent sharing with the upstream partners. Collaborative planning was conducted jointly with both risk and reward being equally shared by the partners. Gulati et al. (2012) defined coordination as the deliberate and orderly alignment or adjustment of partners' actions to achieve jointly determined goals, while cooperation as the joint pursuit of agreed-on goal(s) built on a shared understanding of contributions and payoffs. On the other hand, strategic alliance is referred to "a constellation of agreements characterized by the commitment of two or more partner firms to reach a common goal, entailing the pooling of their resources and activities." (Teece, 1992, p. 19) and can be broadly viewed to be long-term in nature (Soosay et al., 2008). While joint venture implies a group of companies supplying complimentary services joining forces for mutual benefit and frequently leading to a new enterprise with joint ownership (Jagdev and Thoben, 2001). Typically, alliances and joint ventures in the SC require a longer period of time for successful collaboration thus the desirable benefits from these relationships will not be realized until the trading partners have reached a fuller integration (Cheng, 2011). Based on past definitions and studies, the level of a collaborative relationship is interpreted to be increasing gradually from *coordination* to *joint venture*.

1.4 **Problem discussion and purpose of the thesis**

As introduced in Section 1.1, the makespan for product development in today's fashion industry is extensively reduced. However, the time spent in textile production and logistics is not reduced significantly. It is important to improve the efficiency and productivity in today's textile supply chain. Moreover, the demand of customization and personalization is continuously increasing in textile industry. Instead of purchasing traditional ready-to-wear garments, customers are seeking to wear customized clothes fitting their respective individual preferences and body shapes with distinctive materials, styles, patterns or colours. It becomes more and more difficult for textile companies to forecast the demands. As the development of technology for garment customization design in recent years, e.g. virtual try-on (Liu et al. 2017; Hong et al. 2017), corresponding technique development and structure evolution in garment production is inevitable. Consequently, traditional supply chain model will not be feasible in future textile industry. On the basis of above discussion, the demand of small-series production, flexibility and quick responses has become more and more important in future textile supply chain. Although some new strategies are employed to meet such demand and trend, such as demand-driven strategy and make-to-order strategy (see Section 1.1.3), there are still many drawbacks when applied them in textile supply chain.

With the increase of complexity and flexibility in today's supply chain, inter-organizational collaboration between different echelons (partners in different stages of the supply chain) has become an important issue. Companies tend to find suitable partners to improve their SC performance as a whole, for achieving mutual benefits together. Hadaya

& Cassivi (2007) concludes that without strong collaboration among suppliers, it would be impossible to implement the core process improvements in a supply network. Supply Chain Collaboration (SCC) has become an import direction to optimize SC in terms of various aspects, including sustainability (Blome et al. 2014), long-term partnership (Ramanathan & Gunasekaran 2014), risk management(Li et al. 2015), social responsibility (Hsueh 2014). In current textile SC, from fabric manufacturing echelon to garment manufacturing echelon, each company always has a single supplier, forming independent SC structure without collaboration. Therefore, SCC could be a direction to optimize current textile SC in practice. Increased collaboration among textile companies, especially textile SMEs, can be one way for higher complementarity of resources, increased flexibility and reduced lead time for production. Thus, supply chain collaboration is considered as the fundamental ontology to develop novel textile supply chain models in this research.

Most of researches regarding SCC concentrated on joint decision making (Buijs & Wortmann 2014; Abdelsalam & Elassal 2014; Hlioui et al. 2017), incentive alignment contract (Govindan & Popiuc 2014; Vafa Arani et al. 2016; Bai et al. 2017) or information sharing (Inderfurth et al. 2013; Bian et al. 2016; Khan et al. 2016), which all are strategies mainly employed and discussed in vertical SCC. In real-world industry, due to the potential competitive relationship among partners, horizontal collaboration was not widespread either. Even though it was conducted by some companies, they can only be found between companies of two different non-competitive SCs (Naesens et al. 2009). However, in the context of optimizing the whole performance of the SC, collaborations must be realized among two or more directly competitive firms in order to maximize the total production capacity and total benefits and fully make use of their complementarity.

Therefore, horizontal collaboration in the supply chain ought to be considered also by the textile industry, independent of them being competitors or not.

From the discussion above, this thesis seeks to inform theory and practice on the optimization of current textile supply chain through proposing several supply chain collaboration models, which combined both vertical collaboration and horizontal collaboration. The literature review (see Chapter Two) shows that supply chain that combines vertical and horizontal collaboration has not yet been explored and evaluated for the textile industry. Previous studies regarding vertical collaboration and horizontal collaboration supports the rational for carrying out such studies. Multiple SCC approaches, e.g. information sharing and information updating system, resource sharing mechanism, optimal joint-decision making strategy, are merged into these models with corresponding optimization heuristics, so that to realize the latest trend of mass customization, small-series production and flexible production in textile SC. The results of this research are expected to offer solutions for current issues, e.g. long lead time, high cost, in existing textile SC models, e.g. traditional demand-driven SC model, traditional make-to-order SC model. They can also optimize textile SC performance from multiple aspects under distinct conditions.

2. Literature review: supply chain collaboration

The importance of collaboration in Supply Chains (SC) has been demonstrated by many researches (Ramanathan & Gunasekaran 2014, Soosay, Hyland & Ferrer 2008), capturing diverse perspectives, e.g. SC coordination (e.g. Seifert, Zequeira and Liao (2012)), joint venture (e.g. Gerwin and Meister (2002)), strategic alliance (e.g. Howarth (1994)) and open business (e.g. Frankenberger, Weiblen and Gassmann (2013)), amongst others. However, this diversity makes the literature body on Supply Chain Collaboration (SCC) overloaded with multiple terms, topics and foci. In this context, this chapter is based on a systematic review of SCC, to identify diverse embedded research categories and explore systematically these emergent streams addressing SCC. It provides a theoretical foundation and research directions for subsequent sub-studies in this thesis as well as the research questions addressed in the sub-studies of this research, which ends this chapter. More than 300 articles regarding SCC were searched to build a literature database. The systematic review of research in SCC and the statistics approach aided analysis (e.g. hierarchical cluster analysis) has resulted in the identification of four clusters of research: *information sharing paradigm, joint decision making paradigm, coordinating contract paradigm* and *resource sharing paradigm*. Each cluster has been further analysed and the research has been further classified in eleven sub-categories.

2.1 Information sharing paradigm

Information sharing refers to it as an act of capturing and disseminating timely and relevant information for decision makers to plan and control SC operations (Simatupang and Sridharan, 2005). Some authors regard it as the starting point of a collaborative SC for successful management and coordination (Simatupang and Sridharan, 2002, Ganesh et al., 2014). Further, selling and logistics form the main SC stages in this information sharing paradigm. Information sharing paradigm are here categorized in three distinct themes: (i) Vendor Managed Inventory (VMI) and Collaborative Planning, Forecasting and Replenishment (CPFR), (ii) implementation and examination of information sharing, and (iii) platforms, mechanisms and measurement of information sharing, as summarized in Table 2.1.

Table 2.1 Summary of key themes in information sharing paradigm

Key themes	Key references	New modes/models	Effects
VMI & CPFR	Caridi et al. (2005); Dong et al. (2014a); Sari (2008)	CPFR with intelligent agents; VMI with Consignment Stock agreement	Reduced cost; Reduced inventory; Improved customer service levels; Increased capacity utilization
Implementation and examination of information sharing	Trapero et al. (2012); Kuo et al. (2014); Zhao and Xue (2012)	A consumer data sharing business model	Improved forecast accuracy; Improved sustainability; Improved supply chain coordination
Platforms, mechanisms and measurement of information sharing	Lee and Kumara (2007); Kwon et al. (2007); Ramanathan (2013)	A designed decentralized coordination mechanism; A Multi-agent collaboration system MACE-SCM	Eliminated bullwhip effect; Increased profit; Improved performance for addressing uncertainty; Enhanced forecasts accuracy

2.1.1 VMI and CPFR

A number of studies discuss the theme of Vendor Managed Inventory (VMI) and Collaborative Planning, Forecasting and Replenishment (CPFR). VMI and CPFR are the partnership programs primarily developed to encourage retailers to share information (Sari, 2008) and are one of the most common methods employed in SCC, especially in the area of information sharing. In VMI (developed in the mid-1980s), the customer's inventory and replenishment process are managed by manufacturer or supplier (Ramanathan, 2013).

Most of these studies concentrate on exploring the influences on improved performance by applying VMI under different circumstances, e.g. benefits of VMI to downstream firms (Dong et al., 2014a), effects on manufacturers and retailers of attaching RFID tags at the item level in VMI system (Smerekovsky and Zhang, 2008), benefits of VMI to suppliers and retailers amidst a globally uncertain environment (Lee and Ren, 2011). CPFR, on the other hand, is a relatively new initiative in the area of SCC, issued by the Voluntary Interindustry Commerce Standards (VICS), under which both buyer and seller collaborate by correcting, adjusting, proposing prices and quantities to reach an agreement on a unique forecast, so that the buyer's purchase forecast and the seller's sales forecast coincide (Caridi et al., 2005). Among these studies, Panahifar et al. (2014) highlights the benefits and deficiencies of CPFR while the others, e.g. Caridi et al. (2005) and Dong et al. (2014b) emphasize on the implementation and development of CPFR model for improving SC performance by applying CPFR with intelligent agents or incentive-based contracts. In addition, few studies focus on both VMI and CPFR. Sari (2008), for instance, conducts a simulation study to compare VMI and CPFR indicating that the benefits of CPFR outweigh that of VMI. However the gap between their performances does not rationalize the additional resources required for CPFR under some circumstances. Lehoux et al. (2014) similarly asserts the benefits of CPFR over VMI in the forest industry to show their benefits, including operation costs reduction and better use of production and distribution capacities.

2.1.2 Implementation and examination of information sharing

A number of studies in the information sharing cluster focus on the aspect of implementation and examination of information sharing methods under different conditions, and their corresponding influence on SC or business performance. Inderfurth et al. (2013), for example, highlights implementation of information sharing under asymmetric information to examine its impact on SC performance. Further, various advantages of implementing effective information exchange and data sharing is highlighted in the studies, e.g. improved sustainability in textile and apparel industry by efficiently sharing related information to develop more environmental friendly textile products (Kuo et al., 2014), improved SC coordination through consistent forecasting (Xu et al., 2001), or supplier forecasting performance (Trapero et al., 2012). Other studies concentrate on problems related to forecasting and planning during information sharing, e.g. hindering franchisor and franchisee cooperation (Yan and Wang, 2012).

The majority of studies in this theme addresses mainly vertical information sharing, thus lacking a horizontal information sharing aspect due to the competition among buyers (Karabati and Sayin, 2008). Only two studies highlight horizontal information sharing; Zhang (2006) demonstrates the importance of horizontal information sharing between suppliers on inventory status, while Zhao and Xue (2012) conducts study regarding consumer data sharing and competitive target advertising.

2.1.3 Platforms, mechanisms and measurement of information sharing

Studies on this theme highlight the role of various platforms, mechanisms and measurements of information sharing, e.g. cooperative supply optimizer system (Sepehri and Fayazbakhsh, 2012), trustworthy decentralized coordination mechanism (Lee and Kumara, 2007), cloud service broker model (Demirkan and Goul, 2013), MACE-SCM system (Kwon et al., 2007). Sepehri and Fayazbakhsh (2012)'s system mainly supports information exchange aimed at reducing the total SC costs, while Lee and Kumara (2007)'s design is aimed for dynamic lot-sizing in distribution networks, as an effort to motivate information sharing for eliminating the expensive costs of the bullwhip effect.

The cloud service broker model built in Demirkan and Goul (2013), on the other hand, illustrates the collaborative arrangement in a value network to serve as a trusted interface between enterprise, cloud service providers and other organizations. Kwon et al. (2007) proposes a multi-agent and case-based system MACE-SCM to facilitate information sharing among SC partners in the presence of high uncertainties.

In addition, a few studies also highlight measuring information sharing from various perspectives. For instance, Chituc et al. (2009) analyzes and compares e-business frameworks currently in use, emphasizing their strengths and weaknesses towards information exchange in a collaborative networked environment, while Ramanathan (2013) develops an AHP model to rank available information for exchange in terms of their contributions to improve forecast accuracy.

2.2 **Joint decision making paradigm**

The concept of joint decision making is one of the main issues in managing SC coordination between SC members where all members participate, unlike that in a traditional decision making model where each SC member tries to optimize its own profit without considering other members (Heydari, 2014). This has been examined and demonstrated by many researches to be an effective method influencing SC performance (Biehl et al., 2006). Further, logistics is the most represented stage of SC in studies in this cluster. Three key themes underlie in this cluster as shown in Table 2.2.

Table 2.2: Summary of key themes in joint decision making paradigm

Key themes	**Key references**	**New modes/models**	**Effects**
Logistics and shipment policy	Banerjee (2009); Yildiz et al. (2010); Kreng and Chen	A new model of multiproduct batch with full truckload shipment; A centralized logistics model	Reduced shipment cost; Improved transportation efficiency; Reduced SC cost;

	(2007)	considering round-trip shipment	
Production plan	Glock (2012); Chen (2014); Ullrich (2012)	An integrated production–inventory model; OPCD and OPCI	Reduced total cost; Increased system efficiency; Reduced makespan; Reduced order tardiness; Pareto improvement
Replenishment and inventory strategy	Boza et al. (2014); Wang and Axsater (2013)	A new decision support system (DSS); A model of joint determination of order quantity and reorder point using credit option	Reduced inventory holding costs; Reduced stocks fragmentation; Increased customer service level; Streamlined inventory flow

2.2.1 Logistics and shipment policy

Transportation and shipment problem is always an important issue in SC and business; many studies addressed this theme. A number of the studies in logistics and shipment policy highlight the aspects of collaboration related to transportation and shipment in SCs and businesses hence could be classified under this theme. Most of them address the effect of reduced logistics or shipment cost through various joint decision making policies; e.g. Banerjee (2009) demonstrated a model for improving truckload rates by combining less than truckload quantities of the items jointly into a full load, Yildiz et al. (2010) shows how to consider inbound and outbound transportation arrangements from and to the customers and suppliers to utilize unused capacity in return route, Boros et al. (2008) shows how by removing empty containers accumulated at the domestic port can help in scheduling vessels and container-yard operations with conflicting objectives. In addition, Most models in the research on logistics and shipment policy span over multi-echelon SC network. Kreng and Chen (2007) for instance, studies the joint decisions taken in determining economic order quantity, shipment sizes, and number of shipments made under a three-echelon SC including manufacturer, distribution centre (DC), and retailer, thus resulting in reduction of total cost.

2.2.2 Production planning

Another theme that surfaces out under joint decision making paradigm is on joint decision making in the process of production planning. The systematic review resulted in ten studies that concentrated on various joint decision models in production planning to achieve the reduced production or total SC cost, e.g. an integrated production–inventory model of a three-echelon SC (Sajadieh et al., 2013), two coordinative production mechanisms, overlapping production cycles with immediate delivery (OPCI) and overlapping production cycles with delayed delivery (OPCD) with a single buyer and multiple vendors (Glock, 2012). A number of other studies, in this theme of production planning, however show various other purposes rather than just cost reduction. An algorithm proposed by Chung, Chan and Ip (2011) shows how production scheduling in a multi-factory production environment can minimize order tardiness. To increase system efficiency and simultaneously achieve Pareto improvements, Chen (2014) develops optimal dynamic policies for integrated production and marketing planning under VMI with a consignment contract. Ullrich (2012) addresses a joint SC scheduling problem mainly in production planning to explore the potential of makespan reduction.

2.2.3 Replenishment and inventory strategies

A majority of the research in the joint decision making paradigm is about replenishment and inventory strategies. Studies with focus on joint decision making in inventory strategy development mainly show their effects on inventory performance under different circumstances, e.g. Boza et al. (2014) discusses performance improvement through reallocation of available inventory to satisfy homogenous customer requirements in conditions of lack of homogeneity in products, Viswanathan and Piplani (2001) on the other hand demonstrates cost savings in coordinating SC inventories through the use of common replenishment epochs or time periods, while Boute et al. (2008) highlights the role of decision making in reducing bullwhip effect in upstream order.

Furthermore, joint replenishment decision making is identified as another key aspect through the literature review. The studies mainly highlight the effects on improved performance and reduced cost, e.g. Banerjee et al. (2007) shows the effects on cost minimization by linking the inventories at the different echelons of the chain, or streamlining inventory flow for distribution systems with multiple retailers and stochastic demand (Wang and Axsater, 2013), or increased overall chain profitability by using credit option in determination of order quantity and reorder point (Chaharsooghi and Heydari, 2010), amongst others.

2.3 **Coordinating contract paradigm**

In the systematic review of the literature on SCC, a majority is about coordinating contracts. These studies deal with coordinating contract as the main method of collaboration predominantly in the selling echelon of SCs and demonstrates that through proper contractual designs SC members can collectively obtain higher profits, resulting in a win-win situation, thus achieving better SC coordination and performance (Chung et al., 2014). Out of the few popular contract types focused in coordinating contract paradigm, studies on incentive alignment contract, bonus contract, and compensatory and penalty contract emerge as highlighted in Table 2.3.

Table 2.3: Summary of key themes in the coordinating contract paradigm

Key themes	Key references	New modes/models	Effects
Incentive alignment contract	Palsule-Desai (2013); Hsueh (2014); Leng and Parlar (2009); Peng et al. (2013)	A RS-CSR contract; A royalty payment contract	Improved corporate social responsibility performance; Reduced lead-time; Improved production; Improved profit
Bonus contract	Huang et al. (2011); Chen and Yano (2010); Arcelus et al. (2012); Xing and Liu (2012)	A new weather-linked rebate contract; A contract with price match and selective rebate	Reduced number of returns; Pareto improvement; Improved profit; Increased retailer's order quantity; Increased supply chain efficiency.
Compensatory and penalty contract	Lee et al. (2013); Devangan, Amit, Mehta, Swami & Shanker (2013); Mathur and Shah (2008)	A new quality-compensation contract	Improved SC coordination; Improved profits

2.3.1 Incentive alignment contract

In the research on coordinating contract, about half of the studies found in the review relates to incentive alignment contract. Many processes or activities among SC partners could be regarded for incentive alignment, e.g. revenue sharing (Palsule-Desai 2013, Kunter 2012, Cao 2014, Hsueh 2014), risk sharing (Chen et al., 2014, Inderfurth and Clemens, 2014), cost sharing (Toktas-Palut and Ulengin, 2011, Tsao and Sheen, 2012), profit sharing (Leng and Parlar 2009). These studies mostly discuss the implementation process and examine effects of these types of contracts or of any revised version of them under different circumstances.

The researches on incentive alignment contract mostly focus revenue sharing. Among these Palsule-Desai (2013) develops and analyzes a game theoretic model for revenue-dependent revenue sharing contracts where the actual proportion in which the SC revenue is shared among the players depend on the quantum of revenue generated. A revised revenue sharing contract, consisting of a wholesale price, a revenue sharing rate and non-price marketing effort participation rates on both manufacturer and retailer level, is developed by Kunter (2012) for coordination of a manufacturer–retailer channel. Based on pricing and production decision models, Cao (2014) proposes a revenue sharing contract to coordinate the dual-channel SC with or without demand disruptions. Further, a new revenue sharing contract embedding corporate social responsibility is proposed by Hsueh (2014) for coordinating a two-tier SC.

Considering other types of incentive alignment contracts, Inderfurth and Clemens (2014) examines SC coordination by risk sharing contracts under random production yield and deterministic demand, whilst Leng and Parlar (2009) develops a profit-sharing contract to induce the coordination of a two-echelon SC for subsequent lead-time reduction. Tsao and Sheen (2012) examines the effects of promotion cost sharing policy with the sales learning curve on SC coordination. In some literature, two or even more types of incentive alignment contracts are compared or combined. For instance, Peng et al. (2013) analyzes three contracts of revenue sharing, overproduction risk sharing, and combination of revenue sharing and overproduction risk sharing, and contrasted them with uncoordinated model. Chen et al. (2010) proposes a three-parameter risk and profit sharing contract that coordinates the SC with lead-time consideration and price-dependent demand.

2.3.2 Bonus contract

The second key coordinating contract is bonus contract. Various contract types with certain ‘‘bonus’’ features, such as discounts (Chang, et al. 2010, Ke et al. 2014, Huang et al. 2011) and rebates (Wong, Qi and Leung 2009, Chen and Yano 2010, Arcelus, Kumar and Srinivasan 2012), are discussed among them. Quantity discount contracts formed the unit of analysis in some studies, for instance, Chang et al. (2010) utilizes quantity discount contract to minimize the joint costs of all participants associated with holding costs, ordering costs, and purchasing costs. Huang et al. (2011), on the other hand, introduces a quantity discount contract which specifies a payment to the retailer with an amount exponentially decreasing with the number of returns. Ke et al. (2014) studies the problem of optimal coordination in transportations based on discount contracts from the perspectives of the parties who offer them, rather than of those who take them.

Rebate contract is another main contract type identified in this theme. Most studies examine the effect of rebate contract on SC performance from different perspectives, e.g. the SC coordination performance of a sales rebate contract in the context of a two-echelon SC with a single supplier serving multiple retailers (Wong et al., 2009), improved profit under a new weather-linked rebate contract for a seasonal product with weather-sensitive demand (Chen and Yano, 2010). Rebates could be provided either by suppliers or retailers to end customers. The impact upon the profitability and effectiveness of direct rebates from the manufacturer and from the retailer are compared by Arcelus et al. (2012). Xing and Liu (2012) designs a contract with price match and selective rebate fur the purpose of improving SC efficiency and compared it to wholesale price discount contract.

2.3.3 Compensatory and penalty contract

Most studies discuss the “compensatory” feature in coordinating contracts. For instance, Chen and Bell (2011) highlights buyback contract where the manufacturer agrees to compensate the retailer for unsold product and the returned products from customers. Such buyback contracts are utilized under different conditions, such as when demand faced by a retailer is influenced by the amount of inventory displayed on the retail shelf (Devangan et al., 2013) or when facing uncertain customer returns and refund-dependent demand (Liu et al., 2014). In addition, Lee et al. (2013) proposes a new scheme, the quality-compensation contract, in which the manufacturer compensates the retailer for defective products that are inadvertently sold to consumers, showing how such contracts fully coordinate the SC.

Compared to compensatory contract, the "penalty" feature in coordinating contract is paid less attention by researchers. Gurnani and Gerchak (2007) studies various contracts with penalty features and derived the optimal coordinating penalties under a decentralized setting. Two types of service level-based supply contracts, a flat penalty contract and a unit penalty contract, are compared by Sieke et al. (2012), to provide implications for designing optimal contracts for SC coordination. Mathur and Shah (2008) proposes a price compliance regime for contract where the penalties, in the form of price for non-compliance on quantity, are enforceable on both parties.

2.4 **Resource sharing paradigm**

Resource sharing is the process of leveraging capabilities and assets and investing in capabilities and assets with partners (Cao et al., 2010); and this aspect was captured within this cluster. Adequate and timely allocation and sharing of resources is critical for success of SCC (Samaddar and Kadiyala, 2006). Although resource sharing has been proposed to have positive effect on performance (Alfalla-Luque et al., 2013), there is still a clear lack of research in this area compared to other methods in SCC. Few studies have been done on resource sharing, along two key underlying themes as shown in Table 2.4.

Table 2.4: Summary of key themes in resource sharing paradigm

Key themes	**Key references**	**New modes/models**	**Effects**
Logistics	Kurata (2014); Vilkelis and Jakovlev (2014)	An optimal inventory pooling system; A model integrating different automobile	Increased profits; Increased

resource sharing		manufacturers into a single distribution network	utilization of transportation resources
Production resource sharing	Keskinocak and Savasaneril (2008); Shirodkar and Kempf (2006); Soylu et al. (2006)	A collaborative procurement mechanism; A shared capacity model in collaboration with material suppliers; An integration of energy production systems	Reduced cost; Improved environmental performance

2.4.1 Logistics resource sharing

Resource sharing in logistics is not rare; it is widely practiced in many industries however not adequately researched. Few studies classified under this theme highlighted design and development of new models to examine the effects of resource sharing, e.g. Kurata (2014) developed an optimal inventory pooling system for products whose availability would influence customers' purchasing decisions. Albino et al. (2007) on the other hand built a simulation model to examine the benefits (e.g. upgrading quality and reducing costs) of resource sharing in industrial districts, while a single-manufacturer, multi-retailer inventory consignment model was developed by Yu et al. (2012), not only helping manufacturers generate higher profit, but also coordinating retailers to achieve a higher SC profit. Except for inventory sharing between different manufacturers or suppliers, some studies also focus on resource sharing in transportation, for instance, Vilkelis and Jakovlev (2014) developed a model of integrating finished vehicle output of different automobile manufacturers in a single distribution network to improve productivity and utilization of resources.

2.4.2 Production resource sharing

Production resource sharing is the second theme identified within the resource sharing paradigm. Various resources could be shared in the production process, e.g. material procurement sharing (Keskinocak and Savasaneril, 2008), supplier capacity sharing (Shirodkar and Kempf, 2006), production material sharing (Soylu et al., 2006), production facility sharing (Chen and Chen, 2005), to influence performance of the SC and/or business mainly for cost reduction or improved environmental performance. Keskinocak and Savasaneril (2008) studied collaborative procurement among competing buyers, examined the effects of such collaboration on buyer and supplier profitability, and derived the most beneficial condition for each participant. Shirodkar and Kempf (2006) developed a shared capacity model in collaboration with material suppliers to help procure production materials in the semiconductor industry. An integration of production systems, e.g. inter-company material and productions exchanges, was built by Soylu et al. (2006) among different companies in energy SC to improve their economical and environmental performance. Chen and Chen (2005) formulated a model of sharing a common manufacturing facility and/or a common distribution and transportation network and determined optimal inventory replenishment and production policies.

2.5 **Formulation of the research questions**

From the literature review above, three patterns on the research of supply chain collaboration are identified. These are given and elaborated in the following. Based on the identified patterns, the research directions for subsequent sub-studies are derived and research questions are also formulated.

- Incentive alignment contract is the most common theme addressed in supply chain collaboration research; while resource sharing is the least discussed theme.

The systematic review of the literature in supply chain collaboration shows a domination of studies in coordinating contracts. In the studies of coordinating contract, nearly a half of them dealt with incentive alignment. It is the most addressed theme in research of supply chain collaboration. On the other hand, few studies were classified into resource sharing paradigm, therefore it became the theme least concentrated in research. This pattern can also be reflected in current collaboration in supply chain. Most enterprises are reluctant to sacrifice own benefits (resources) to obtain maximum benefits as a whole. They only collaborate through certain type of coordinating contract, as enterprises do not need to pay extra when signing contract in most cases.

- Financial and efficiency oriented performances are frequently discussed in research of supply chain collaboration while quality and environment oriented performances are less addressed.

The effects on supply chain performance were highlighted in each theme, which are the main contributions of all supply chain collaboration. In general, those performances can be generalized into four aspects, viz. financial oriented performance (e.g. cost, profit), efficiency oriented performance (e.g. lead time, facility utilization), quality oriented performance (e.g. customer satisfaction, rejection/return rate), and environment oriented performance (e.g. sustainability, social responsibility). Financial oriented and efficiency oriented performance are involved in almost every identified theme; while quality oriented and environment oriented performance are less addressed. It is shown that increasing efficiency to get financial advantages is obviously more attractive. Profit is still the most important performance for enterprises although quality and environment are paid more and more attentions in recent years. Previous research shows that these performances play a vital role in evaluating the development of supply chain collaboration models, thus these identified supply chain performances, e.g. efficiency, profit, lead time, customer satisfaction, are utilized for sub-studies in following chapters as evaluation criteria for each developed supply chain collaboration model.

Table 2.5 Supply chain performances mainly addressed in each theme

		Low concentration of studies		High concentration of studies	
		Quality oriented performance	Environment oriented performance	Financial oriented performance	Efficiency oriented performance
Low concentration of studies	Logistics resource sharing			X	X
	Production resource sharing		X	X	
Medium concentration of studies	VMI&CPFR	X		X	X
	Implementation of information sharing		X	X	
	Platforms, mechanisms and measurement of information sharing	X		X	X
	Joint decision in production planning	X		X	X
	Joint decision in logistics and shipment policy			X	X
	Joint decision in replenishment and inventory strategy	X		X	X
High concentration of studies	Incentive alignment contract		X	X	X
	Bonus contract	X		X	X
	Compensatory and penalty contract			X	X
*X means corresponding performance was addressed in studies under this theme based on our literature database					

- Resource sharing is the most promising direction for future research regarding SCC field.

However, the number of studies in each cluster differs greatly, meaning that they received different focus by researchers in this field. Coordinating contract paradigm contributes more than 50% of the studies. On the other hand, resource sharing paradigm is so far least studied in supply chain collaboration context. Considering the rise of sharing economy nowadays, logistics resource sharing and production resource sharing are more promising than other themes to study; they could represent future research direction.

In summary, resource sharing is a salient direction and approach for future research, considering it to be still a less explored in inter-organizational supply chain collaboration. The successful implementation of other identified supply chain collaboration strategies can be also applied in textile industry. The application of these strategies respectively or combinedly has potential to improve supply chain performance in multiple aspects and solve aforementioned issues in demand-driven textile SC and make-to-order textile supply chain model, e.g. long lead time, high cost as discussed in Chapter One. Based upon above points, three research questions are posed, as listed in Table 2.7. The research questions are addressed in Chapter Three, Four and Five respectively.

Table 2.6 Research questions list

	Research question
Chapter Three	RQ 1: What are effects of resource sharing mechanism on garment manufacturing?
Chapter Four	RQ 2: What are effects of application of a combination of identified supply chain collaboration strategies, e.g. information sharing, joint-decision making, resource sharing and profit sharing, on demand-driven textile supply chain?
Chapter Five	RQ 3: What are effects of application of a combination of identified supply chain collaboration strategies, e.g. information sharing, joint-decision making, resource sharing and profit sharing, on make-to-order textile supply chain?

Three sub-studies are conducted to solve the research question with corresponding sub questions respectively in Chapter Three, Four and Five. In each sub-study, a supply chain collaboration model is developed by merging identified supply chain collaboration methods based on this systematic review. Resource sharing is explored and implemented as a main supply chain collaboration strategy in all three models in this research. The sub-study in Chapter Three explores the application of resource sharing strategy on textile supply chain. In Chapter Four and Five, resource sharing was also employed as one of the main collaborative strategies used for developing the supply chain collaboration models. Other identified themes are also refereed as supply chain collaboration strategy applied in this research, e.g. implementation of information sharing in Chapter Four and Chapter Five, joint decision-making in production planning in Chapter Four and Chapter Five, incentive alignment in Chapter Four. Moreover, the four summarized supply chain performance directions are also utilized in the following chapters.

3. Resource sharing mechanism for optimizing garment manufacturing echelon

As concluded in Chapter Two, Resource Sharing (RS) is the most promising direction in Supply Chain Collaboration (SCC). Therefore, the implementation of RS is explored for garment manufacturing echelon in this chapter. The objective of this chapter is mainly to address the first research question (RQ 1: What are effects of resource sharing mechanism on garment manufacturing?) with specific sub- research questions, as follows:

RQ 1-1: What are effects of resource sharing mechanism on garment manufacturing in terms of efficiency, financial aspect and customer satisfaction?

RQ 1-2: What is the optimal RS scenario?

To achieve the objective and answer the questions a simulation-based experiment is done, which are presented in following sections.

Currently, many garment manufacturers apply RS mechanism within organization itself, facilities and operators are shared between different teams for improving performance. There is also a flexible manufacturing strategy (modular manufacturing) in garment manufacturing. Operators are organized into teams and they are cross-trained to handle a variety of operations using an assortment of equipment so that they could be shared for different production (Burns & Bryant 2002). As the facilities and techniques of garment production are more or less same in every garment manufacturer, resource sharing mechanism could be applied across organizations instead of within organization. In recent years, due to the increasing demand of flexibility and customization, garment manufacturers started to pay attention to RS for improving their efficiency. However, it is possible for a manufacturer to suffer negative effects if they apply RS mechanism with a partner, e.g. delay of own production or poor quality. Therefore, it is valuable to explore the effect of RS mechanism before applying it in practice. Besides, an extensive literature search has not located any study dealing with RS in garment manufacturing. Most studies discussing SCC in garment industry concentrated on coordinating contracts (Xiao & Jin 2011) and information sharing (Kuo et al. 2014). Therefore, a research into RS in garment manufacturing is conducted by proposing a RS mechanism and corresponding scenario optimization method.

3.1 **Conceptual model**

In traditional garment production model (Figure 3.1), customers stochastically place different garment production orders to garment manufacturers. Then garment manufacturers would check its recent production plan. If there is sufficient capacity (e.g. specific operators and machines) for received order, then manufacturer accepts it and puts it into system waiting for production. Otherwise, manufacturer would reject order due to limited capacity in a short period of time. Two steps for processing the order before start production in traditional model are summarized as follows:

1) The status of waiting orders in the system is checked to determine whether to accept or reject new received order. If there is any other same type order is waiting for production, the order would be rejected directly, as it means the new arrived order cannot be processed in a short period of time. If there is no same type order currently waiting in the system, then the order is proceed to step 2;

2) The status of resource capacity is checked to determine whether to start production of the order immediately or not. If there is idle resource available currently, then manufacturer starts the production. If there is no idle resource left, then the order

would be kept in the system. The status of resource capacity was checked every ten minutes, once any idle capacity is identified in the system, the waiting order would be proceed to production immediately.

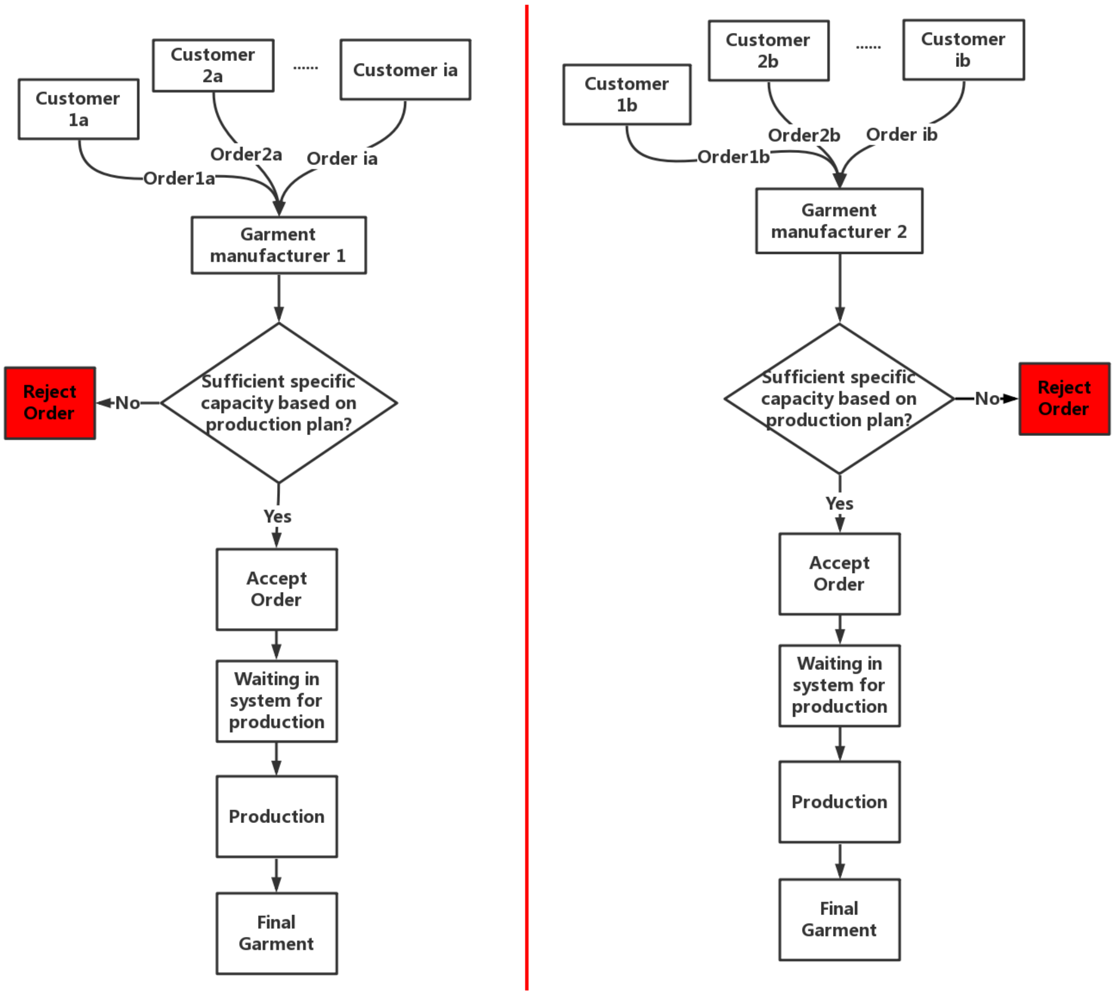


Figure 3.1. Flowchart of traditional garment production mode

Under RS mechanism, manufacturers become collaborative partners with each other. On the premise of ensuring that the production of self-owned orders is not affected, production capacity is shared among partners based on mutual agreement. The flowchart of production model under RS mechanism is illustrated in Figure 3.2. A third step, which is a new decision-making process, was added following the first two steps on the basis of traditional production model.

3) The status of resource capacity of partner is checked to determine whether the order is sent to partner for production. If a manufacturer (M1) has no idle resource currently for production, instead of waiting for idle resource in M1, the resource status of partner (M2) would be checked. The order would be delivered to M2, if idle resource for production is available in M2 and simultaneously no order is waiting for production in M2.

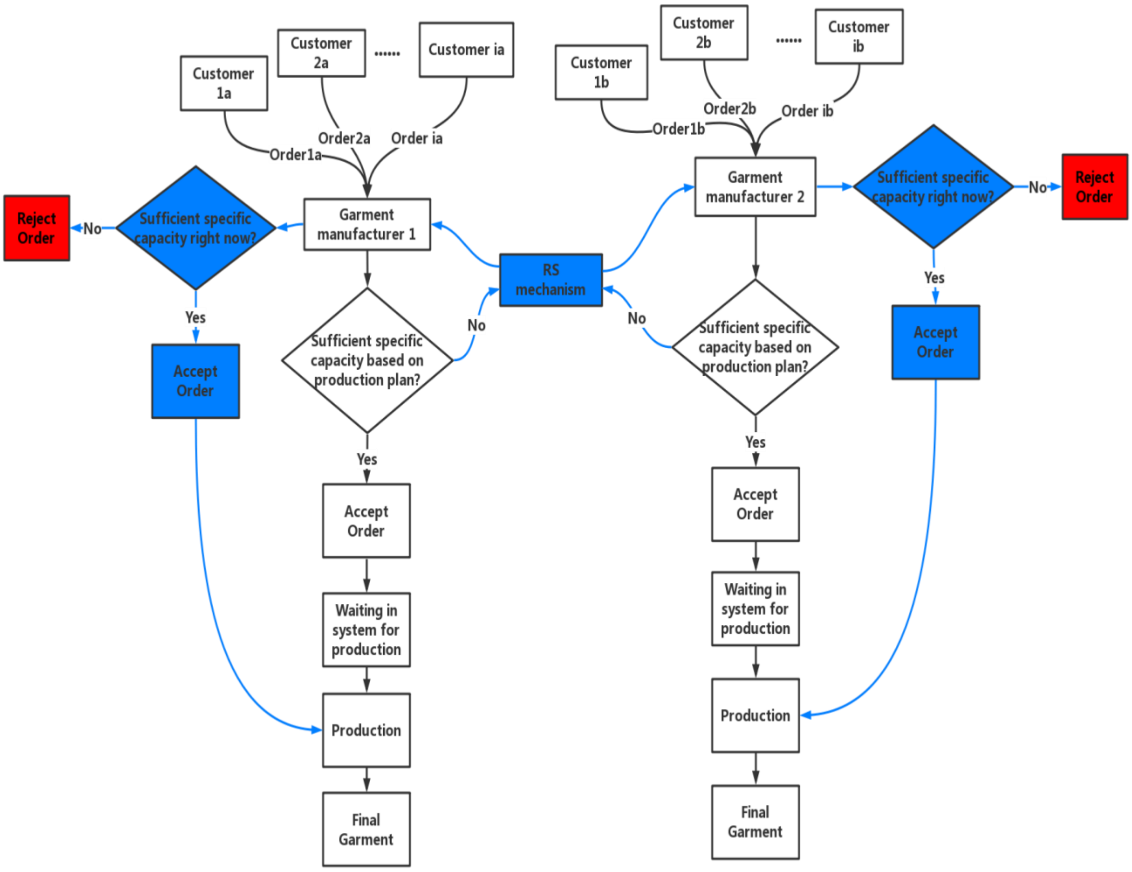


Figure 3.2. Flowchart of production model under RS mechanism

3.2 **Methodology**

3.2.1 Simulation model

There are many parameters in both traditional production scenario and RS scenarios, most of them are stochastic. Also considering the complexity of constraints and stochastic nature of them, the presentation and evaluation of each scenario are hardly solved by traditional analytical methods or mathematical modelling. It is not feasible to run different experiments regarding RS in real-world either. Based on aforementioned reasons, also considering its previous successful applications on research in production (Anglani et al. 2002; Brahmadeep & Thomassey 2014), discrete event simulation (DES) technology was the best option in this sub-study to present traditional garment production scenario and corresponding RS scenarios based on the concepts and assumptions introduced in Section 3.1.1. Discrete-event simulation concerns the modelling of a system as it evolves over time by a representation in which the state variables change instantaneously at separate points in time (Kelton & Law 2000). Experiments were designed and were run in the simulation model to evaluate SC performance of different RS scenarios. SIMIO© (SImulation Modelling framework based on Intelligent Objects) was used as the simulation engine for building simulation model.

Two medium-sized garment manufacturers were simulated. Manufacturer 1 (M1) has 40 units of resources (combination of operators and machines) for garment production while manufacturer 2 (M2) has 50 units. As the main objective of this sub-study is to explore the influence of RS model on SC performance, only the most common production process in garment manufacturing was considered. Some relatively uncommon events, which have little influence on the comparison between traditional scenario and RS scenario, were not included in the simulation model, e.g. machine breakdown and maintenance or special treatment for orders. Therefore, to reduce the complexity of the simulation model, three common assumptions in simulation are shown as follows:

- All process in the simulation model followed a First-In-First-Out principle and a push flow;
- The influence of raw materials supply was ignored;
- Breakdown/failure for each process was ignored.

First-In-First-Out principle is the most common practice in supply chain studies, there is no need to consider other ways, as it is not the objective of this sub-study. Supplies of raw materials are not the objective of this sub-study either, assuming a smooth supply of raw material has no influence on the exploration to the research questions. Breakdowns/failures are uncommon events, it is not necessary to include them in the simulation since they are not likely to have any effect on the simulation results.

In general, the simulation model was divided into two parts: order processing system and garment production flow. The order processing system was developed to process new arrived orders and waiting orders in the model, realizing all logics inside the first two or first three steps before starting production as shown in Section 3.1.1. Three functions were mainly performed within this system: (1) Checking the status of waiting orders in the system and determining whether to accept or reject new arrived order; (2) Checking the status of resource capacity within manufacturer and determining when to start production, and (3) Checking the status of resource capacity of partner and determining whether sending current order to partner for production under RS system.

The garment production flow simulated each step in garment production, starting with order arrival to the manufacturer until complete of garment production. The production process for each type of garment basically followed a linear chain. In garment production, there are many different tasks for each type of garment; however, the technique is similar, and machines remain the same as well. Therefore, operators and machines could be utilized for the same process production of all types of garments in one manufacturer.

3.2.2 Multi-objective evaluation

In SCC, most studies concentrated on the positive or negative effect of collaborative model on several SC performances. The common indicators of SC performance includs efficiency, customer service level and lead time. For this sub-study, five SC performance indicators were selected due to their importance in garment manufacturing and suitability for this sub-study, including *facility utilization*, *lead time*, *productivity*, *order rejection rate* and *profit*. Performance indicators that are not relevant to the research objective, and also hard to measure in the simulation model, were excluded in this experiment, e.g. social responsibility performance and forecast accuracy.

It is hard to compare each scenario with five individual indicators. A scenario may have higher facility utilization and productivity than another scenario; while it has lower profit and longer lead time. Therefore, these indicators have to be merged into a single indicator (KPI) according to the desired objective of the manufacturer so that to evaluate and compare each scenario easily. Analytic Network Process (ANP) was utilized as main approach in the KPI definition. ANP is a well-proven decision making technique developed by Thomas L. Saaty (Saaty 2004) and has been used in SC researches for multiple criteria decision analysis. ANP is a generalization of the Analytic Hierarchy Process (AHP), which is probably the most common multiple criteria decision analysis method, by considering the dependence between the elements of the hierarchy (Saaty 1996). As SC performance indicators in this sub-study are not independent, e.g. increased productivity may lead to shorter lead time, it doesn’t fit one of the assumptions for AHP: the decision criteria are considered to be independent of one another, therefore AHP is not appropriate for this sub-study. ANP can reflect the feedback and interdependent relationships among decision attributes and alternatives; it could provide more accurate result (Agarwal et al. 2006). ANP can also easily quantify qualitative criteria (various checked SC performances in this sub-study), also considering its pairwise comparison nature (comparing different scenarios), it is suitable for this sub-study perfectly. Considering aforementioned reasons (1) multiple criteria decision making; (2) interdependent relationships among checked SC performance indicators; (3) pairwise comparison of each scenario, ANP was applied to generate an overall performance indicator to evaluate an overall SC performance of different scenarios in a comprehensive way.

In this sub-study, the criteria involving profit indicator was excluded for ANP, as it is considered as the most vital factor for manufacturers under most circumstances. Therefore, it was set aside until the overall priority of other SC performance were evaluated based on ANP. The four remaining criteria, viz. facility utilization, lead time, productivity, order rejection rate, were used to evaluate different scenarios. The structure of ANP implemented in this experiment is illustrated in Figure 3.3. Firstly, the influence of each criterion to each candidate scenarios in ANP was defined. As the importance evaluation is subjective to different garment manufacturers, three classical multi-criteria objectives in SC were set with corresponding combinations of importance in this sub-study, viz. (1) time oriented multi-criteria objective (Lead time=8, Productivity=4, Facility utilization=2, Rejection rate=1), efficiency oriented multi-criteria objective (Facility utilization=8, Productivity=4, Lead time=2, Rejection rate=1), and customer oriented multi-criteria objective (Rejection rate=8, Lead time=4, Productivity=2, Facility utilization=1). In order to make each criteria relatively dispersed for three objectives, the scale of importance is set as 2 to have a bigger gap. The weight of each candidate scenario with the respect to each criterion was determined by the ratio of their corresponding output based on simulation experiment. The interdependency relationships were also defined among criteria, viz. facility utilization was related to productivity and lead time; productivity was related to lead time and facility utilization; lead time was related to productivity and facility utilization; order rejection rate was related to productivity and facility utilization. Finally, the overall priority (OP) of each scenario was calculated for three multi-criteria objectives respectively.

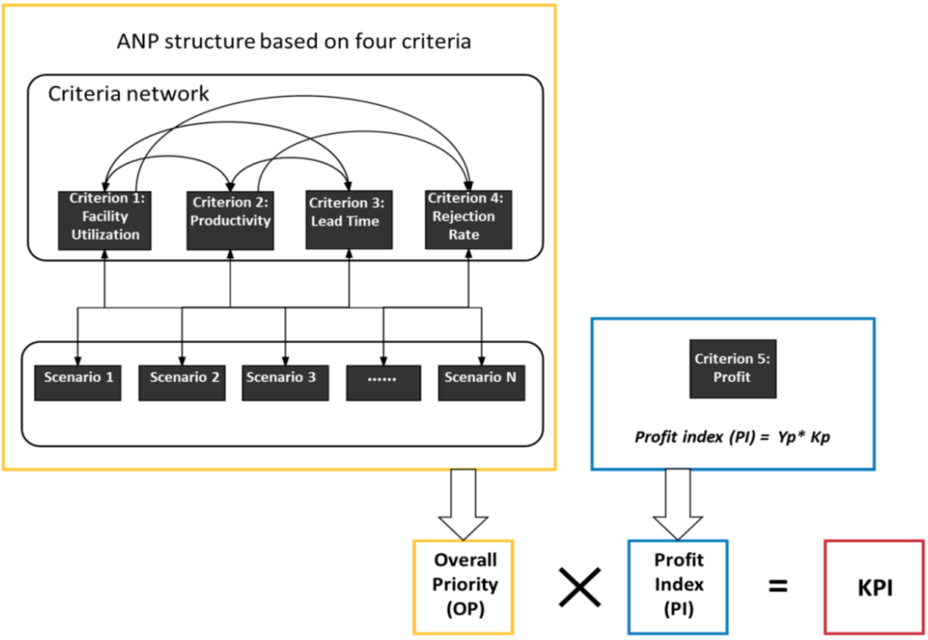


Figure 3.3. The structure of KPI based on extended ANP approach

In the regard of profit indicator, as garment manufacturers can gain higher profit from product with complex process (long unit production time) under most circumstances, a factor to neutralize this situation was defined as follows.

$$K_p = \frac{PT_p}{PT_{min}} \tag{3.1}$$

where PT_p represents mean unit production time of product p and PT_{min} is minimum mean unit production time among all products (10 mins in this case), was introduced to reflect this phenomenon.

Then, a profit index, which is to show the overall profit in each scenario, was designed for this sub-study as follows.

$$PI = \sum_{p}^{n}(Y_p \times K_p) \quad (3.2)$$

where Y_p is the yield of product p obtained by simulation in two manufacturers. For example, in one scenario two manufacturers produced 10000 pieces of daily T-shirt (PT_p=10 mins) and 5000 pieces of daily suit (PT_p=60 mins) in 40 weeks, while in another scenario they produced 8000 T-shirt and 6000 suits, then the PI of first scenario is 10000×10/10+5000×60/10=40000 while PI of second scenario is 8000×10/10+ 6000×60/10 = 44000. Although the total yield of second scenario is smaller than that of the first one, the total profit of second scenario is higher.

Finally, the proposed KPI (Figure 3.3) based on extended ANP approach is calculated as the product of profit index multiplied by final overall priority of ANP, as follows.

$$KPI = OP \times PI \quad (3.3)$$

It reflects both the level of profit and comprehensive SC performance. Manufacturers do not need to sacrifice profit to obtain increase in other SC performance if they apply the scenario selected based on this designed KPI.

3.2.3 Input parameters

The input of garment production flow in this simulation model was garment production order. Therefore, the order in the simulation model was defined at the beginning. Each order indicated the requirements of customer on the production of garment, viz. pattern, colour and style of garment. Hundreds of patterns, colours and styles exist in various garment production. The requirements of production vary from order to order and from customer to customer. Therefore, it is infeasible and also meaningless to define the order in the simulation model on this basis. By interviewing several professionals in garment manufacturing industry and reading relevant literatures, it is found that different requirements of pattern, colour and style are mainly reflected on different unit production time (PT), the process of production more or less remained the same, viz. cutting, sewing and finishing. Therefore, three types of PT were defined in the model, viz. long (e.g. jacket and suit), medium (e.g. trousers and sweat shirt) and short (e.g. T-shirt and polo shirt), to represent different requirements on production. In general, there are two types of production, mass production and small-series production. For fashion-forward or customized garment products, small series production is used; while for daily and basic merchandise, mass production is a preferred option (Keiser & Garner 2012). Two types of production were mainly reflected on order size (OS) and order frequency (OF). OS below 1000 pieces is typically considered as small order size (small series production); while OS above 3000 pieces is considered as large order size (mass production). Manufacturers receive orders of fashion products more frequently than orders of daily products due to the flexible nature of fashion product. Under most circumstances, a medium-sized manufacturer receives orders for fashion products every one or two weeks (high frequent order) while for basic garment products every one or two months (low frequent order). As it is uncommon to order fashion products for mass production or daily basic product for small series production, only the combination of high OF with small OS and low OF with large OS were considered in this model. Finally, orders were classified into six types (O_1-O_6) according to their OF and OS and PT. A classification of orders and corresponding probability distribution used in the simulation model are shown in Table 3.1. O_1, O_3 and O_5 stand for orders of fashion-forward garment products for small series production; while O_2, O_4 and O_6 represent orders of basic daily garment products for mass production. Uniform distribution was used for OF and OS, as all values within presented range have an equal probability of occurring. Concerning PT, triangular distribution was used as the value of PT should be relatively constant for each type of garment and it is recommended in SIMIO for definition of processing time. In this way, the input of simulation model is relatively less complicated but still robust. The simulation results on this basis are also meaningful for a wide range of garment manufacturers.

Table 3.1 Order classification and corresponding probability distribution

Type	**Order Frequency (days)**	**Order Size (pieces)**	**Production Time (minutes)**	**Example Product**
O_1	*High: Un(5,15)*	*Small: Un(50, 1000)*	*Long: Tri(80, 90,100)*	Fashion jacket
O_2	*Low Un(30,50)*	*Large: Un(3000, 10000)*	*Long: Tri(50, 60, 70)*	Daily suit
O_3	*High: Un(5,15)*	*Small: Un(50, 1000)*	*Medium: Tri(35, 40, 45)*	Fashion sweat shirt
O_4	*Low: Un(30,50)*	*Large: Un(3000, 10000)*	*Medium: Tri(25, 30, 35)*	Daily trousers
O_5	*High: Un(5,15)*	*Small: Un(50, 1000)*	*Short: Tri(13, 15, 17)*	Fashion polo shirt
O_6	*Low: Un(30,50)*	*Large: Un(3000, 10000)*	*Short: Tri(8,10, 12)*	Daily T-shirt

*Un = Uniform distribution, Tri = Triangular distribution

3.2.4 Experiment for optimization

As we want to explore whether the application of RS is suitable for the production of different type of product and we also want to find the optimal scenario for applying RS, in this section, the methods to generate new optimized scenarios and experiment design were introduced. Heuristics for optimization and principles for selecting effective scenarios were presented as well.

Table 3.2: Scenario design for the first iteration of experiment

Scenario \ Order Type	O_1	O_2	O_3	O_4	O_5	O_6
T	No	No	No	No	No	No
RSAll	Yes	Yes	Yes	Yes	Yes	Yes
RS1	Yes	No	No	No	No	No
RS2	No	Yes	No	No	No	No
RS3	No	No	Yes	No	No	No
RS4	No	No	No	Yes	No	No
RS5	No	No	No	No	Yes	No
RS6	No	No	No	No	No	Yes

Scenario “T” stood for the traditional production scenario (without RS) in garment manufacturing, which played a benchmark role in the experiment. In scenario “RSAll”, RS was applied to the production of all types of orders. Scenario “RSx”, where *x* is a combination of {1, 2, 3, 4, 5, 6}, means that RS was only applied on the production of order types O_x (defined in Table 3.1). For example, scenario “RS246” means the scenario where RS was applied on the production of O_2, O_4 and O_6. In the first iteration of experiment (Table 3.2), the scenarios “T”, “RSAll” and the six scenarios where RS was applied to only one order type were designed for the simulation model. Independent sample t-Test with a confidence interval (CI) = 95% was used to determine whether there is a significant difference between RS scenarios and scenario “T” (traditional production scenario) on certain performance indicators. The output of scenario “RSAll” was compared to scenario “T” to demonstrate whether RS model is overall beneficial or not. Scenario “RS1” to “RS6” were designed to show that applying RS in production of which type of order is effective. New optimized scenarios and next iteration of experiment would be generated based on the results of it.

As there are in total of 2^X (where *X* stands for the number of order type) possible scenarios, it is not efficient to run all the scenarios in the experiment since *X* could potentially become very high in some cases (for instance, there are 64 scenarios in this simplified case with X=6). It is essential to effectively generate scenarios to reduce the number of experiments. Thus, a heuristic for generating optimized scenarios for new iteration of experiment is designed. To explain it, two sets were introduced: set A is a set of $1 \times X$ binary matrix A_n ($0 \leq n \leq 2^X-1$) and set B is a set of $1 \times Y$ binary matrix B_m ($0 \leq m \leq 2^Y-1$, where Y stands for the number of performance indicator). Element a_x and b_y respectively represent elements in matrix A_n and B_m, where "x" represents the order type, "y" represents the performance indicator (1: lead time, 2: facility utilization, 3: rejection rate, 4: productivity and 5: profit index). a_x and b_y are all binary numbers. $a_x = 1$ indicates that RS is applied on x order type in production, otherwise $a_x = 0$. $b_y = 1$ means that there is a significant increase (based on independent sample t-Test) in y performance indicator, otherwise 0. Each A_n represents a scenario in simulation experiment, and a corresponding B_m is obtained after simulation run of A_n. Initially, A_0 = [0, 0, 0, 0, 0, 0] and B_0 = [0, 0, 0, 0, 0]. The generation of scenarios for next iteration of experiment was based on the results of previous iteration of experiment. As the proposed *KPI* consists of two parts, *OP* and *PI*, it is expected to generate new scenarios that could obtain significant increase in both of them. The heuristic for generating scenarios for new iteration of experiment is illustrated in Figure 3.4. For instance, in the first iteration of experiment, eight scenarios are run as explained above (Table 3.2) which are "T" (A_0 = [0,0,0,0,0,0]), "RSAll" (A_{63} = [1,1,1,1,1,1]), "RS1" (A_1 = [1, 0, 0, 0, 0, 0]), "RS2" (A_2 = [0, 1, 0, 0, 0, 0]), "RS3" (A_3 = [0, 0, 1, 0, 0, 0]), RS4 (A_4 = [0, 0, 0, 1, 0, 0]), "RS5" (A_5 = [0, 0, 0, 0, 1, 0]) and "RS6" (A_6 = [0, 0, 0, 0, 0, 1]). As mentioned previously, the purpose of the scenario "RSAll" is to demonstrate whether RS is overall beneficial or not. By comparing the output of remaining six RS scenarios to scenario "T", six corresponding output matrix B_m were obtained (B_1 = [1, 0, 1, 0, 0], B_2 = [0, 0, 0, 0, 0], B_3 = [0, 1, 0, 0, 1], B_4 = [1, 0, 1, 0, 0], B_5 = [0, 0, 1, 0, 0], B_6 = [1, 1, 1, 0, 1]). The $b_{1,5}$ of B_1 to B_6 were checked initially, only B_3 and B_6 had $b_{1,5}$ = 1 which means "RS3" and "RS6" had significant increase in profit index, therefore matrix A_3 and A_6 were stored in set P. Scenario "RS1", "RS3", "RS4", "RS5" and "RS6" respectively has significant increase in other performance indicators (facility utilization, lead time, productivity and order rejection rate); therefore A_1, A_3, A_4, A_5 and A_6 were stored in set Q. To generate new scenarios, new set of $\{A_n\}$were calculated based on simply combining in pairs any matrix in P and any matrix in Q. Therefore, scenario "RS13" (A_7 = [1,0,1,0,0,0]), "RS34" (A_8 = [0,0,1,1,0,0]), "RS35" (A_9 = [0,0,1,0,1,0]), "RS16" (A_{10} = [1,0,0,0,0,1]), "RS46" (A_{11} = [0,0,0,1,0,1]), "RS56" (A_{12} = [0,0,0,0,1,1]) and "RS36" (A_{13} = [0,0,1,0,0,1]) were obtained for second iteration of experiment. Same principles were applied to following iterations of experiments until no more new scenarios could be generated.

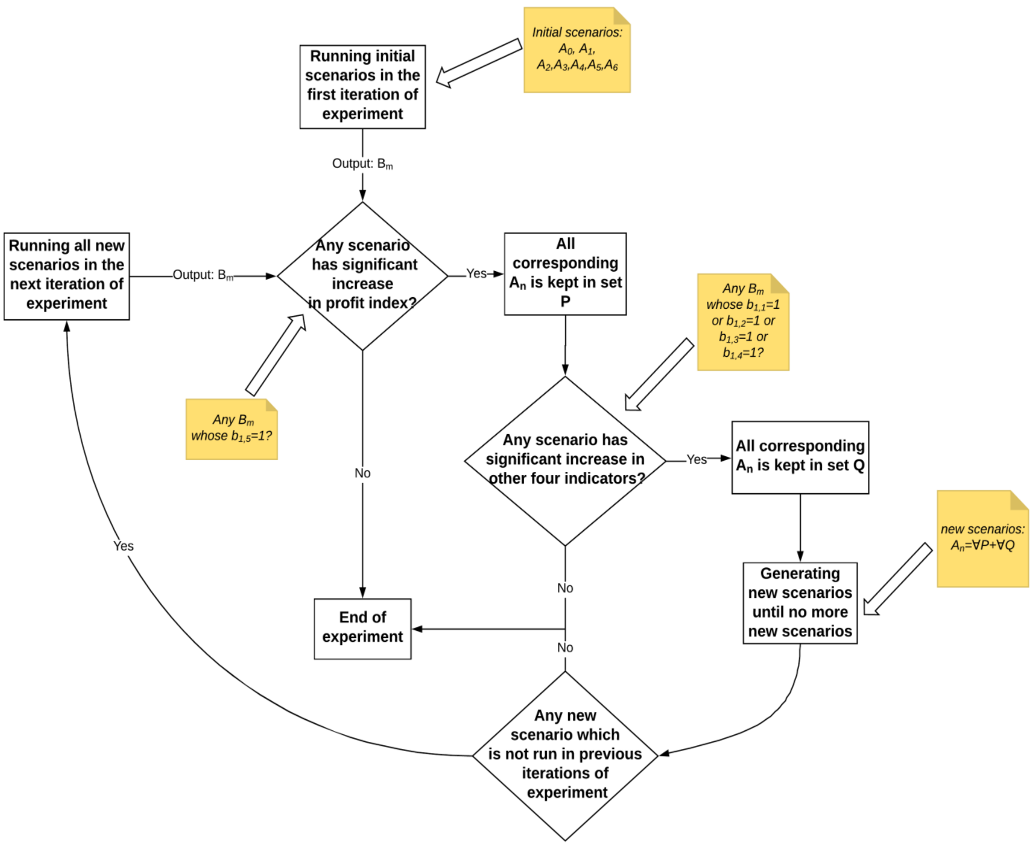


Figure 3.4. Heuristic for generating optimized scenarios for simulation experiment

Finally, for the three defined objectives in this sub-study, only scenarios which have significant increase in two most important performance indicators of each objective (e.g. lead time and productivity for time oriented objective) and simultaneously have significant increase in profit index were considered as candidates of the optimized scenario. The KPI of them were calculated respectively and the scenario with highest value becomes the final optimal scenario.

3.3 **Results and discussion**

In the simulation experiment, each scenario was run for a duration of 40 weeks with 50 replications respectively. A standard working schedule of five days per week and eight hours per day was employed.

In the traditional production scenario (scenario T), the facility utilization is 87.9% and the productivity reaches 1079.07 pieces/day of the two manufacturers. These two measurements fit the medium to high level of a medium-sized garment manufacturer in Europe. Moreover, the simulation model was traced and debugged step by step while building the simulation model for traditional production scenario, also considering it is strictly developed based on each process of conceptual model introduced in Section 3.1.1, therefore these results demonstrate that the simulation model can be considered as realistic under the assumptions and in any cases the scenario T is relevant for comparison with a RS scenario.

The outputs of all scenarios generated by the heuristic were compared to scenario while independent sample t-Test was conducted to show whether there is significant difference in each comparison. For example, in scenario RS16, the mean facility utilization among 50 replications is 90.8%, while in scenario T, it is 87.9%. There is a 3.27% increase in terms of this performance indicator. The difference between these two values is significant based on the t-test result (t (98) = -2.713, sig. = 0.008). The t-test results of other checked performance indicators between these two scenarios are illustrated in Table 3.3. Same methods were applied to all other comparisons. According to the heuristics introduced in Section 3.2.3, eventually, in total of 25 scenarios (8 scenarios in initial iteration of experiment and 17 new generated scenarios) were generated and four iterations of experiments were conducted (Table 3.4). Scenarios met the selection criteria for optimized candidate scenarios of each objective were then selected among all 25, as shown in Table 3.5. Seven candidate scenarios respectively were obtained for time oriented objective and efficiency oriented objective; while fourteen candidate scenarios were suitable for customer oriented objective. Corresponding OP and KPI were calculated. KPI of each candidate scenario for three different objectives is illustrated in Figure 3.5.

Table 3.3 Independent t-test results between scenario RS16 and T

	t value	**Degrees of freedom**	**Significance (2-tailed)**	**Significant different or not**
Lead Time	*3.979*	*98*	*0.000*	*Yes*
Facility Utilization	*-2.713*	*98*	*0.008*	*Yes*
Rejection Rate	*3.801*	*98*	*0.000*	*Yes*
Productivity	*-1.249*	*98*	*0.215*	*No*
Profit Index	*-2.712*	*98*	*0.008*	*Yes*

Table 3.4: Significant effect based on Independent sample t-test in (a) first iteration, (b) second iteration, (c) third iteration and (d) fourth iteration of experiment

(a)						
Performance indicators	**Scenario RS1**	**Scenario RS2**	**Scenario RS3**	**Scenario RS4**	**Scenario RS5**	**Scenario RS6**
Lead Time	*Y**	*N**	*N*	*Y*	*N*	*Y*
Facility Utilization	*N*	*N*	*Y*	*N*	*N*	*Y*
Rejection Rate	*Y*	*N*	*N*	*Y*	*Y*	*Y*
Productivity	*N*	*N*	*N*	*N*	*N*	*N*
Profit Index	*N*	*N*	*Y*	*N*	*N*	*Y*

*Y: Significant difference compared to traditional scenario; N: No significant difference compared to traditional scenario (the same below)

(b)							
Performance indicators	**Scenario RS13**	**Scenario RS34**	**Scenario RS35**	**Scenario RS16**	**Scenario RS46**	**Scenario RS56**	**Scenario RS36**
Lead Time	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*
Facility	*N*	*N*	*N*	*Y*	*Y*	*N*	*N*

Utilization							
Rejection Rate	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*
Productivity	*N*	*N*	*N*	*N*	*N*	*N*	*N*
Profit Index	*N*	*N*	*N*	*Y*	*Y*	*N*	*N*

(c)								
Performance indicators	**Scenario RS136**	**Scenario RS1346**	**Scenario RS1356**	**Scenario RS146**	**Scenario RS156**	**Scenario RS346**	**Scenario RS3456**	**Scenario RS456**
Lead Time	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*
Facility Utilization	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*
Rejection Rate	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*
Productivity	*Y*	*N*	*Y*	*N*	*Y*	*N*	*Y*	*Y*
Profit Index	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*

(d)		
Performance indicators	**Scenario RS1456**	**Scenario RS13456**
Lead Time	*Y*	*Y*
Facility Utilization	*Y*	*Y*
Rejection Rate	*Y*	*Y*
Productivity	*N*	*Y*
Profit Index	*Y*	*Y*

Table 3.5 Candidates of optimized scenario for each objective

Objectives	**Candidate scenarios**
Time oriented	*RS136, RS1356, RS156, RS3456, RS456, RS13456, RSAll*
Efficiency oriented	*RS136, RS1356, RS156, RS3456, RS456, RS13456, RSAll*
Customer oriented	*RS6, RS16, RS46, RS136, RS1346, RS1356, RS146, RS156, RS346, RS3456, RS456, RS1456, RS13456, RSAll*

Based on the result of simulation on traditional production scenario, facility utilization reached almost 90%, which is already a high standard in manufacturing. It seems that there is not much potential in the rest 10% capacity for significant improvement in SC performance. However, results based on simulation experiments of RS contradicted this assumption. Garment manufacturers can really get great benefits by applying RS in production with their partners. Remarkable improvements in lead time and order rejection rate were achieved. In traditional scenario, mean lead time for one order was around 16 days and mean order rejection rate was around 10%, while the best RS scenario can shorten lead time to 10.78 days and can reduce the rejection rate to 2.76%, which are around 50% and 240% improvement respectively. An increase in facility utilization (max.

4.429%) was obtained as well even though it already locates on a high level in traditional scenario. A maximum 3.152% increase in productivity and a maximum 4.429% increase in profit index were got by applying RS in production. As no additional facilities or operators are needed for manufacturers to apply RS introduced in this sub-study, no explicit additional cost is needed in general. Considering the improvements in every checked SC performance, RS is a promising business model for garment manufacturing. It is recommended for manufacturers to find a suitable partner implementing RS together to achieve more benefits as a whole.

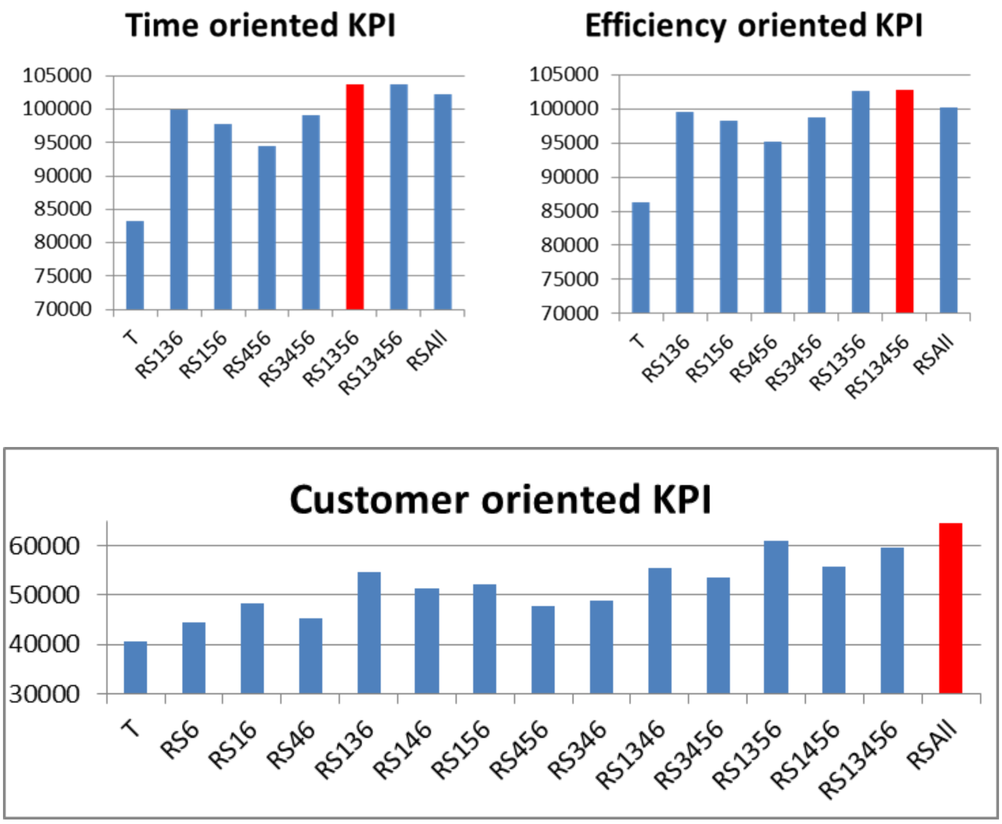


Figure 3.5. KPI of each candidate scenario for three different objectives

According to Figure 3.5, several interesting patterns were found as well. Scenario with highest KPI was different for three multi-criteria objectives, that is to say the configuration of optimized RS scenario for garment manufacturers depended on purposes: higher efficiency, shorter lead time or higher customer satisfaction. In fact, top three scenarios with highest KPI remain the same for each objective, viz. RSAll, RS1356, and RS13456. It is shown that RS can bring synthesized improvement in SC performances, not only one or two of them. It is also found that, in general, the more types of orders on which RS is applied, the higher KPI is obtained in all three objectives. Therefore, manufacturers should be opener to collaboration with proper partner so that to achieve more benefits.

All candidate scenarios include RS for production of O_6 while most candidate scenarios include RS for production of O_3. At the same time, scenario RS3 and RS6 are only two scenarios which applies RS on singe type of order and has significant increase in profit and simultaneously in at least one of other SC performances. If manufacturer is reluctant to apply RS for production of all or multiple types of orders, RS on order for mass production of garment product with less complexity (e.g. T-shirt) or order for small series production of garment with medium unit production time (e.g. trousers) are recommended options. It could be a starting point for manufacturers to try RS in real production.

3.4 **Conclusions**

This part of the research aims to answer the research question that whether RS mechanism is beneficial for garment manufacturer in terms of various SC performance and what the optimal RS scenario is. A simulation-based experiment was set up to answer this question, which resulted in three distinct conclusions as follows:

- In general, RS mechanism can bring comprehensive improvement in garment manufacturing for individual garment manufacturers and whole garment manufacturing cluster. The more types of orders on which RS is applied, the higher

KPI is obtained. Therefore, manufacturers should be opener to collaboration with proper partner so that to achieve more benefits.

- Scenario with highest KPI was different for each multi-criteria objective, that is to say, the configuration of optimized RS scenario for garment manufacturers depended on purposes: higher efficiency, shorter lead time or higher customer satisfaction.
- If manufacturer is reluctant to apply RS for production of all or multiple types of orders, RS on order for mass production of garment product with less complexity (e.g. T-shirt) or order for small series production of garment with medium unit production time (e.g. trousers) are recommended options. It could be a starting point for manufacturers to try RS in real production.

Chapter Two concludes resource sharing as the most salient SCC strategy and research direction in SCC. Therefore, this chapter proposes a novel RS mechanism for garment manufacturing. The simulation experiment presents the benefits of the application of RS. Therefore, it could be useful to extend the proposed RS mechanism and its application on the whole textile SC. The combination of RS mechanism and other identified SCC strategies could be also beneficial for textile SC, especially for the existing textile SC models (demand driven model and make-to-order model). They have been done and these sub-studies are presented in the following chapters.

4. Central order processing system for optimizing demand-driven textile supply chains

In the previous chapter, Supply Chain Collaboration (SCC) strategy was applied only on one echelon in the textile supply chain (SC), the benefit of collaboration was also demonstrated. In this chapter, the implementation of SCC strategy is expanded to the whole textile SC. A Central Order Processing System (COPS) is proposed to realize SCC and to optimize textile SC. COPS combines both vertical and horizontal collaborations in the new collaborative model of the demand-driven textile SC, merging the resource sharing mechanism discussed before and other SCC strategies identified in the literature review regarding SCC. The main purpose is to optimize current demand-driven textile SC through a top-down SCC strategy, so that to better realize demanding features in future textile industry. This sub-study addresses the second research questions (RQ 2: What are effects of application of a combination of identified supply chain collaboration strategies, e.g. information sharing, joint-decision making, resource sharing and profit sharing, on demand-driven textile supply chain?) with three specific sub- research questions as follows.

RQ 2-1: What advantages are brought to the textile supply chain through COPS?

RQ 2-2: If COPS is applied under high workload condition or low workload condition, what is the difference in terms of supply chain performance?

RQ 2-3: If COPS is applied in one SC echelon, what is the difference in terms of SC performance?

This will be explored based on a simulation-based experiment. By using discrete-event simulation technology, a four-echelon textile SC centred on a COPS is compared to a traditional demand-driven textile SC, so as to see whether the whole SC can obtain significant performance improvement by applying this model. A large set of real data extracted from a French garment company is utilized for building the simulation model. When COPS cannot be applied on all echelons of a demand-driven textile SC, the COPS is applied into different SC echelons respectively in simulation experiment to check which echelon needs such system most. In fashion industry, there are always several fashion seasons (Spring/Summer and Fall/Winter) at specific time per year, leading to peaking season and idle season for textile/garment production (Keiser & Garner 2012), which has significant influence on production and distribution strategy of suppliers. Therefore, several scenarios are also designed in simulation experiments to check whether the COPS has same influence on SCs in different seasons, and under what condition the COPS performs best.

4.1 **Central Order Processing System (COPS)**

As elaborated previously (Chapter 1), to meet the trend of mass customization, demand-driven model has been developed and could become a solution for textile SC. In the example shown in Figure 4.1, in a traditional demand-driven textile SC model, a garment retailer places a demand of garment with small order size to a garment manufacturer; the garment manufacturer calculates material (dyed fabric) it needed for the production based on the quantity and requirement of the demand, sending corresponding order to its dyeing supplier. The dyeing workshop then estimates the quantity of fabrics needed and sends another order for fabric production to its fabric supplier. It can overcome many drawbacks in old forecast-based SC model (high inventory cost, low forecast accuracy (Mendes et al. 2016)). However, it still has several apparent defects, such as long lead-time, higher cost, unsmooth production flow and long delay between two echelons in the SC. The highest difference between the traditional SC and the new collaborative model is the information flow (Figure 4.2). Instead of companies, COPS is responsible for order receptions, generation, and distribution.

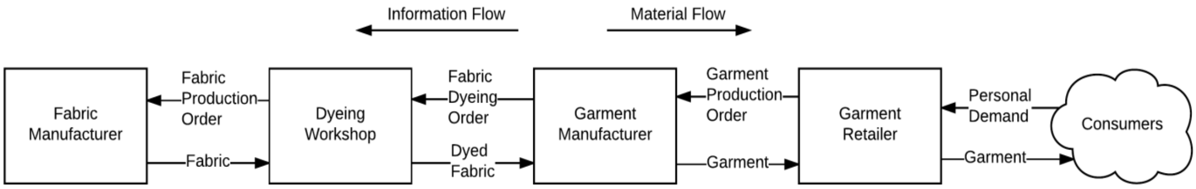


Figure 4.1 Information flow and material flow of demand-driven textile supply chains

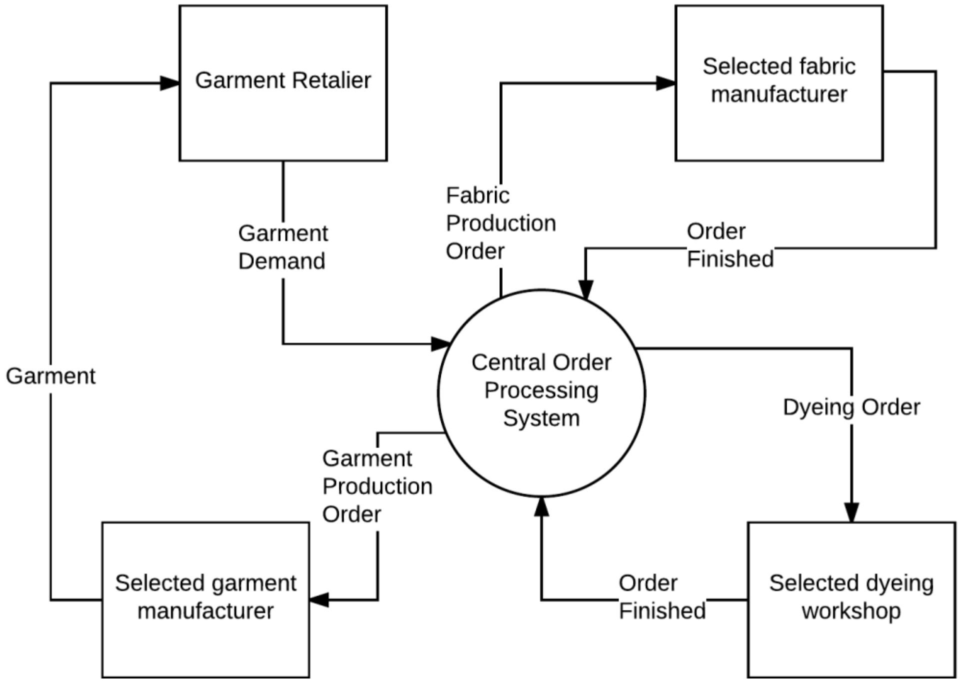


Figure 4.2. Information flow of new collaborative model

The COPS enables to create flexible SCs with various relations between different partners. Instead of a fixed one-to-one relationship between suppliers from different echelons in a classical single SC, collaborative relationships between suppliers can be dynamically changing in the new collaborative model. All suppliers connected to the COPS form an organization or a cluster; they all are potential collaborative partners, vertically and horizontally. The COPS is a third-party, playing the "brain" role in this organization, namely analyzing received data from its members and determining the distribution of resources objectively. Resources are shared among suppliers from the same SC echelon, so that orders could be delivered to any supplier in next SC echelon. Information of each supplier, e.g. production capacity, order status, is shared to the system. The COPS distributes each order based on the predefined criteria from an overall perspective, which is a way of joint decision making. In general, the COPS consists of three components: 1) order reception and generator, 2) order classifier and 3) order distributor, to realize aforementioned functions.

4.1.1. Order reception and generator

In a traditional textile SC model, retailers send orders directly to garment manufacturers. In the new model, the COPS is responsible for receiving all orders from garment retailers. They are called original orders in this chapter. The data of these original orders, (e.g. order size, order type) are stored in the COPS. They are analyzed by the system so as to estimate the demand of raw materials (fabrics, dyes, yarns …) for production in each SC echelon based on an internal database, whose data are shared by suppliers. A general example of the database is shown in Table 4.1. Then the COPS would generate the first sub-order corresponding to its original order and it is put in a queue, waiting for further classification and distribution in the following steps.

Table 4.1: A general example of the database in the COPS order generator*

Order	Fabric Type	Fabric Quantity	Cutting Pattern Length	Dyeing Batch Quantity
O_{nm}	F_n	$Q_{nm} \times FL_m$	$Q_{nm} \times CL_m$	$\lceil Q_{nm} \times FL_m\ W_m \times D_m / DC_m \rceil$

*Notations:

O_{nm} is the order of product m from the retailer in supply chain n;

Q_{nm} is the quantity of order O_{nm};

F_m is the fabric for product m in fabric manufacturer;

FL_m is the length of fabric needed per product *m* for production in fabric manufacturer;
CL_m is the cutting pattern length per product m for production in the garment manufacturer;
DC_m is the dyeing machine capacity per batch for product *m* in the dyeing workshop;
D_m is the density of fabric for product *m*;
W_m is the width of fabric for product *m*;

Once a supplier completes a sub-order, the COPS is informed and generates another sub-order for production in next SC echelon. This sub-order is also stored in the system and waiting for classification and distribution in following steps of the COPS.

4.1.2. Order classifier

In textile SCs, every company has one or multiple collaborative suppliers who produces and transports raw materials. If one company has multiple suppliers, it usually classifies them into different priorities. Demand for raw materials is first sent to the supplier with the highest priority. If the supplier with the highest priority cannot accept this order due to the insufficient capacity or raw materials or other reasons, the company would turn to the supplier with the second highest priority. The company put their own suppliers on top priorities due to their previous performance in the past collaborative experience.

The priority classification concept is introduced to the COPS as one of predefined criteria for supplier selection. Although a dynamic collaborative environment is created in the new model, it is beneficial for companies, e.g. easy communication and mutual trust building, to have relatively stable collaboration with fixed suppliers under most circumstances. In traditional model, there are many SCs, named as supply chain 1 (SC1), supply chain 2 (SC2), supply chain 3 (SC3),…, supply chain N (SCN). It is assumed that there is no overlap of suppliers between each single SC. Each company has a fixed and unique collaborative supplier in each SC. Those suppliers naturally become suppliers with the highest priority for each other in the new collaborative model. Then, other priority suppliers are assigned to each company based on predefined criteria, e.g. distance between two companies or familiarity between two companies. One supplier could be a first priority supplier to one company, and simultaneously be a second, third,…, nth priority supplier to another company.

As RS is applied in the COPS, facility and human resource are shared among suppliers, so that orders could be delivered to any supplier in the same SC echelon. Therefore, according to the priority classification of suppliers, those new generated sub-orders are also classified into different priorities to each company in next SC echelon. Same as priority classification of suppliers, an order is simultaneously classified into different priority queues to different company in next SC echelon. Considering the reality in garment industry, it is unfeasible to interrupt undergoing production; the concept of non-preemptive priority queue is implemented for the order queue in front of each company in next SC echelon. Priority queue is a concept in queuing theory or computer science field, it has many applications in different field, e.g. inventory control of perishable goods (Deniz et al. 2010), medical resource distribution (Sharif et al. 2014), call centres problem (Brandt & Brandt 1999) and wireless body network (Gündoğdu & Çalhan 2016). In a priority queue, each element is ordered by its associated priority (Rönngren & Ayani 1997), elements with higher priority were served first. In a non-preemptive priority queue, if an element with higher priority arrives to the queue, it should wait until the service of element being served is completed. Many research discussed non-preemptive priority queues (Kao & Wilson 1999; Williams 1980; Takagi 2016). In this sub-study, the new collaborative model could be regarded as a multi-echelons multi-queues non-preemptive priority queue system, which is a very difficult and complex problem in modelling and is less discussed in previous research.

In the model, the orders in the same priority queue follow a first-come-first-serve principle. The classification of orders into different priority queues is processed in the COPS order classifier, as illustrated in Figure 4.3. In this example, the orders for a company in supply chain K (SCK) are classified. The sub-orders generated in SCK are classified into first priority order queue; the sub-orders generated in other SCs are classified into corresponding priority order queues. Every time one or several new sub-orders are generated in COPS order generator, COPS classifier would classify corresponding orders for each company in next SC echelon.

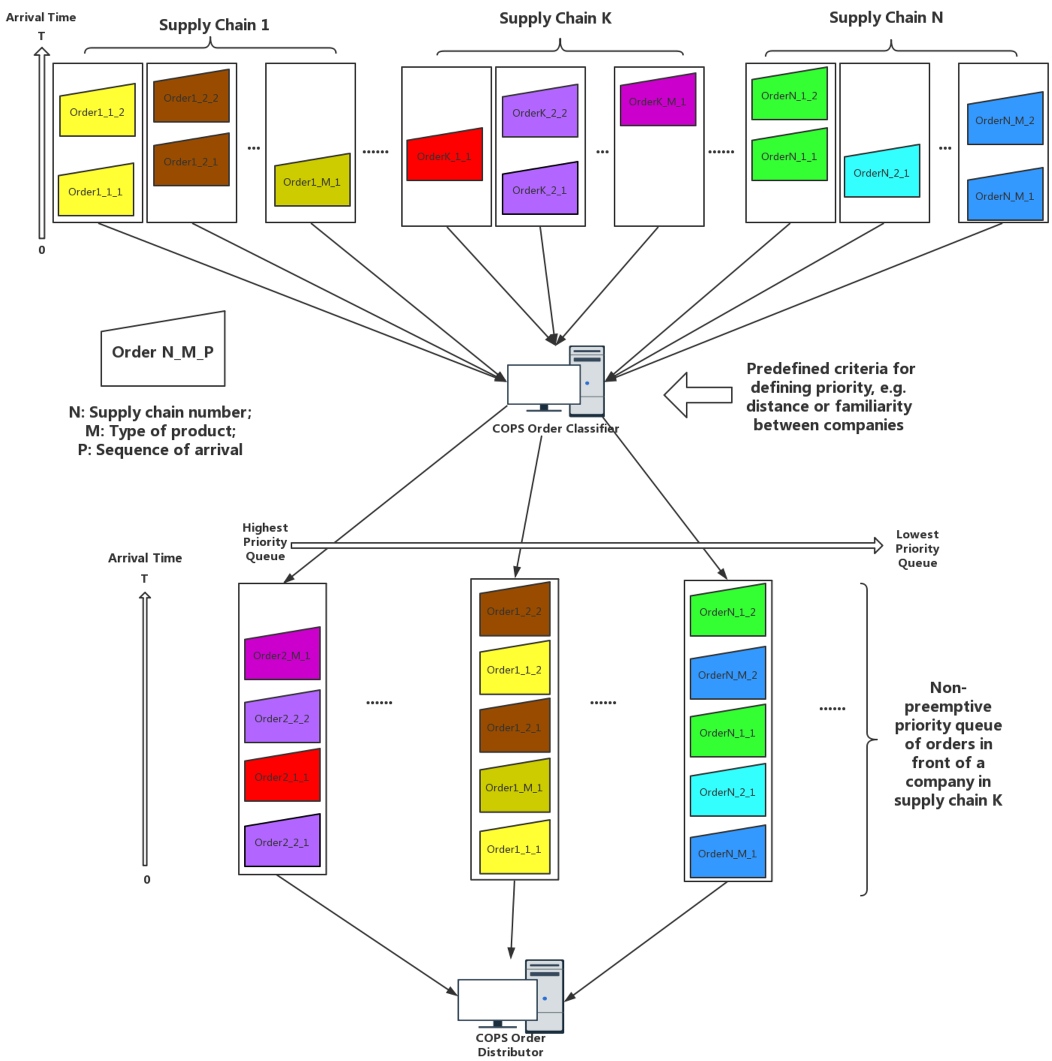


Figure 4.3. The process of order classifying for a company in supply chain K

4.1.3. Order distributor

After orders are classified into different priority queues, they are distributed to different suppliers in next SC echelon based on RS strategy and priority criteria. This process is occurred in the COPS order distributor. Production capacity status of all suppliers in each echelon of SC for different types of products is updated in the system. As introduced in Section 4.1.2, each order is assigned different priorities in front of each company in next SC echelon respectively and vice versa. Each company in next SC echelon has different priorities to each order the other way around. The process of order distribution for an order which has three potential suppliers was illustrated in Figure 4.4. For each order waiting in the queue, the system continually checks for idle capacity in potential suppliers according to their respective order priority defined above and send corresponding order to selected supplier.

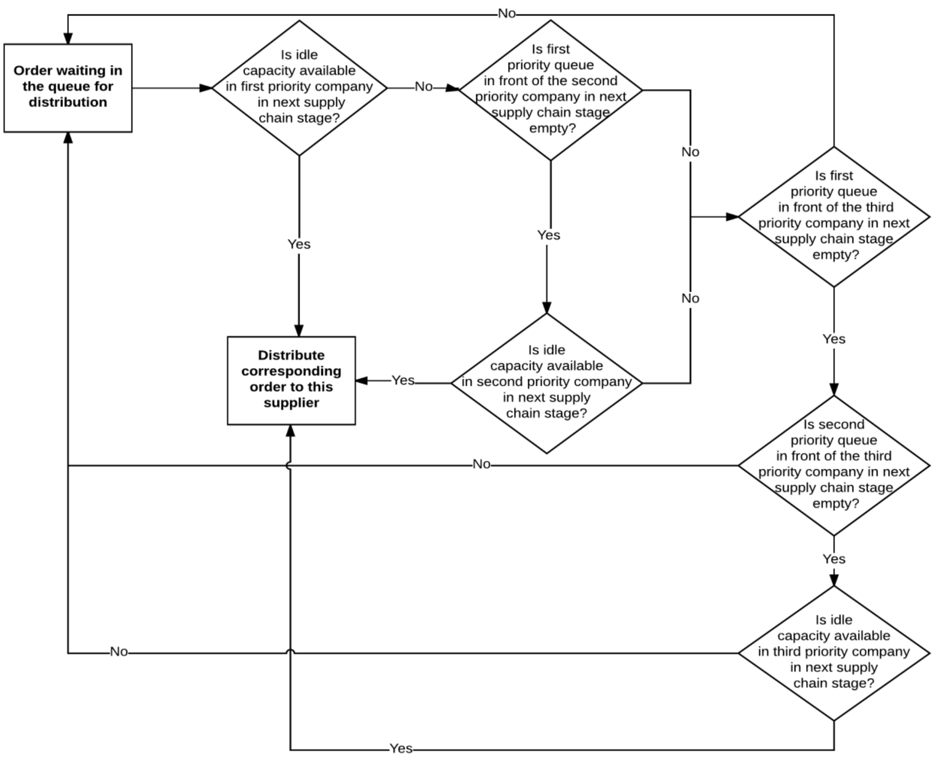


Figure 4.4. Order distribution flowchart

Another process happened in order distributor is the profit sharing mechanism. As suppliers are always reluctant to share their orders to their competitors in most cases, to stimulate them to share orders, a ratio (R) of profits for shared orders obtained in another company is paid for original order holder (first priority supplier). In this case, company holding the original order can get profits by sharing their orders to other companies under this mechanism. They would be more willing to accept the new collaborative model.

4.2. Methodology

4.2.1. Discrete-event simulation modelling

In this sub-study, SImulation Modelling framework based on Intelligent Objects (SIMIO) was utilized as the simulation engine for building the simulation model. A simulation model was built for traditional SC model initially. Then COPS was developed in the simulation model. As introduced in Section 4.1, three main functions were realized in the COPS. They were respectively set and programmed in the simulation model.

1) The COPS order reception and generator:

To generate sub-orders, an internal database was required to estimate quantity and type of raw material for production in each SC echelon, as shown in Table 4.1. In the simulation model, several data tables were created for dress, trousers and jacket respectively. While running the simulation, each table was referenced for corresponding product at suitable trigger point. A summary of database in this simulation model is shown in Table 4.2.

Table 4.2: Raw materials quantity and type

	Dress (poplin)	**Trousers (denim)**	**Jacket (polyester)**
Fabric Length	*Uniform(1.2, 3) m/piece*	*Uniform(1, 1.5) m/piece*	*Uniform(1.4, 1.8) m/piece*
Cutting Pattern Length	*Uniform(11.378,11.747) m/piece*	*Uniform(12.974,14.431) m/piece*	*Uniform(28.269, 29.664) m/piece*
Fabric Width	*1.5m*	*1.5m*	*1.5m*

Fabric Density	*0.1kg/m2*	*0.23kg/m2*	*0.23kg/m2*

2) COPS order classifier:

To create non-preemptive priority queues in front of each supplier, several paths were set to represent different queues in the simulation model. Routing logic and selection weight of each path were assigned.

3) COPS order distributor:

Production capacity of each process was updated and checked during working hours in the simulation model. Several "wait" processes were defined to realize the storage of products in each supplier's warehouse and also represent the status of waiting for available destination. As aforementioned, there are three suppliers in each SC echelon in this simulation model; therefore each generated order has three potential destinations with different priorities. If there is at least one order waiting in the queue, order distribution process is triggered as shown in Figure 4.4. It was realized in the simulation model by defining and programming relevant logics in SIMIO. For example, a logic definition for the selection of fabric manufacturer is illustrated in Figure 4.5. General algorithm with Pseudo codes for order distribution is shown as follows:

Algorithm for order distribution

Notations:

p stands for the priority of potential supplier for current order;
b stands for the priority of non-preemptive priority order queue in front of a company;
N stands for the total number of supply chains;
CR_p stands for the capacity remaining in the p th priority supplier for current order;
Q_{bp} stands for the number of order waiting in the b th priority queue in front of the p th priority supplier for current order.

Input: *p, b, N, CRp, Qbp*

Output: *selected supplier*

Codes:

for (p=1; p<=N; p++)
{
boolean NoHigherPriorityOrder = true;
for (b=1; b<p; b++)
{
if (Q_{bp}*>0)*
{p th priority supplier is not available;
NoHigherPriorityOrder = false;
break;}
}
if (NoHigherPriorityOrder==true&&CR_p*>0)*
{sending current order to p th priority supplier;
break;}
}

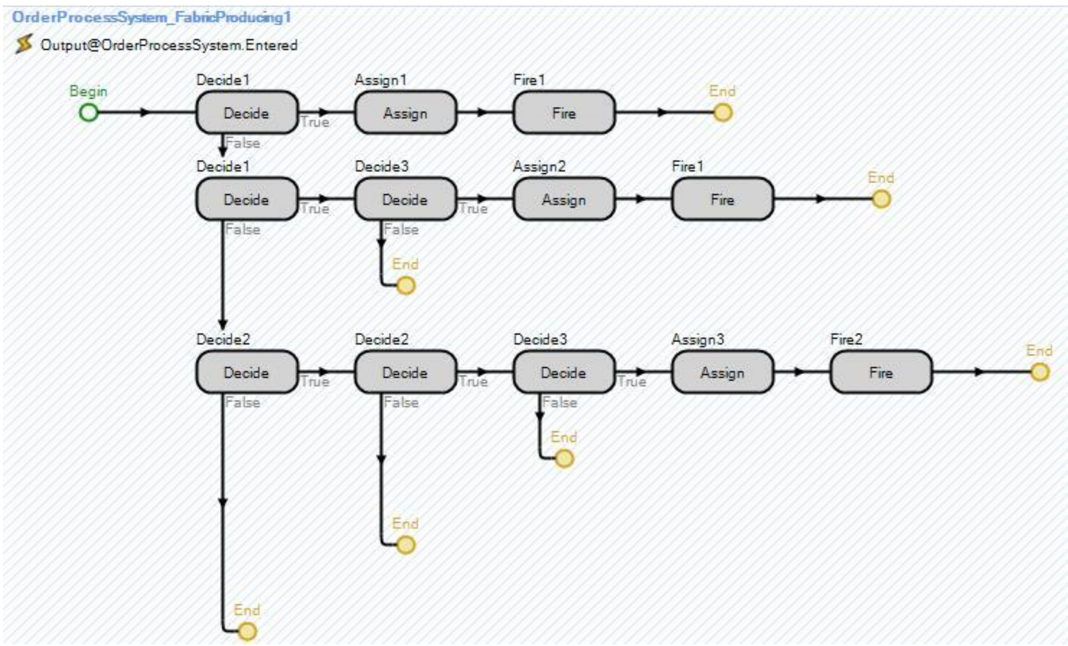


Figure 4.5 Screenshot of the logic definition in SIMIO for the selection of fabric manufacturer

4.2.2. Multi-objective evaluation

Most studies in SCC or demand-driven SCs concentrated on the SC performance evaluation of proposed models. The evaluated performances are mainly on several aspects, e.g. financial aspect (Wee & Wang 2013; Wang et al. 2012; Wang et al. 2010), efficiency aspect (Li & Dai 2009; Chaharsooghi & Heydari 2010), time aspect (Li et al. 2012; Leng & Parlar 2009; Heydari 2014), and service satisfaction aspect (Boza et al. 2014; Xiao & Xu 2013). They can be reflected in various performance indicators. Considering the objective of this sub-study and the measurement capability in simulation model, Order completion rate, productivity, lead time, facility utilization and profit index were selected as key performance indicators (KPIs). In general, these indicators can cover the majority of common aspects in SC performance evaluation. The definitions of selected KPIs were introduced as followings:

Order completion rate = Number of completed original orders/ Number of all received original orders

Facility Utilization = Machine Running Time/Total Working Time

Productivity = Total yield / Total working days

Lead Time: Average time for completing each original order from its arrival until its completion

Profit Index (PI): the overall profit level of one or several companies in a period of time.

$$PI = \sum_{p}^{n}(Y_p \times K_p) \qquad (4.1)$$

where Y_p is the yield of product p. Under most circumstances, companies can gain higher profit from product with long unit processing time. Therefore, the same factor, as introduced in Equation 3.1, was defined as follows

$$K_p = \frac{PT_p}{PT_{min}} \qquad (4.2)$$

where PT_p represents mean unit processing time of product p and PT_{min} is minimum mean unit production time among all same type of products (garments, fabrics and dyed fabrics in this simulation model).

If considering the ratio (R) of profits for producing shared orders which is paid for original order holder, PI of one company could be divided into three parts: PI_1, PI_2, and PI_3. PI_1 stands for profits obtained by producing products whose corresponding orders are first priority orders (belonged to the company itself), so

$$PI_1 = \sum_p^n (Y_{1p} \times K_p) \qquad (4.3)$$

where Y_{1p} is the yield of product p produced in the company while corresponding orders are first priority orders to this company. PI_2 stands for profits obtained by producing products whose corresponding orders are not first priority orders (initially belonged to other companies), so

$$PI_2 = \sum_p^n (Y_{2p} \times K_p \times (1 - R)) \qquad (4.4)$$

where Y_{2p} is the yield of product p produced in the company while corresponding orders do not belong to this company. PI_3 stands for profits obtained by sharing orders to other companies, so

$$PI_3 = \sum_p^n (Y_{3p} \times K_p \times R) \qquad (4.5)$$

where Y_{3p} is the yield of product p produced in other companies while corresponding orders are first priority orders to this company. Therefore,

$$PI = PI_1 + PI_2 + PI_3 = \sum_p^n (Y_{1p} \times K_p + Y_{2p} \times K_p \times (1 - R) + Y_{3p} \times K_p \times R). \qquad (4.6)$$

4.3. Experiment based on a case in a French garment company

4.3.1. Experiment input parameters and assumptions

As aforementioned, a four echelons demand-driven textile SC model was simulated, including fabric manufacturers, dyeing workshops, garment manufacturers and garment retailers. Three single demand-driven textile SCs were included in the model. That is to say, in each echelon, three individual suppliers were available (three priorities for each company) and could provide same type of service. Therefore, in total of twelve companies were included in the simulation model. Garment retailers demanded three types of garments, viz. dress, trousers and jacket. The simulation model started with the arrival of orders from garment retailers. In the classical model, as shown in Figure 4.1, garment manufacturers received orders first and demanded raw materials. In the new collaborative model, the COPS received orders and made the corresponding reactions as introduced in Section 4.1. For the production of dress and trousers, the sequence of suppliers in material flow is fabric manufacturer, dyeing workshop and garment manufacturer. For the production of jacket, the sequence is dyeing workshop, fabric manufacturer and garment manufacturer, which means yarns were dyed before weaving. A processing flowchart of one single SC in simulation model is illustrated in Figure 4.6.

Data regarding orders, e.g. size of order, type of order, were collected based on one-year historical data (in total of 1546 orders) provided by a garment company in France. Those orders were stored in the simulation model database, and it was randomly selected each time when garment retailer put an order during each simulation run. Data regarding processing time (Table 4.3) were obtained by interviewing professionals in garment industry and were also calculated according to handbooks, including Ormerod & Sondhelm

(1995) and Broadbent (2001). Triangular distribution was applied on sewing time to add randomness as sewing process is mainly operated by workers, unlike other process which is mainly operated by machines. Capacity of each company was shown in Table 4.4

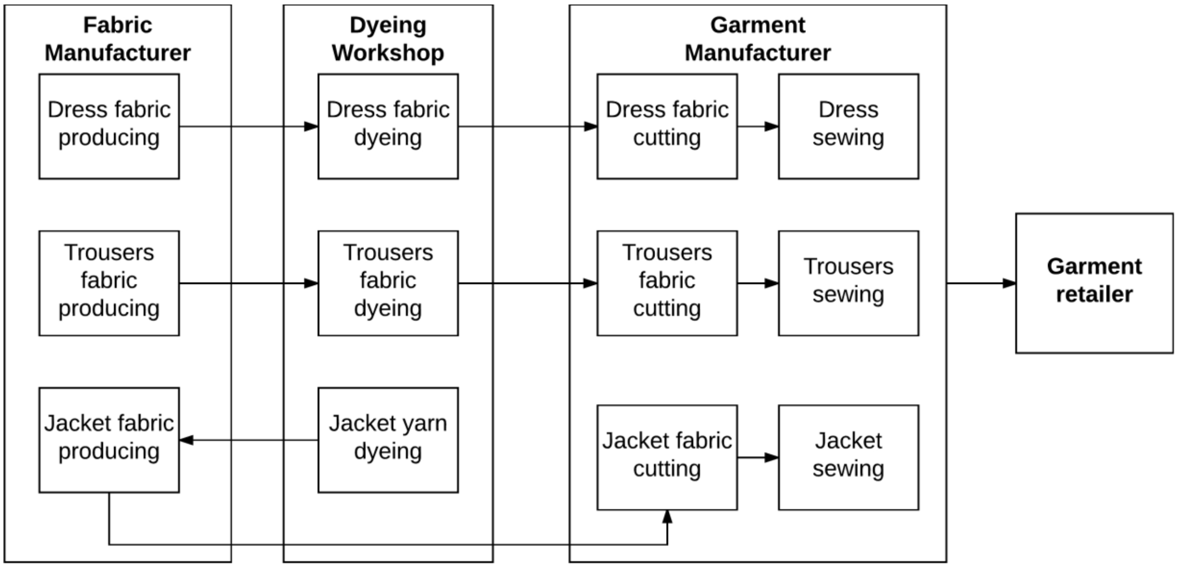


Figure 4.6 Process flowchart of a classical single textile supply chain for the three considered types of garment

Table 4.3: Processing Time

Processing Time	Dress	Trousers	Jacket
Weaving Time	*1.63 min/m*	*2.08 min/m*	*4.34 min/m*
Dyeing Time	*7 hours/batch (Fabric)*	*7 hours/batch (Fabric)*	*5 hours/batch (Yarn)*
Cutting Time	*4 s/m*	*4 s/m*	*4 s/m*
Sewing Time	*Triangular (41.90, 46.55, 51.21) min/piece*	*Triangular (29.37, 32.63, 35.89) min/piece*	*Triangular (38.79, 43.1, 47.41) min/piece*
Total processing Time	*52.57 min/piece*	*38.64 min/piece*	*59.04 min/piece*

Table 4.4: Capacity (number of machines) of each company

	Suppliers in Supply Chain 1	Suppliers in Supply Chain 2	Suppliers in Supply Chain 3
Weaving Machine	*7*	*6*	*5*
Fabric Dyeing Machine	*3 (capacity:80kg)*	*3 (capacity:72.5kg)*	*2 (capacity:65kg)*
Yarn Dyeing Machine	*2 (capacity:65kg)*	*2 (capacity:60kg)*	*2 (capacity:55kg)*
Cutting Machine	*2*	*2*	*1*
Sewing Machine	*48*	*43*	*40*

Some constraints and assumptions were also defined for the simulation model to make it closer to reality as follows:

- All companies followed a standard working schedule: 8 hours per day and 5 days per week. Operators and workers would suspend processing immediately at the end of each shift.
- Delivery of products to next echelon of SC only occurred when corresponding order was finished. Moreover, transporters would wait one hour if its capacity is not full when delivery is required. For example, fabrics were produced in a fabric manufacturer and were stored in its warehouse. Once corresponding order is finished, then fabrics were ready for delivery. Fabrics were still stored in the warehouse until a supplier in the system was selected as destination. So, if it took long time for waiting an available supplier, several orders of fabrics may be stored in the warehouse and they could be mixed together for delivery if the destination is same. On the contrary, if there is only one small order ready for delivery to selected supplier, vehicles would wait one hour to see if there may have more products for delivery together. This constraint is to increase transportation facility utilization.
- Collaborative priorities were defined based on familiarity between suppliers, which was reflected in time consuming for transportation preparation, communication in the simulation model. It took 60 minutes for a supplier to prepare before delivery to a first priority supplier in next SC echelon, 90 minutes to a second priority supplier and 120 minutes to a third priority supplier.

4.3.2. Experiment design

As described at the beginning of this chapter, I wanted to check the performance of new collaborative model under different workload in different seasons. Therefore, six levels of workload were defined as shown in Table 4.5. A peaking season (high workload condition) means an excessive number of orders were received in a period, the whole SC cannot complete received orders in time. A normal season (normal workload condition) means that a suitable number of orders were received in a period; the whole SC can approximately address all received orders in time without resources being in long idle status. An idle season (low workload condition) means a small number of orders were received in a period; the whole SC can address all received orders in time but with resources in long idle status. Each level of workload has a corresponding order arrival frequency in the simulation model. For example, the highest level workload means every two days there is a demand for dress, trousers and jacket respectively; in other words, three orders arrive to the garment manufacturer in the traditional model or COPS in the new collaborative model every two days. Consequently, twelve scenarios were designed based on level of workload, viz. $\{T_i, N_i\}$, $i \in [2,7]$ (T stands for traditional model, N stands for new collaborative model, i represents order arrival frequency in days), which became the first experiment. After running this first experiment, the output results of each pair of scenarios were compared to illustrate the differences between traditional model and new collaborative model under different workload conditions.

Table 4.5: Level of workload and corresponding designed scenarios

Level of workload	**Lowest → Highest**					
Order arrival frequency of each type of product (days)	7	6	5	4	3	2
Designed scenarios of traditional model	T7	T6	T5	T4	T3	T2
Designed scenarios of new collaborative model	N7	N6	N5	N4	N3	N2

Another problem this sub-study delved into is to check the performance of COPS on different echelons of SC and to determine the most demanding SC echelon for the new collaborative model. Scenario T4 was selected as the benchmark scenario for this problem, as it stands for a normal workload condition which is the most common condition in real industry. Therefore, three more scenarios, which represented COPS only applied on one SC echelon respectively whereas other echelons remains traditional, were designed, viz.

N4 Weaving, N4 Dyeing and N4 Sewing, creating the second experiment. The output of these three scenarios and scenario T4 were compared to each other so that to evaluate the most demanding SC echelon. Finally, in total of 15 scenarios were designed and experimented in the simulation model.

4.4. Results and discussion

Each scenario in the simulation experiments was run for the duration of 20 weeks, and with 50 replications. The first 2 weeks were considered as warm-up period and its statistics was cleared to remove the effects of atypical initial system condition. Under normal workload condition (e.g. scenario T4), average order completion rate of 50 replications is 92.85%, average facility utilization is 73.02%, average lead time is 10.78 days and average productivity is 1084.91 pieces/day in the traditional model for all three SCs. According to the interviews of professionals in garment industry, those measurements are plausible and fit the real situation in garment industry. Therefore, the simulation model is representative in this perspective. Moreover, the theoretical maximum average yield was calculated (if the distribution of orders in quantity between dress, trousers and jacket is homogenous: theoretical maximum average yield = total time × total capacity/average processing time) of each supplier in 18 weeks based on each company's capacity and average processing time (Table 4.3 and Table 4.4). For example, for fabric manufacturer 1, maximum average theoretical yield = 18 weeks × 5 days × 8 hours × 60 min × 7 machines ÷ ((1.63 minutes/metre +2.08 minutes/metre +4.34 minutes/metres) ÷ 3) = 112695.65 metres. Maximum average theoretical yield of each company was compared to average yield of each company in the simulation model under highest workload (scenario T2 and N2), as machine is always running under this condition so that its result should close to the maximum average theoretical value, as shown in Table 4.6. There is a gap between theoretical value and simulation value in some cases because distribution of orders in quantity between dress, trousers and jacket is unequal and stochastic in the simulation and facility utilization cannot reach 100% in the simulation either, but generally the output value based on simulation is close to the theoretical value; therefore the simulation model can be considered as realistic. Furthermore, as aforementioned, the input parameters for building the simulation model is based on real historical data, academic literatures and interviewing professionals in garment industry, while the simulation model is built strictly step by step based on each process in the conceptual model with a thorough debugging procedure. Consequently, the simulation model in this sub-study can be considered as validated under the assumptions and parameters for building the model.

Table 4.6: Comparison between theoretical maximum average yield and average yield in simulation under highest workload

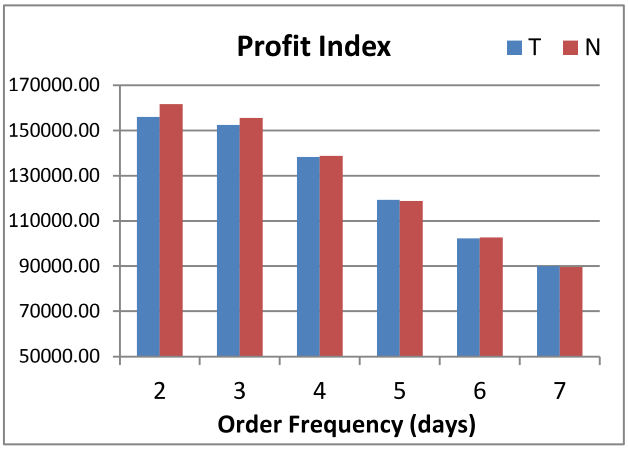
	Theoretical maximum average yield	**Average yield in T2**	**Average yield in N2**
Fabric Manufacturer 1	112695.65 metres	118988.36 metres	133744.86 metres
Fabric Manufacturer 2	96596.27 metres	110220.30 metres	112485.42 metres
Fabric Manufacturer 3	80496.89 metres	79325.96 metres	85331.74 metres
Dyeing Workshop 1	568.42 batches	493.18 batches	541.38 batches
Dyeing Workshop 2	568.42 batches	527.48 batches	557.44 batches
Dyeing Workshop 3	454.74 batches	470.74 batches	460.84 batches
Garment Manufacturer 1	50873.41 pieces	54328.02 pieces	54062.36 pieces
Garment Manufacturer 2	45574.09 pieces	48154.06 pieces	48758.68 pieces
Garment Manufacturer 3	42394.50 pieces	27411.40 pieces	30877.14 pieces

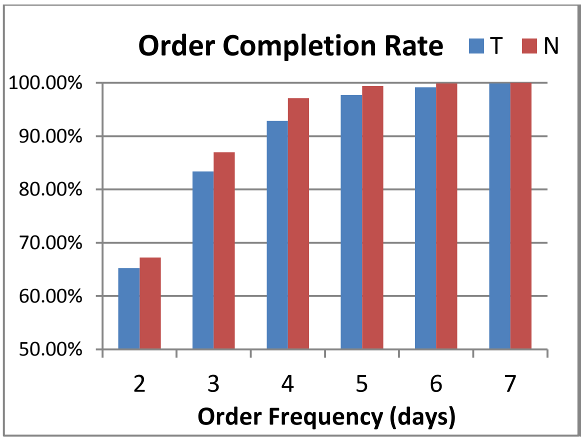
As introduced in Section 4.3.2, two experiments were conducted by designing 15 scenarios. The average values for 50 replications of each checked SC KPI of these 15 scenarios were illustrated in Figure 4.7 and Figure 4.8 respectively. An independent sample T-test (confidence interval = 95%) was also conducted on output data to determine whether there is statistical evidence that the average value of represented population are significantly different with each other based on the output of 50 replications. If it is significantly different in terms of checked KPI based on conducted T-test, it means the increase or decrease in terms of this KPI obtained from the simulation model is significant and meaningful. The comparison results are shown in Table 4.7.

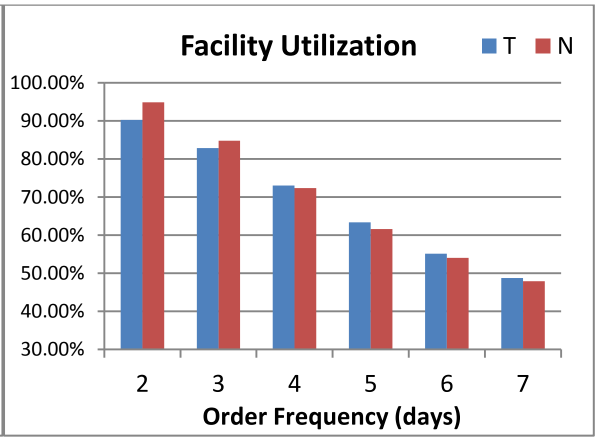
Table 4.7: Comparison results

Experiment	Scenario comparisons	Profit Index	Productivity	Lead Time	Order Completion Rate	Facility Utilization
First Experiment	T2 vs. N2	**3.64%**	**3.03%**	**10.61%**	**3.02%**	**5.09%**
	T3 vs. N3	**2.09%**	**2.29%**	**-2.78%**	**4.35%**	**2.33%**
	T4 vs. N4	0.43%	**0.97%**	**-23.91%**	**4.59%**	-0.84%
	T5 vs. N5	-0.49%	-0.16%	**-27.75%**	**1.69%**	**-2.74%**
	T6 vs. N6	0.40%	0.80%	**-18.81%**	**0.74%**	**-1.98%**
	T7 vs. N7	-0.39%	-0.04%	**-16.72%**	0.09%	**-1.80%**
Second Experiment	T4 vs. N4 Weaving	**3.61%**	**4.10%**	**-21.12%**	**4.62%**	0.36%
	T4 vs. N4 Dyeing	**2.70%**	**3.15%**	**-22.82%**	**4.66%**	0.63%
	T4 vs. N4 Sewing	0.20%	**0.38%**	**-12.77%**	**2.40%**	-1.03%

Bold means significant difference between corresponding two scenarios based on independent sample T-test (confidence interval = 95%)







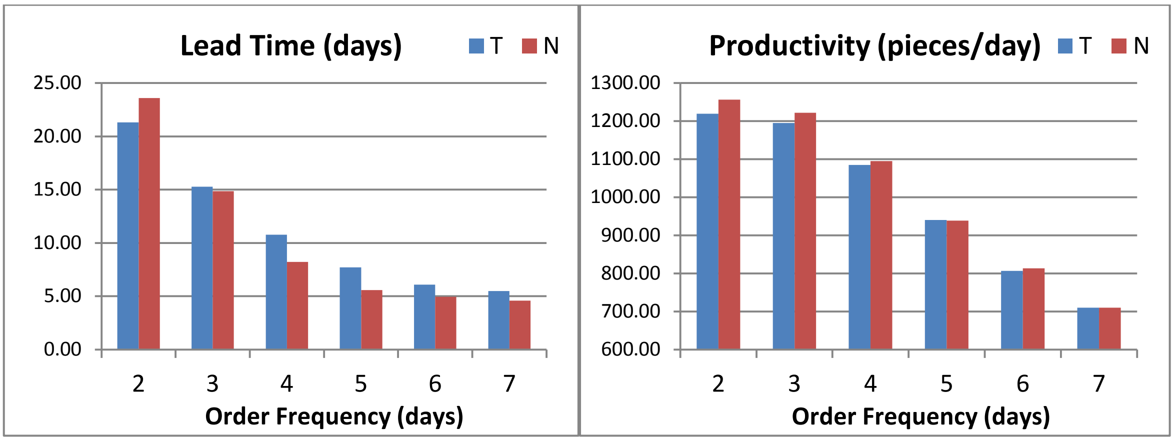


Figure 4.7 Mean value of supply chain KPIs under different workloads

Based on the results of first experiment (Figure 4.7), improvements in terms of each checked KPI were generally obtained in the new collaborative model with COPS, especially under high workload conditions (viz. order frequency equal to 2 days or 3 days). Therefore, new collaborative model with COPS can really bring great benefits to companies. SC performance improvements of new collaborative model under low workload conditions were less apparent. Only lead time and order completion rate were significantly improved, while facility utilization was decreasing. The decrease of facility utilization is due to the increase of efficiency, leading to shorter machine running time.

Based on output results of the second experiment (Figure 4.8), generally, improvements were achieved in all KPIs no matter which echelon applied COPS. However, much higher improvements in terms of all checked KPIs was found when COPS was utilized in the echelon of fabric manufacturer or dyeing workshop compared to when COPS was utilized in the echelon of garment manufacturer. Therefore, fabric manufacturers or dyeing workshops were more demanding for COPS. These two echelons could be considered as bottlenecks for the simulation model in this sub-study.

Figure 4.8. Mean value of supply chain KPIs when COPS is applied in a single supply chain echelon

As aforementioned, profit sharing mechanism was utilized in the new collaborative model. According to the function for calculating *PI* introduced in Section 4.2.2, individual *PI* under different profit sharing ratio (*R*=0% to 90%) was calculated as well. *PI* of each company as well as total PI of each SC echelon were shown from Figure 4.9 to Figure 4.20.

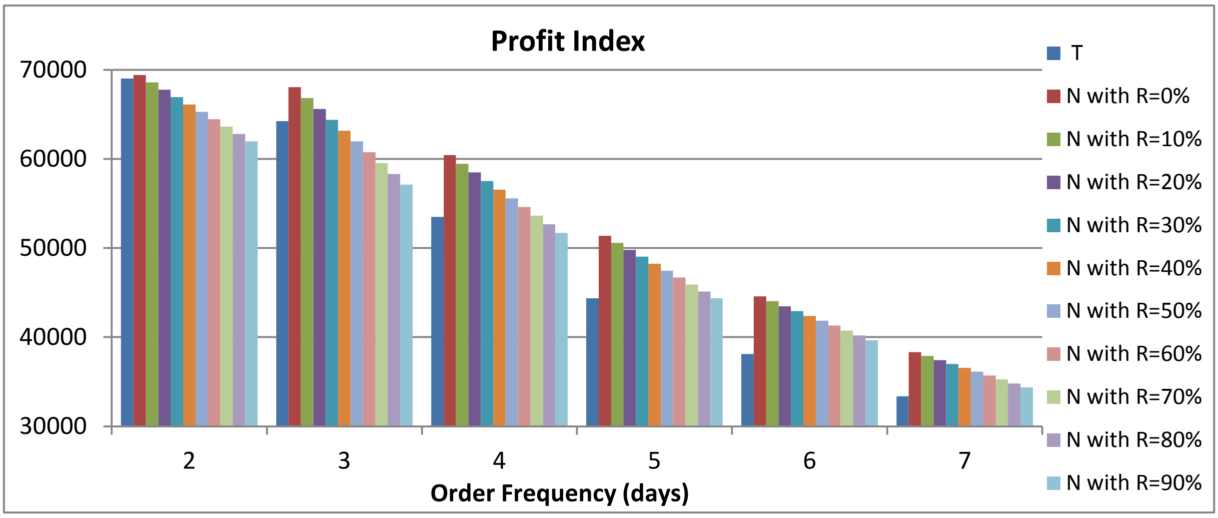


Figure 4.9 PI according to R for Garment Manufacturer1 (capacity: 48 sewing machines)

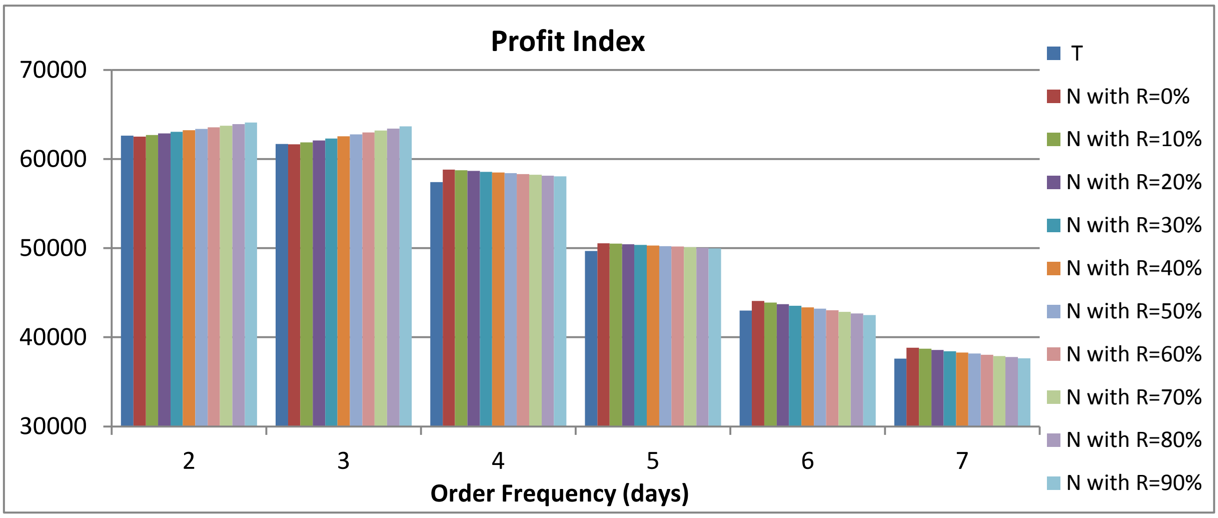


Figure 4.10 PI according to R for Garment Manufacturer2 (capacity: 43 sewing machines)

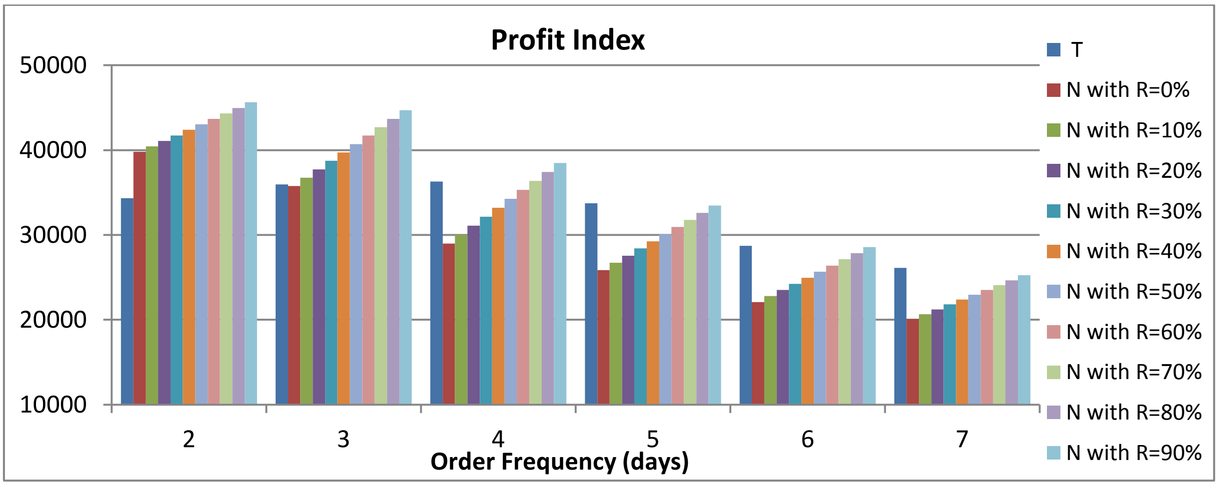


Figure 4.11 PI according to R for Garment Manufacturer3 (capacity: 40 sewing machines)

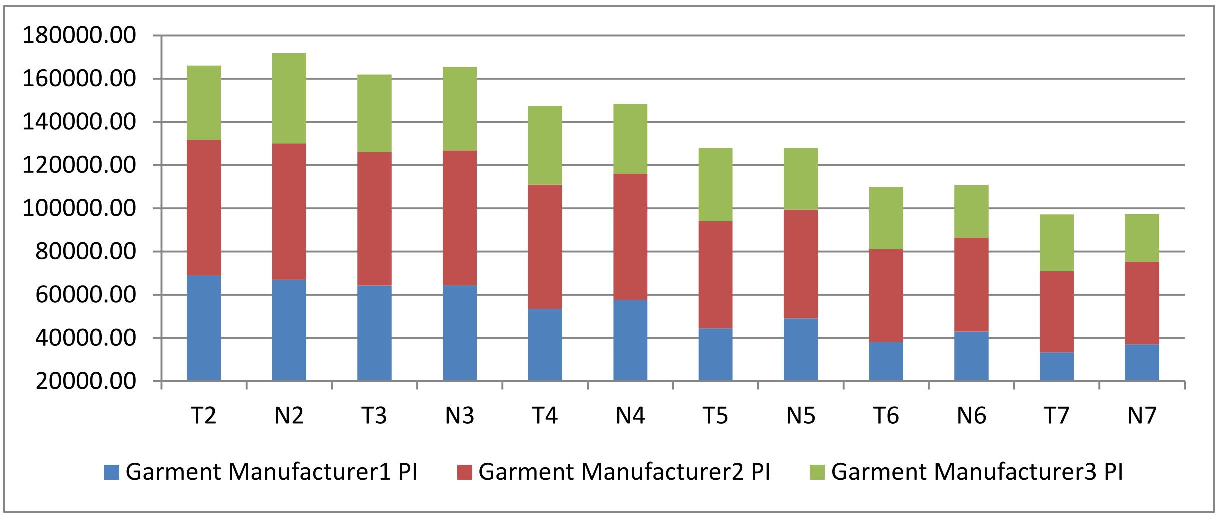


Figure 4.12 Total PI of all three Garment Manufacturers (R = 30%)

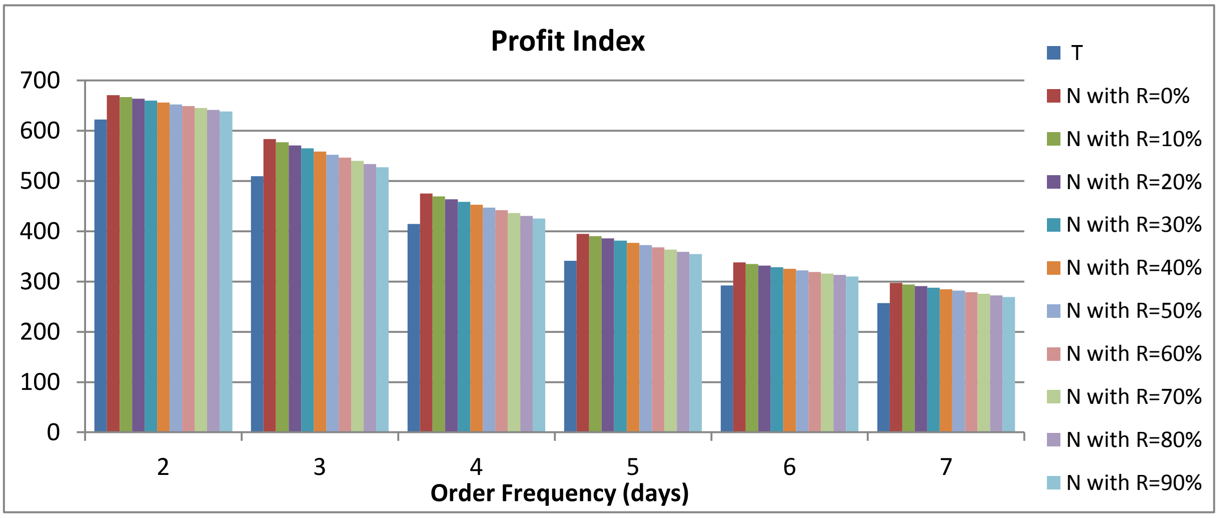


Figure 4.13 PI according to R for Dyeing workshop1 (capacity: 5 dyeing machines)

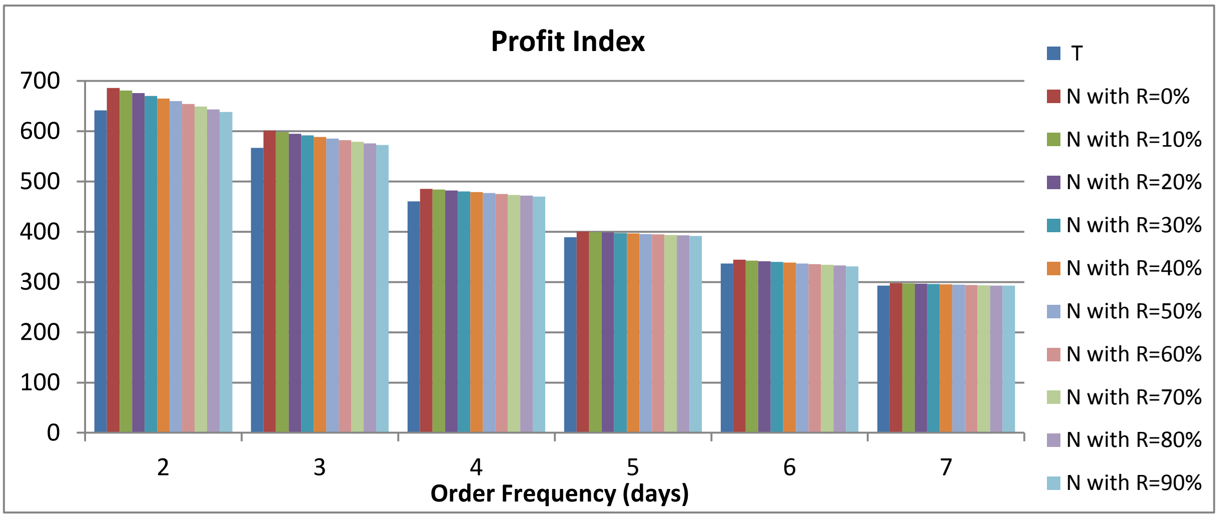


Figure 4.14 PI according to R for Dyeing workshop2 (capacity: 5 dyeing machines)

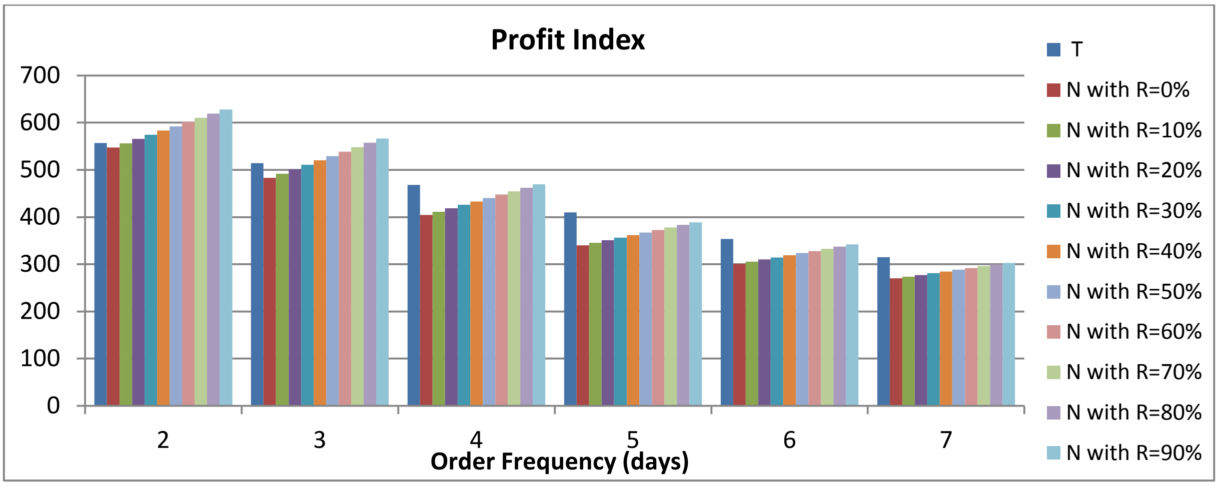


Figure 4.15 PI according to R for Dyeing workshop3 (capacity: 4 dyeing machines)

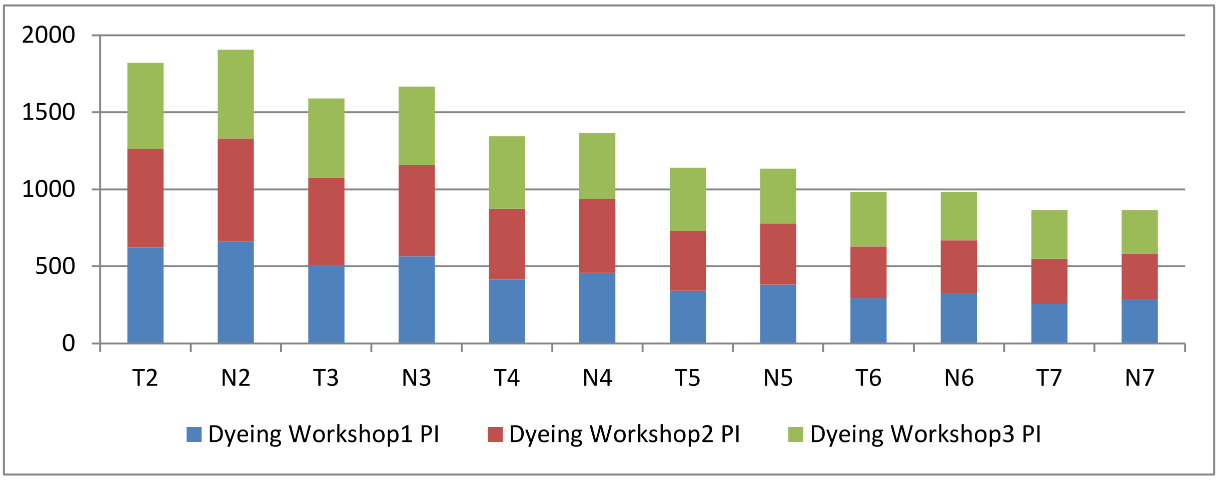


Figure 4.16 Total PI of all three Dyeing Workshops (R = 30%)

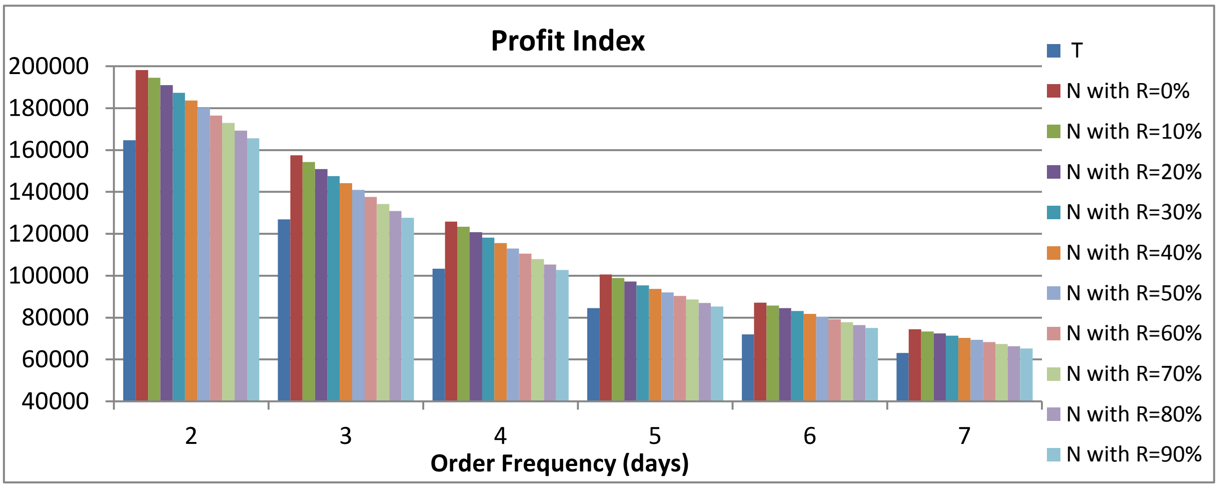


Figure 4.17 PI according to R for Fabric Manufacturer1 (capacity: 7 weaving machines)

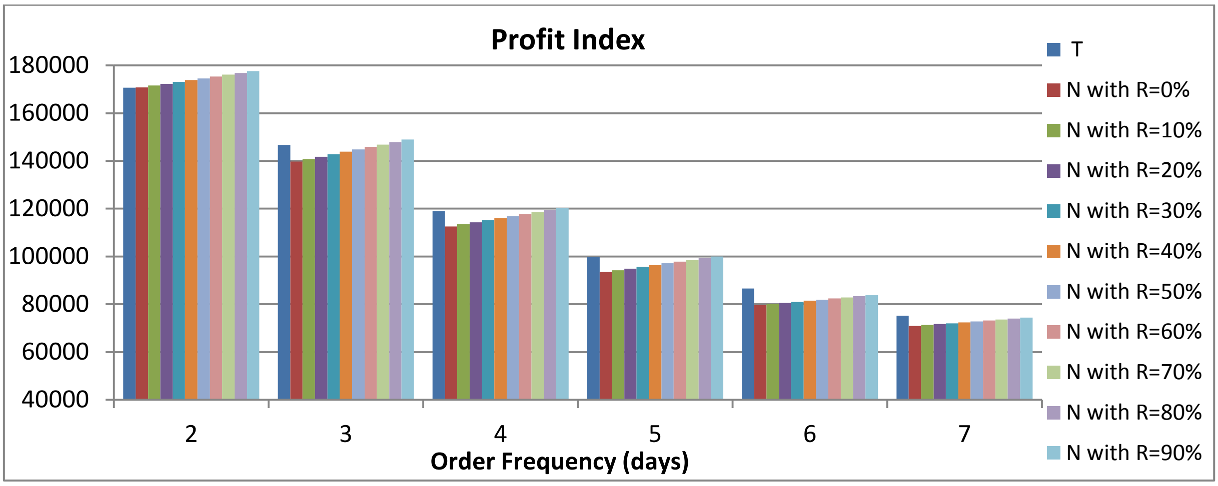


Figure 4.18 PI according to R for Fabric Manufacturer2 (capacity: 6 weaving machines)

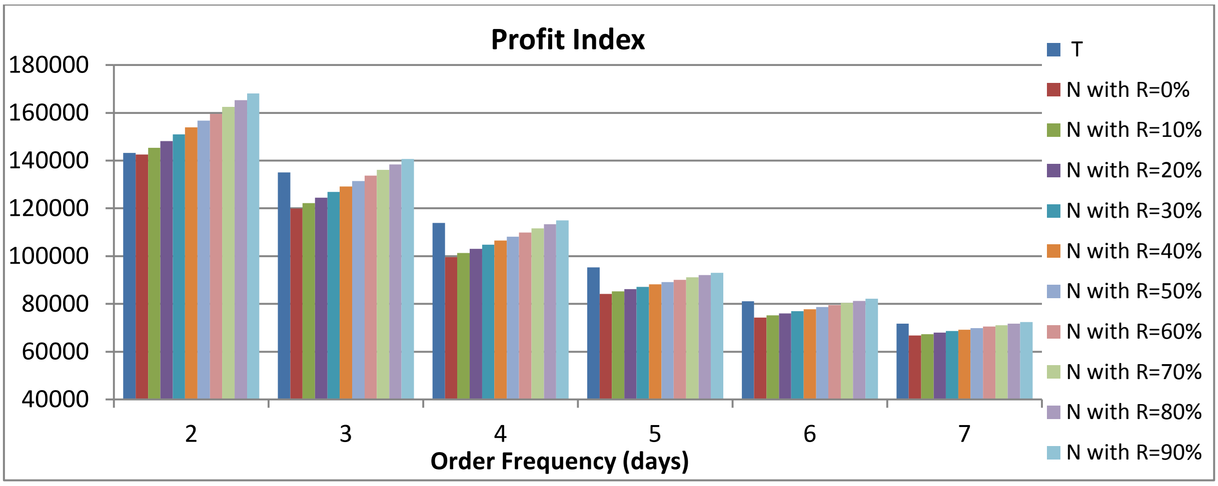


Figure 4.19 PI according to R for Fabric Manufacturer3 (capacity: 5 weaving machines)

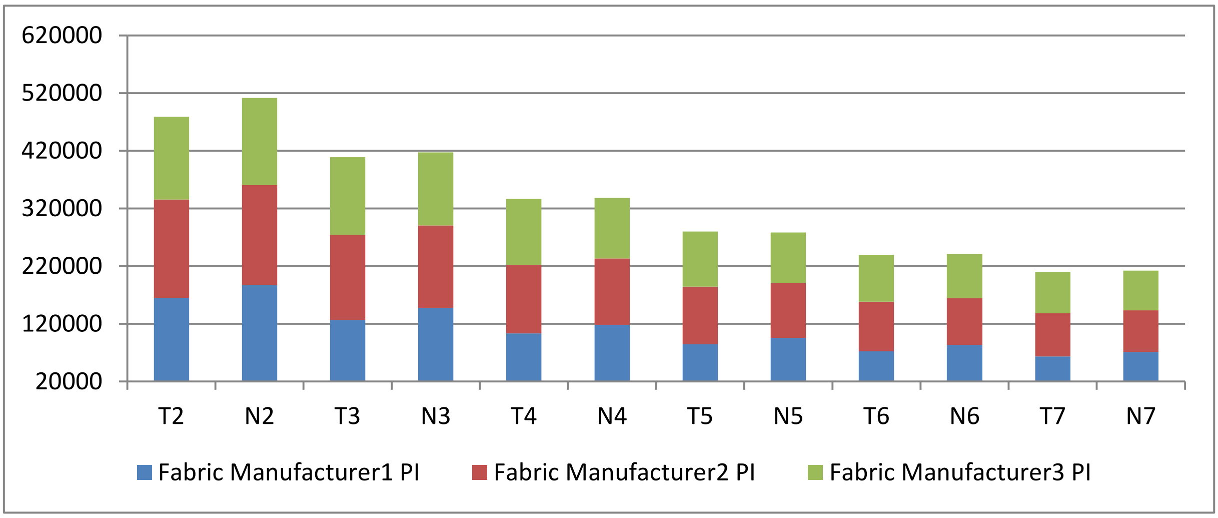


Figure 4.20 Total PI of all three Fabric Manufacturers (R = 30%)

According to the results of individual *PI* (Figure 4.9 to 4.20), an increase of total profits was obtained in every SC echelon. There was always a decrease of individual *PI* as the increase of *R* in the first company (relatively highest capacity among the three companies) in each SC echelon. There was also always an increase of individual *PI* as the increase of *R* in the third company (relatively lowest capacity among the three companies) in each SC echelon. This phenomenon is because the first company received more orders from other companies than it shared to other companies, while the third company shared to other companies more orders than it received from other companies. According to the Equation (4.6), Equation (4.7) was obtained as follows

$$PI = \sum_{p}^{n}(K_{\mathrm{p}} \times (Y_{1\mathrm{p}} + Y_{2\mathrm{p}}) + K_{\mathrm{p}} \times (Y_{3\mathrm{p}} - Y_{2\mathrm{p}}) \times R) \tag{4.7}$$

PI is a monotonically increasing function in terms of *R* when $Y_{3p} > Y_{2p}$, while PI is a monotonically decreasing function when $Y_{3p} < Y_{2p}$. That is to say, a company obtains more profits as the increase of *R* when it shared more to other companies than received from other companies; while a company obtains more profits as the decrease of R when it received orders from other companies more than shared to other companies. Another interesting phenomenon is that, profit improvements never occurred on three companies in each SC echelon simultaneously when the sharing ratio is 0%. In other words, profit sharing mechanism is necessary to guarantee profit increase of each involved company.

4.5. Conclusions

Due to the increasing demand for small series and customization in production, demand-driven SC models have increasingly been employed more in the garment industry. However, there were still many drawbacks in traditional model, viz. long lead time, high cost, unsmooth production flow, delay between SC echelons and low efficiency. In this chapter, a new collaborative model integrating vertical and horizontal collaboration was proposed for demand-driven textile SCs by designing a Central Order Processing System (COPS) to solve aforementioned issues and improve textile SC performances. COPS handles order reception, order classification, and order distribution. Discrete-event simulation technology was utilized to experiment the new collaborative model under different conditions. Multiple key performance indicators for the whole SC and also for individual companies were checked after experiments. Based on simulation experiment results, four conclusions were obtained as follows.

- The new proposed collaborative model with COPS got significant improvements in multiple key performance indicators. In finance perspective, COPS could help the whole SC gain more profits and reduce cost for each unit of product as the total cost remain the same (labour and machine cost) while higher yield was obtained. Productivity and facility utilization were increased, so that the efficiency of involved suppliers was improved significantly. Lead time was decreased while order completion rate was increased, so that higher customer satisfaction could be obtained.
- The performances of new collaborative model under different workload conditions were different. COPS provided more significant improvements under high workload condition than under low workload condition. KPIs were significantly improved in new collaborative model under overload condition, while only lead time was significantly improved under low workload condition. If it is impossible for garment companies to apply COPS all the time or garment companies are reluctant to collaborate for long period, COPS could be regarded as a special temporary strategy in peaking season.

- Generally, improvements were achieved in terms of all checked KPIs no matter which echelon applied COPS. Applying COPS in earlier SC echelon could lead to higher improvements in SC performances. This is probably due to the positive influence of capacity and demand balancing among suppliers at the beginning.

- COPS can not only increase overall profit level of the whole SC but also individual profit level of each company. Increase of total profit index in each SC echelon was obtained under all experimented conditions. Companies with more capacity can obtain more profit increase as the decrease of ratio for profit sharing, while companies with less capacity can obtain more profit increase as the increase of ration for profit sharing. Profit sharing mechanism embedded in COPS played a vital role in guaranteeing the benefit of each involved company, as improvement of profits simultaneously in all three companies of each SC echelon never occurred when profit sharing mechanism is not implemented (R=0%).

In this sub-study, the application of SCC strategy was extended from one SC echelon (Chapter Three) to the whole SC. In general, according to the main characteristic of demand-driven SC (all activities are driven by orders), a top-down SCC strategy (joint decision-making for order distribution in the centralized system COPS and then conduct individual activity at company level) was developed. Resource sharing mechanism which was proposed in previous sub-study (in Chapter Three), with information sharing, joint-decision making and profit sharing strategy which all were identified in the literate review on SCC (Chapter Two), were merged into one system. The proposed system provided a solution for optimizing traditional demand-driven SC model. For make-to-order SC (introduced in Chapter One), the COPS is not appropriate due to the decentralized structure of make-to-order SC. Therefore, a bottom-up SCC model is demanded for optimize make-to-order SC, which has been done and is to be introduced in next chapter.

5. Collaborative cloud service platform for optimizing make-to-order textile supply chain

In this chapter, make-to-order SC is studied as main research objective. This sub-study proposes a novel collaborative SC model by designing a Collaborative Cloud Service Platform (CCSP) to develop a "service to business to customer" (S2B2C) structure. It was developed on the basis of the resource sharing mechanism (Chapter Two) and the previous identified SCC strategies. Companies maintain their individual right to make decision of whether to keep an order or use the cloud service. It aims at solving issues (e.g. long lead time, low efficiency, high cost) in existing make-to-order textile SC models (traditional SC model and SC model with outsourcing mechanism) and increasing the performance of the whole SC. Agent-based simulation technology is utilized to realize the platform and help to answer the third research question in this thesis (RQ3: What are effects of application of a combination of identified supply chain collaboration strategies, e.g. information sharing, joint-decision making, resource sharing and profit sharing, on make-to-order textile supply chain?) and two corresponding sub- research questions in this sub-study, as follows:

RQ 3-1: What advantages are brought to the whole textile supply chain through CCSP?

RQ 3-2: What is the different effect brought to big companies and SMEs through CCSP?

In a make-to-order SC, except of the production activity that is solely triggered by received order, other activities (e.g. replenishing for raw material, inventory level) are operated and determined based on individual criteria in each company. It is different from the characteristic of a demand-driven SC whose all activities are totally driven by orders. Therefore, a top-down SCC strategy, such as COPS, is difficult for such SC model. Multiple aforementioned and successfully applied SCC strategies, e.g., resource sharing (in

Chapter Three), joint decision making and information sharing (in Chapter Four), are still considered as main paradigms in this chapter. However, a bottom-up structure for applying these SCC strategies is more appropriate for a make-to-order SC.

5.1 Two typical make-to-order textile supply chain models

5.1.1 Traditional make-to-order textile supply chain model

In traditional make-to-order textile SC, information flow and material flow are reversed, as shown in Figure 5.1.

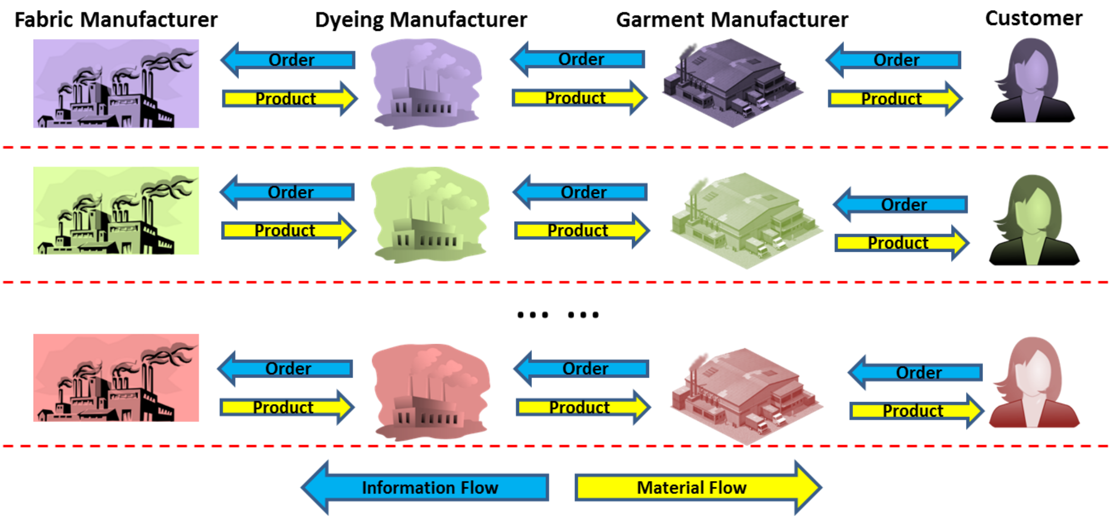


Figure 5.1. Traditional make-to-order textile supply chain model

In a four-echelon textile SC, customers place orders to the garment manufacturer. According to the order, garment manufacturer start production if there are raw material and production capacity available. If there is no sufficient raw material, the garment manufacturer place an order for to the dyeing manufacturer. The same principle applies to dyeing manufacturer and fabric manufacturer. In the traditional model, companies always collaborate with the same downstream suppliers and upstream suppliers. They do not have connections either with other downstream and upstream suppliers or with companies in the same SC echelon. That is, every SC is decentralized and independent in a general perspective. The traditional model is still widely used in textile SC, especially in textile SMEs.

5.1.2 Make-to-order textile supply chain model with outsourcing mechanism

On the basis of traditional make-to-order SC model, outsourcing mechanism is developed and is also widely utilized in textile SC in past decades. Outsourcing mechanism plays a vital role in today's SC as it could bring many advantages to companies, such as better quality of service and product delivery capability improvement (Pascual et al. 2013). In textile SC, under most circumstances, this mechanism is usually utilized by a large company in textile SC to re-distribute their orders to a group of SMEs. For example, 60 percent of the manufacturing jobs of ZARA were outsourced in countries close to the Zara headquarters in Spain (Keiser & Garner 2012). There are plenty of ways and levels to outsource certain operations in a SC. It could be realized horizontally (in the same SC echelon) or vertically (in different SC echelons) (Caniato et al. 2015). In this chapter, only horizontally outsourcing is considered in the textile SC.

As shown in Figure 5.2, besides the information flow and material flow in traditional model, companies have another option to complete and distribute orders. They could partially or totally re-distribute received order to another company in the same SC echelon if they are not able to complete the order in time or do not want to produce the order. Outsourcing mechanism is a common strategy for collaboration and optimizing resource distribution; however, the collaboration is still at a low level and it is a mechanism mainly used by big textile companies but not by textile SMEs. Therefore, it cannot be regarded as an optimized model from a general SC scope, as it neglects textile SMEs, which are an important part of today's textile SC.

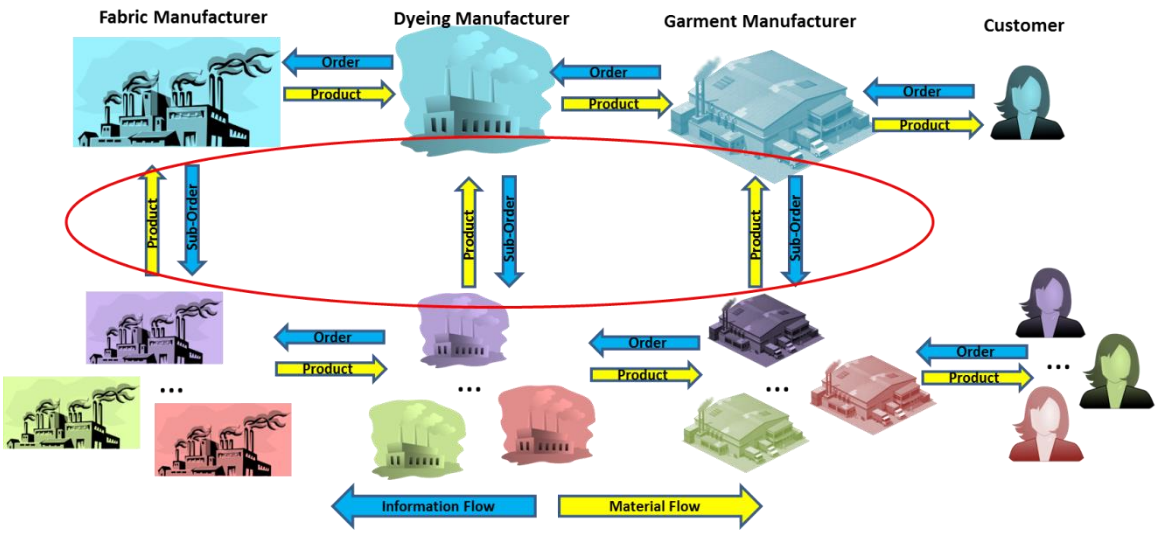


Figure 5.2. Make-to-order textile supply chain model with horizontal outsourcing mechanism

5.2 Collaborative Make-to-Order Textile Supply Chain Model with Collaborative Cloud Service Platform

To optimize current make-to-order textile SC, a new collaborative model was proposed by developing a collaborative cloud service platform (CCSP). As shown in Figure 5.3, CCSP is a third-party, centralizing companies in SC from all echelons. Same as the information flow and material flow in the traditional SC model, companies start production according to orders from downstream suppliers and place order to upstream suppliers for raw materials. However, if a company cannot produce a received order in time due to insufficient capacity or raw material, after evaluating the pros and cons (such as lost profit for sharing the order, penalty for late delivery and worse customer satisfaction for late delivery), it could send a demand with relevant information to CCSP. Through internal database and decision-making system, CCSP is responsible for selecting a suitable service provider in the platform to take over the order. In the new collaborative model, collaborative relationships are inter-organizational, inter-echelons, interactional and dynamic.

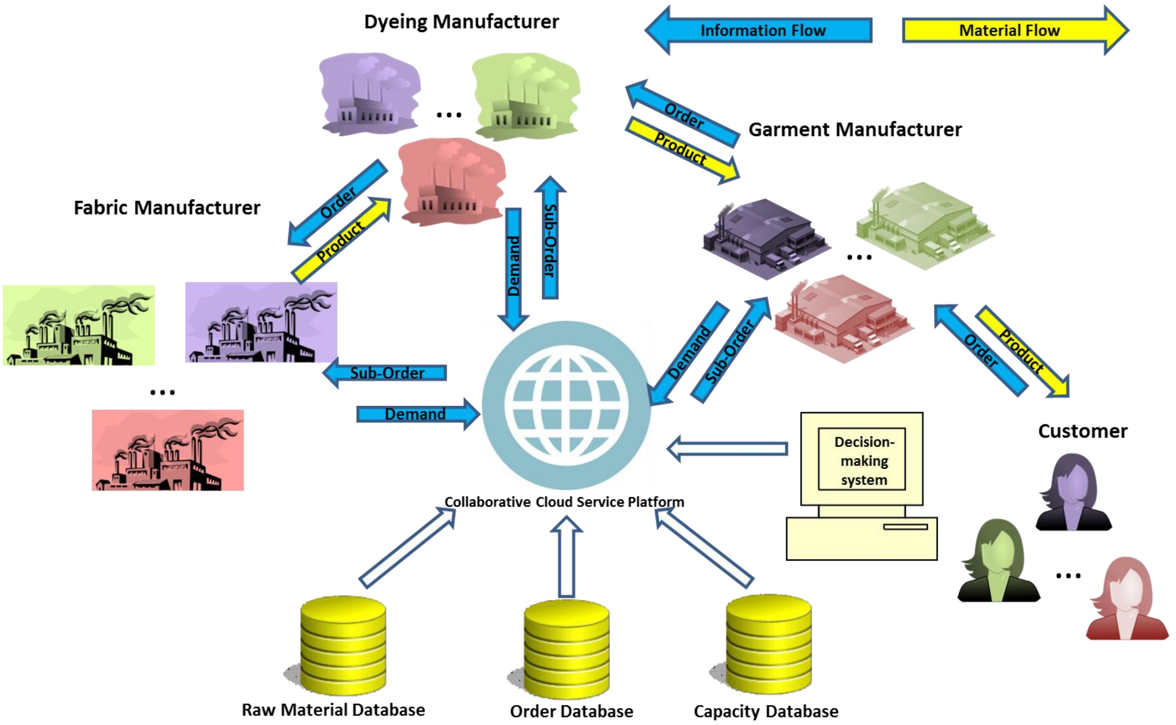


Figure 5.3. Collaborative make-to-order textile supply chain model with CCSP

5.2.1 Information and data system

All the companies on the CCSP should update their data to the platform database, including remaining raw material quantity, remaining production capacity and remaining orders to be processed. Those data are utilized for optimally selecting service provider in decision-making system. Moreover, companies should provide relevant information, e.g. order size, required lead time, accompanying with the demand to the CCSP if they place a demand to the platform. Provided information is served as input parameters in decision-making process.

In the new collaborative model, information and data are only shared to the platform but are not shared to other companies or so-called competitors. CCSP, as a third-party, does not have mutual interests with all suppliers on the platform. Therefore, there is no risk for data leakage.

5.2.2 Decision-making system

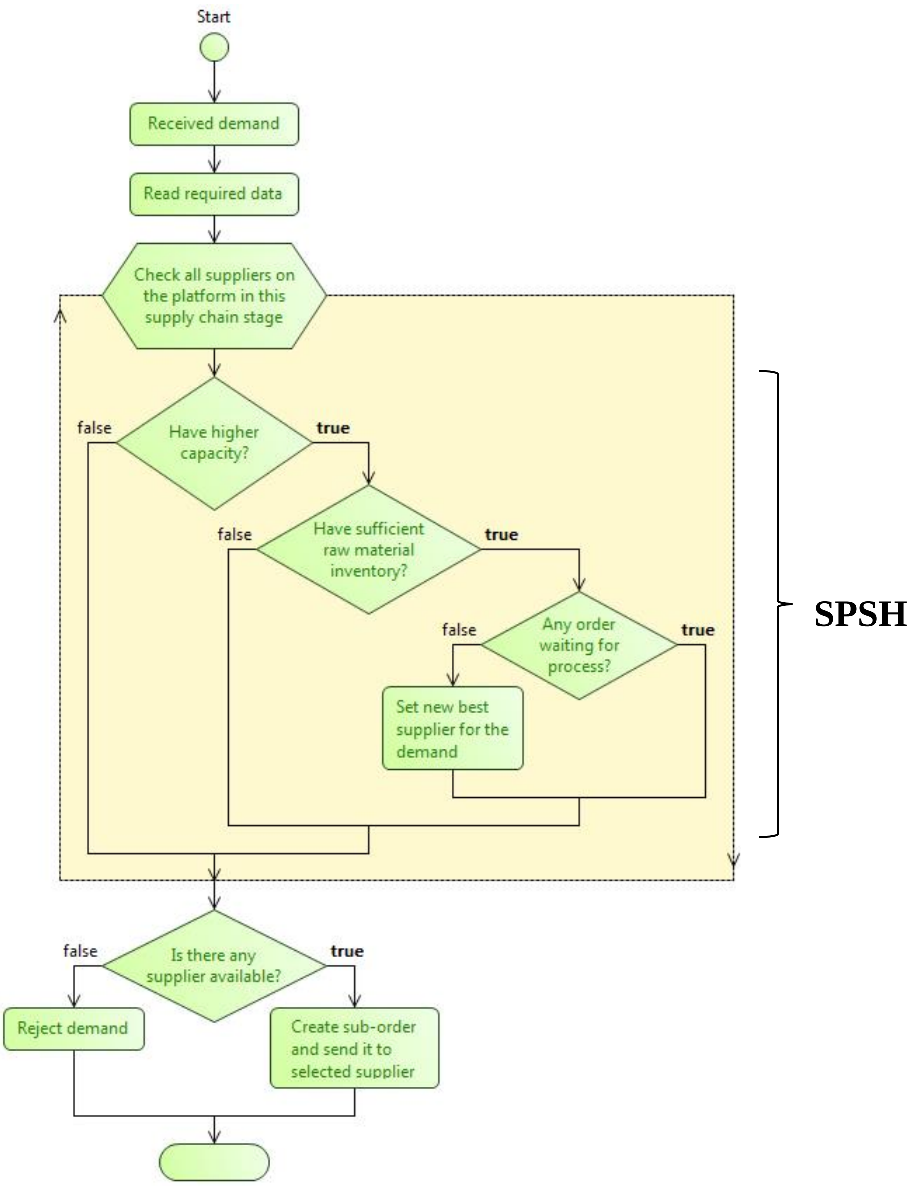


Figure 5.4 Flowchart of decision-making system

Once the platform receives a demand from company, the decision-making process is activated for selecting optimal service provider to the demand, as shown in Figure 5.4. A service provider selection heuristic (SPSH) was designed for the decision-making system in CCSP. It could select the most suitable service provider corresponding to each received demand. In general, two screening steps and one selection step are conducted in SPSH for all potential service providers (suppliers) corresponding to the demand one by one, as follows:

1) The production capacity is checked. If examined supplier has higher capacity than currently selected optimal supplier, it would be proceeded to next step. If not, the supplier is abandoned for the demand.

2) The raw material status is checked. If examined supplier has sufficient raw material for production of corresponding demand, it would be proceeded to next step. If not, the supplier is abandoned for the demand.

3) The order queue of examined supplier is checked. If there is any order waiting in the queue for production, the supplier is abandoned for the demand. If not, it would be selected as new optimal supplier.

After looping through all candidate service providers with conducting the three steps, the most appropriate service provider, which has the highest production capacity with sufficient raw material and without same production task waiting in the queue, is finally selected for corresponding demand. The mathematical formulation of SPSH and its realization in simulation model are introduced in detail in the Methodology section.

5.3 **Methodology**

To produce a shared order from CCSP may incur additional raw material order fee and may have influence on the production of own order. Besides, manufacturers cannot gain full profits by producing a shared order from CCSP, as the ratio of profit that a company can keep in terms of a shared order was defined. It aims to stimulate their willingness to enhance collaboration and use the service of CCSP. Therefore, it is necessary to evaluate the exact influence of the proposed SC model on the whole SC and individual companies by comparing it to existing models (traditional SC model and SC model with outsourcing mechanism). In this section, the problem through mathematics formulation was described first. Considering the complexity and stochastic nature of the model, agent-based simulation technology was employed to develop three make-to-order textile SC models introduced in Section 5.1 and 5.2. Experiments were conducted in the multi-agent simulation model to explore the effect of new collaborative model and to compare it to traditional model and model with outsourcing mechanism.

5.3.1 Mathematical formulation

Indices:	
c	index of company in each supply chain echelon (c = 1, 2, 3, …, C)
s	index of supply chain echelon (s = 1, 2, 3, …, S) (1 means the most downstream supply chain echelon (closest to the retailer), S means the most upstream supply chain echelon (farthest from the retailer))
r	index of retailer (r = 1, 2, 3, …, R)
o	index of order (o = 1, 2, 3, …, O)
Parameters:	
PC_{cs}	production capacity of company c in supply chain echelon s
PT_{cs}	production time of company c in supply chain echelon s
MI_{cs}	maximum inventory of company c in supply chain echelon s
ROP_{cs}	reorder point for raw material of company c in supply chain echelon s
WT_{cs}	working time of company c in supply chain echelon s
PD_{cs} ($=PC_{cs} \times T_{cs}/PT_{cs}$)	maximum productivity of company c in supply chain echelon s
RM_s	raw material needed per product in supply chain echelon s
P_s	profit per product in supply chain echelon s
OS_{or}	order size for order o from retailer r
OR_r	number of orders placed by retailer r per month
LT_{or}	demanded lead time for order o from retailer r
CI	cost of warehouse per month
PL	penalty per day for late delivery
PR	ratio of total profit of an order when sharing the order to another company

BT	buffer time for production
Variables:	
I_{cs}	remaining inventory of raw material of company *c* in supply chain echelon *s*
RC_{cs}	remaining capacity of company *c* in supply chain echelon *s*
WT_{ocs}	waiting time of order *o* in the order queue of company *c* in supply chain echelon *s*
RO_{cs}	remaining number of orders waiting in the queue of company *c* in supply chain echelon *s*
RP_{cs}	remaining number of products for production in company *c* in supply chain echelon *s*
OS_{ocs}	order size for order o from company *c* in supply chain echelon *s*
LT_{ocs}	demanded lead time for order *o* from company *c* in supply chain echelon *s*
PI_{ocs}	profit index of order o from company *c* in supply chain echelon *s*
ED_{ocs}	expected delayed days for order *o* from company *c* in supply chain echelon *s*
Decision variables:	

$$\text{Mode} = \begin{cases} 0, traditioanl\ supply\ chain\ model \\ 1, supply\ chain\ model\ with\ outsourcing\ mechanism \\ 2, new\ collaborative\ suppy\ chain\ model\ with\ SCCSP \end{cases}$$

Based on the introduction of textile SC in Section 5.1, several variables were defined as follows:

$$LT_{ocs} = \frac{OS_{ocs}}{PD_{c(s+1)}} + BT \tag{5.1}$$

$$LT_{ocs} = LT_{oc(s-1)} - WT_{ocs} - \frac{O_{Socs}}{PD_{c(s+1)}} \tag{5.2}$$

$$OS_{ocs} = MI_{cs} - I_{tcs} + RM_{ts} \times OS_{oc(s-1)} \tag{5.3}$$

$$ED_{ocs} = OS_{ocs}/PD_{cs} + max\ (RP_{cs}/PD_{cs}, LT_{ocs}) + WT_{ocs} - LT_{oc(s-1)} \tag{5.4}$$

Equation (5.1) defines demanded lead time for an order which is only used for replenish raw material inventory. Equation (5.2) defines demanded lead time for an order which is used for production when a company has no sufficient inventory of raw material but still can accomplish the order in time. Equation (5.3) defines demanded order size for order *o* from company *c* in SC echelon *s*. Equation (5.4) defines expected delayed days for order *o* from company *c* in SC echelon *s*.

Constraints and assumptions:

1) Condition for a company start production for received order:

$$\begin{cases} I_{tcs} > RM_{ts} \times OS_{oc(s\text{-}1)} \\ RC_{cs} > 0 \end{cases} \quad (5.5)$$

Condition for a company to replenish raw material:

$$I_{tcs} - R_{Mts} \times O_{Soc(s-1)} < ROP_{cs} \quad (5.6)$$

2) Condition for a company to share order to the platform/for a big company to outsource the order:

$$\begin{cases} RS \times ED_{ocs} \times PL > PR \times PI_{oc(s\text{-}1)} \\ ED_{ocs} > 0 \end{cases} \quad (5.7)$$

3) Condition for selecting company *x* for shared order:

$$\begin{cases} I_{xs} > RM_{xs} \times OS_{oc(s\text{-}1)} \\ RC_{xs} = max\, RCcs > 0 \\ RO_{xs} = 0 \end{cases} \quad (5.8)$$

5.3.2 Multi-agent simulation modelling

In this sub-study, multi-agent-based simulation technology was utilized to realize and analyze aforementioned model with corresponding parameters, variables, rules, assumptions and constraints. Agent-based simulation, derived from the field of artificial intelligence, can provide "an innovative and insightful way to examine SC structure and management problems"(Ge et al. 2015), it is "a great support in methodology and technology for SC network modelling and analysis"(Long 2014). It has been successfully used in SC research in past decades (e.g. (Akanle & Zhang 2008; Huang & Song 2017; Pan & Choi 2016; Garcia-Flores & Wang 2002)). In agent-based simulation, agents play a vital role. Agents have been regarded as one of the most appropriate tools to convey information and to represent real world (Pan & Choi 2016). Three types of agents were defined in the simulation model. Their definitions and internal structures were introduced as follows.

a. Retailer Agent Type

Retailer agent type represents retailers in textile SC. It is responsible for stochastically generating garment production orders and sending them to corresponding garment manufacturers.

b. Supplier Agent Type

Fabric manufacturers, dyeing manufacturer and garment manufacturer in textile SC belong to supplier agent type. Each supplier agent contains process and logic for receiving order, production and placing order for raw material.

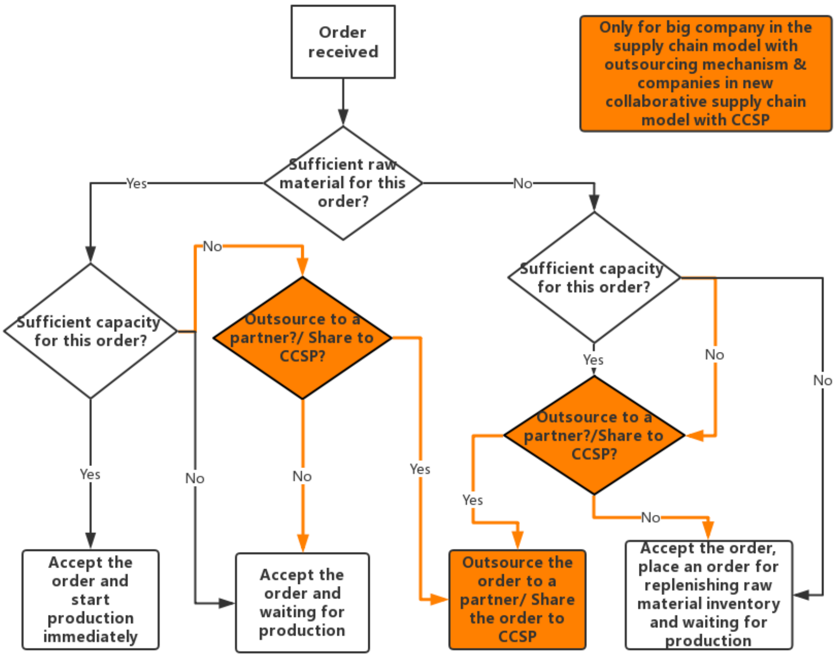


Figure 5.5. Flowchart of decision-making process within supplier agent type.

Each supplier agent has four alternative statuses when an order is received:

1) receive the order with sufficient capacity and raw material;
2) receive the order with sufficient capacity and insufficient raw material;
3) receive the order with insufficient capacity and sufficient raw material; and
4) receive the order with insufficient capacity and insufficient raw material.

According to the condition for start production (Equation (5.5)) and condition for share order (Equation (5.7)), one out of five possible actions was chosen as follows:

1) accept the order and start production immediately;
2) accept the order and waiting for production;
3) accept the order, place an order for replenishing raw material inventory and wait for production;
4) outsource the order to a partner (only applicable for big company in the SC model with outsourcing mechanism); and
5) share the order to CCSP (only applicable in new SC model with CCSP).

The flowchart of decision-making process within supplier agent type is indicated in Figure 5.5.

c. Collaborative cloud service platform agent

In the simulation model, CCSP is a unique agent type. Supplier agent sends demand to this agent if supplier decides to share the order. Once a demand is received in this agent type, the SPSH as introduced in Section 5.2.2 is activated. Based on Figure 5.4, the general java code of SPSH in the agent-based simulation model is illustrated as follows:

```
for (c = 0; c < C; c++)
{
if (supplier[c].OrderQueue.size()>0)
break;
if (supplier[c].RawMaterialQueue.size()<RawMaterialNeeded)
break;
if
(supplier[c].Machine.idle()>SelectedSupplierForSharingOrder.Machine.idle()
SelectedSupplierForSharingOrder = supplier[c];
}
```


5.3.3 Evaluation Criteria

To evaluate and compare the performance of three SC models, five SC key performance indicators (KPIs) were defined as criteria, as follows:

- Unit cost = (Total inventory cost + Total late delivery penalty + Total raw Material Cost)/Yield of a company
- Average lead time: The average duration in a company from receiving an order to completing the order
- Facility utilization = Effective machine operating time/Total working time of a company
- Delayed order percentage = Total number of not-on-time completed order/Total number of completed order of a company
- Yield: The total number of products produced in a company in the given period of time

The five KPIs served as output of the simulation. They covered various perspectives of a SC, e.g., financial perspective, customer satisfaction perspective, efficiency perspective and operation perspective. Therefore, the model could be evaluated comprehensively according to the five KPIs.

5.4 Experiment based on a case in a Chinese garment company

5.4.1 Input Parameters in the Simulation

Data was collected from a big textile company located in Jiangsu Province, China. This company applied make-to-order strategy for production and had many SME partners to implement outsourcing mechanism. Several interviews were also conducted with professionals working in textile industry. In the simulation model, there are 50 companies (1 big company and 49 SMEs) in each SC echelon. The differences between big company

Table 5.1 Input parameters

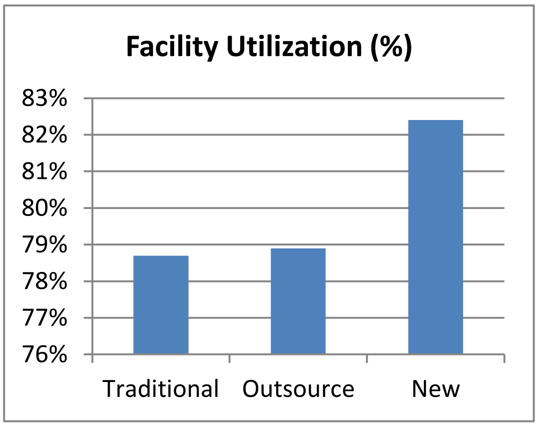
	Big Apparel Manufacturer	Apparel Manufacturing SMEs	Big Dyeing Manufacturer	Dyeing SMEs	Big Fabric Manufacturer	Fabric Manufacturing SMEs
PC_{cs}	120 sewing machines	Uniform (30, 40) sewing machines	8 dyeing machines	Uniform (2, 3) dyeing machines	12 weaving machines	Uniform (5, 8) weaving machines
PT_{cs}	35 min	35 min	420 min	420 min	2.08 min	2.08 min
MI_{cs}	8000 m	Uniform (2000, 4000) m	16,000 m	Uniform (4000, 8000) m	Infinity	Infinity
ROP_{cs}	4000 m	Uniform (1000, 2000) m	8000 m	Uniform (2000, 4000) m	-	-
WT_{cs}	8 h/day	8 h/day	8 h/day	8 h/day	8 h/day	8 h/day
RM_s	Uniform (1.5, 2) m/piece	Uniform (1.5, 2) m/piece	1 m/m	1 m/m	-	-
P_s	Uniform (5, 15) CNY/piece	Uniform (5, 15) CNY/piece	Uniform (0.5, 1.5) CNY/m	Uniform (0.5, 1.5) CNY/m	Uniform (0.5, 1.5) CNY/m	Uniform (0.5, 1.5) CNY/m
OS_{or}	Uniform (30, 1000) pieces/order	Uniform (30, 1000) pieces/order	-	-	-	-
OR_r	60 orders/month	Uniform (15, 20) orders/month	-	-	-	-
LT_{or}	Triangular (5, 20, 30)	Triangular (5, 20, 30)	-	-	-	-
CI	40,000 CNY/month	Uniform (10,000, 20,000) CNY/month	40,000 CNY/month	Uniform (10,000, 20,000) CNY/month	40,000 CNY/month	Uniform (10,000, 20,000) CNY/month
PL	500 CNY/day	500 CNY/day	500 CNY/day	500 CNY/day	500 CNY/day	500 CNY/day
PR	50% (outsourcing)/ 70% (CCSP)	50% (outsourcing)/ 70% (CCSP)	50% (outsourcing)/ 70% (CCSP)	50% (outsourcing)/ 70% (CCSP)	50% (outsourcing)/ 70% (CCSP)	50% (outsourcing)/ 70% (CCSP)
BT	Uniform (5, 10) days	Uniform (5, 10) days	Uniform (5, 10) days	Uniform (5, 10) days	Uniform (5, 10) days	Uniform (5, 10) days

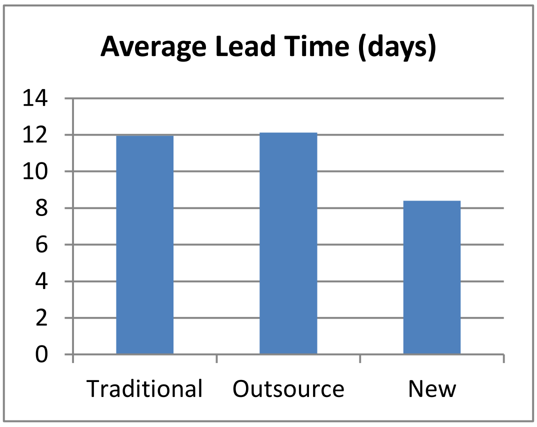
and SMEs are reflected in their capacity scale, warehouse scale and order arrival rate per month. Only one type of production was considered, namely the production of shirt, to reduce the complexity of simulation model. It is also assumed that the raw material inventory of all fabric manufacturers is infinity, as they are on the most upstream echelon in the SC model. The PR are different between outsourcing mechanism and sharing to CCSP, as big manufacturer has leading power in the SC model with outsourcing mechanism while CCSP provides an equal position for all players on the platform. Discrete uniform distribution was employed on some input parameters to make sure every company is unique. Probability distribution was also used for order size and demanded lead time, so that every order placed by customer is stochastic and different from each other. Based on collected data, interviews and aforementioned discussions, input parameters were defined for the simulation model, as shown in Table 5.1.

5.4.2 Experiment results and discussion

Three SC models for 30 replications, respectively, in simulation for a duration of 180 days. For each replication, the seed of random number generator was same for three models to guarantee the validation of comparison. Output data was processed and five predefined KPIs of each company were calculated in each replication. Then, the average value of KPIs was calculated for big company, SMEs and whole cluster (all companies) in each SC echelon in each replication. As assumed that the inventory is infinite for fabric manufacturing echelon, companies in this SC echelon were not taken into consideration for further analysis. Finally, the range of each KPIs was obtained and the 95% confidence interval (CI) for mean of 30 replications was also calculated. The output data obtained by simulation of SC model with outsourcing mechanism are close to the real data collected from the company in Jiangsu, China. Besides, the simulation model was built step by step, as introduced in Section 5.3.2. The strict debugging process was undertaken strictly. Therefore, the simulation model could be regarded as representative and validated to this case.

The comparisons of mean value of each KPIs of different clusters and companies are shown in Figures 5.6–5.9. Based on Figures 5.6 and 5.7, a pattern was found that new proposed SC model performed much better for the whole textile industry cluster in all aspects compared to traditional SC model and SC model with outsourcing mechanism. For garment manufacturer cluster, the improvement was remarkable in the new model in terms of average lead time, unit cost and delayed order percentage: at least 29.62% improvement was obtained. For dyeing manufacturer cluster, the improvement was also significant in new model in terms of unit cost and delayed order percentage, with at least 26.63% improvement compared to the two other models. Therefore, the proposed SC model with CCSP is optimal choice for textile industry cluster in each SC echelon. If SC model with outsource mechanism was compared to traditional SC model, the difference is not significant at all: slight improvements were obtained in some aspects, while declines were also discovered in other aspects. Therefore, outsourcing mechanism cannot bring general benefits to the whole textile industry cluster.





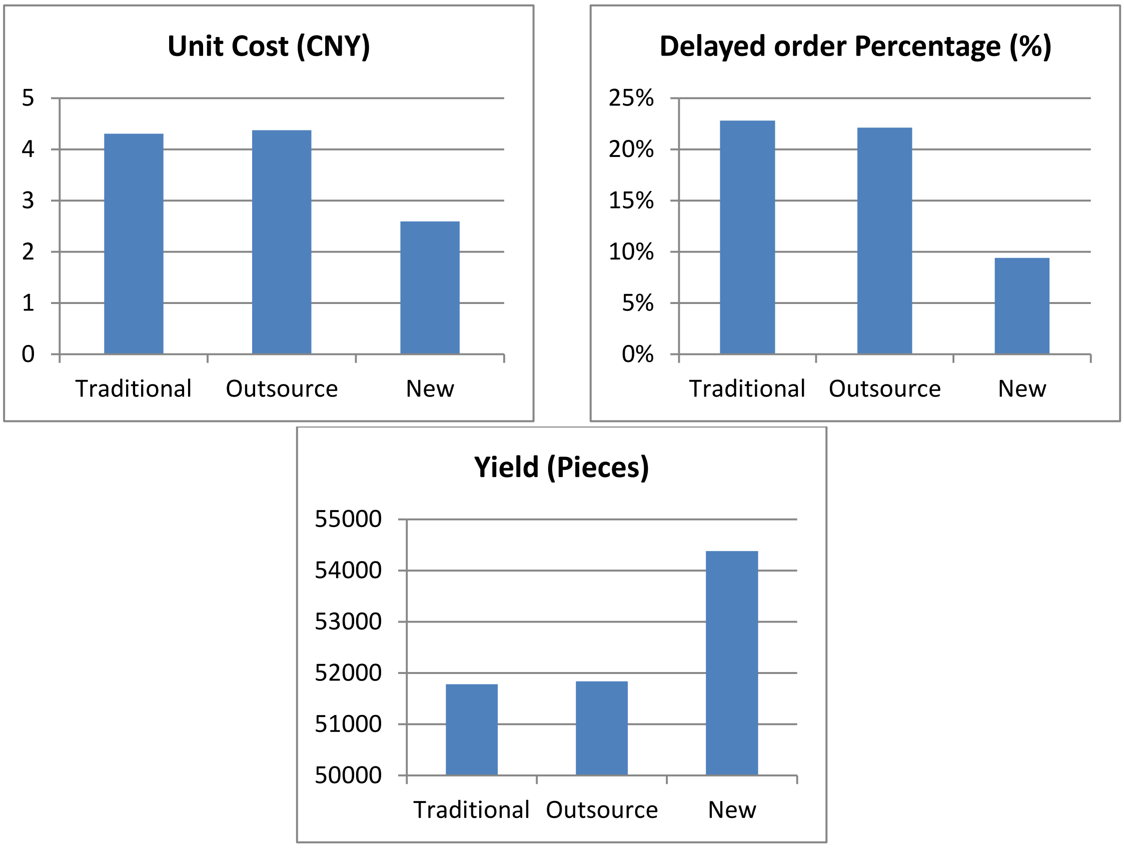


Figure 5.6 KPIs of garment manufacturer cluster

According to Figure 5.8, the influence of outsourcing mechanism and CCSP on garment manufacturers of different scales was obtained. For big garment manufacturers, outsourcing mechanism significantly increased their SC performance in all checked aspects, especially in terms of average lead time, unit cost and delayed order percentage, with a dramatic raise of 40.21–92.86% compared to traditional SC model. Outsourcing mechanism performed much better than new SC model with CCSP in these three aspects. However, its improvements were not as high as new SC model in terms of facility utilization and yield. This is because big manufacturers outsource many orders to their SME partners, thus they are not always in full workload. Therefore, outsourcing mechanism is a better choice for big garment manufacturers. For garment manufacturing SMEs, the effect is different. The performance of SC model with outsourcing mechanism and traditional SC model were almost the same in five checked aspects. It is expected that SMEs could get increase in facility utilization and yield, as they may receive additional orders from big garment manufacturers. However, it is not reflected in the simulation model. On the other hand, new collaborative model helps garment manufacturing SMEs achieve dramatic upgrade in all five KPIs. Therefore, CCSP can bring comprehensive benefits to garment SMEs.

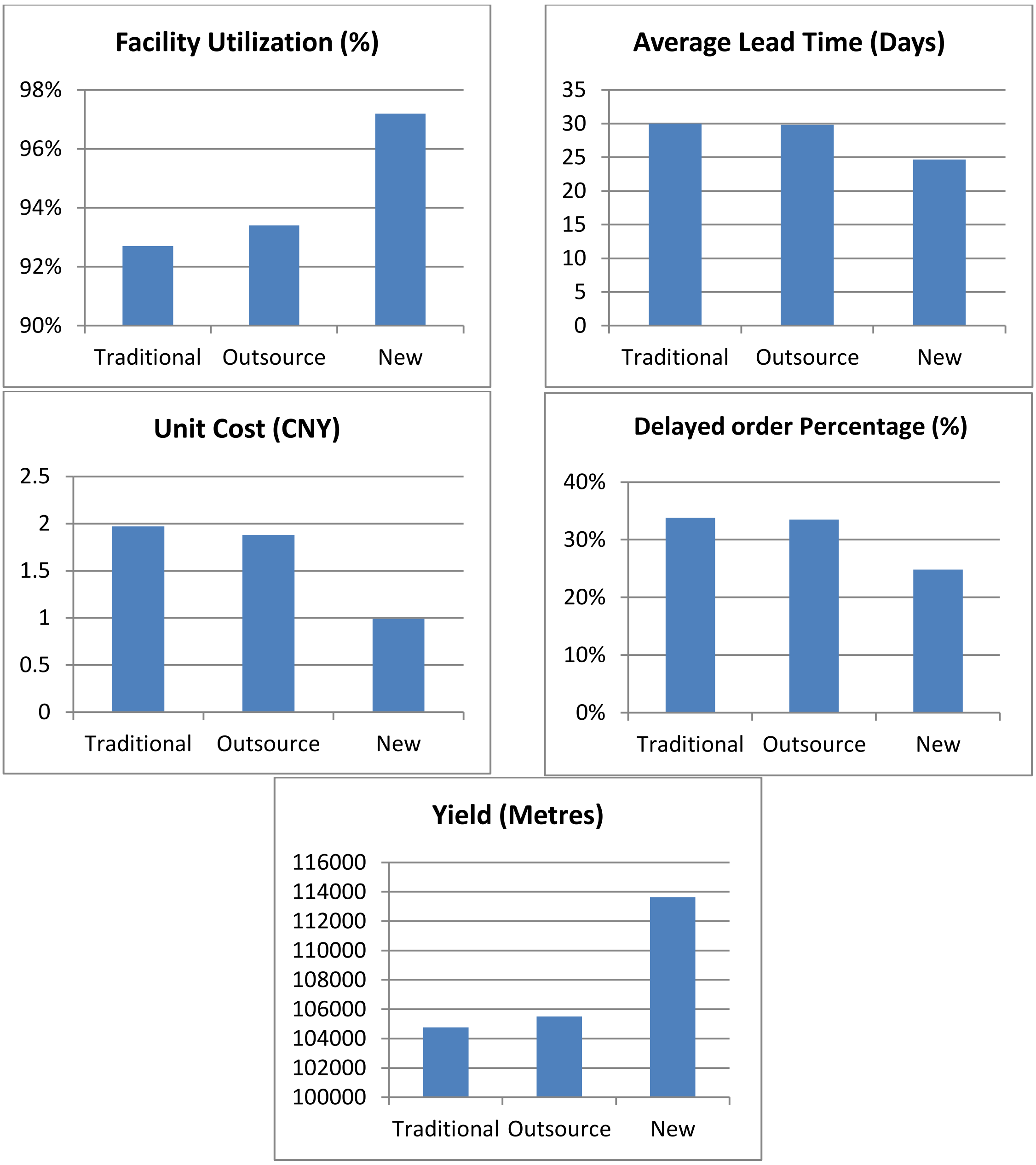


Figure 5.7 KPIs of dyeing manufacturer cluster

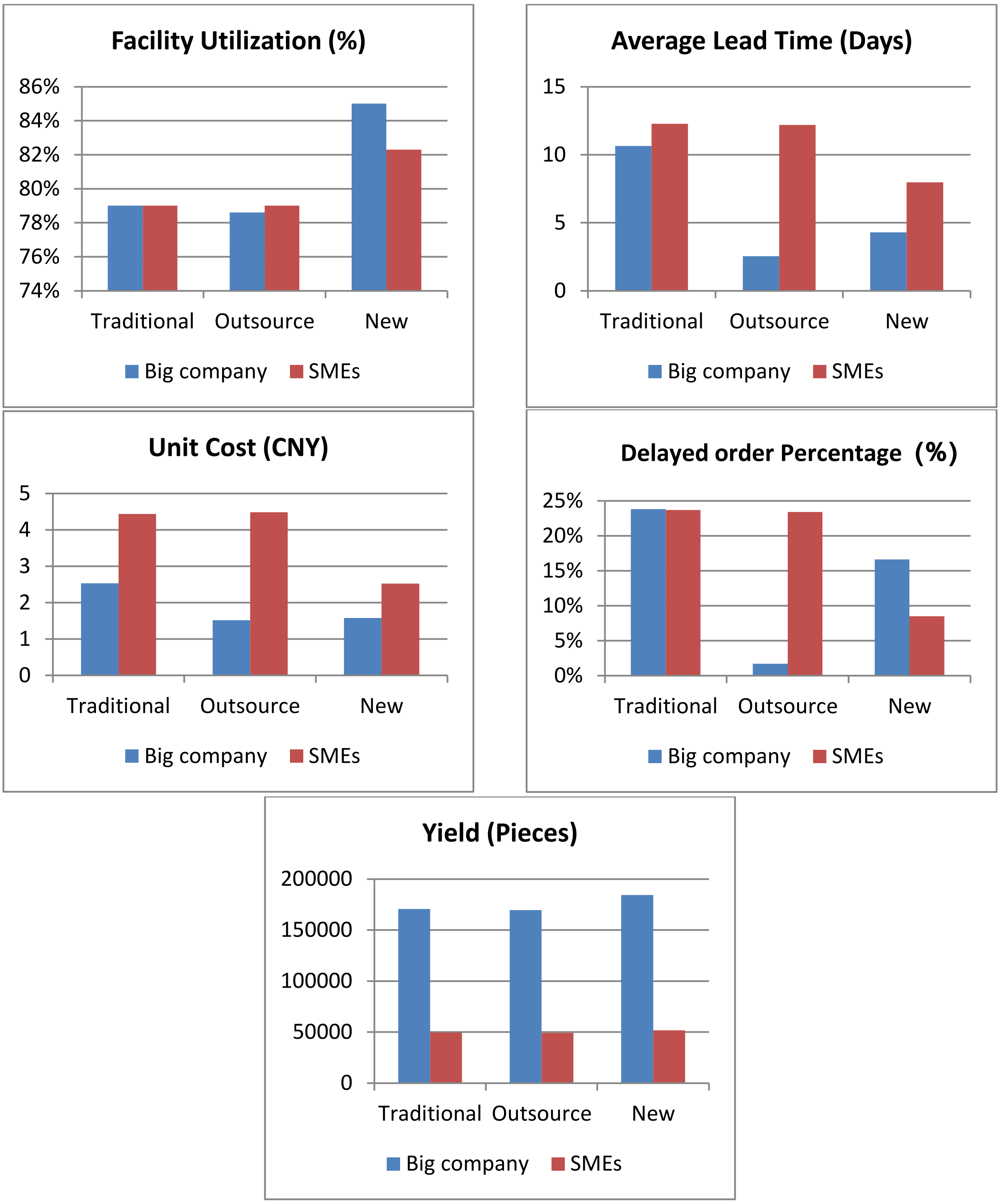
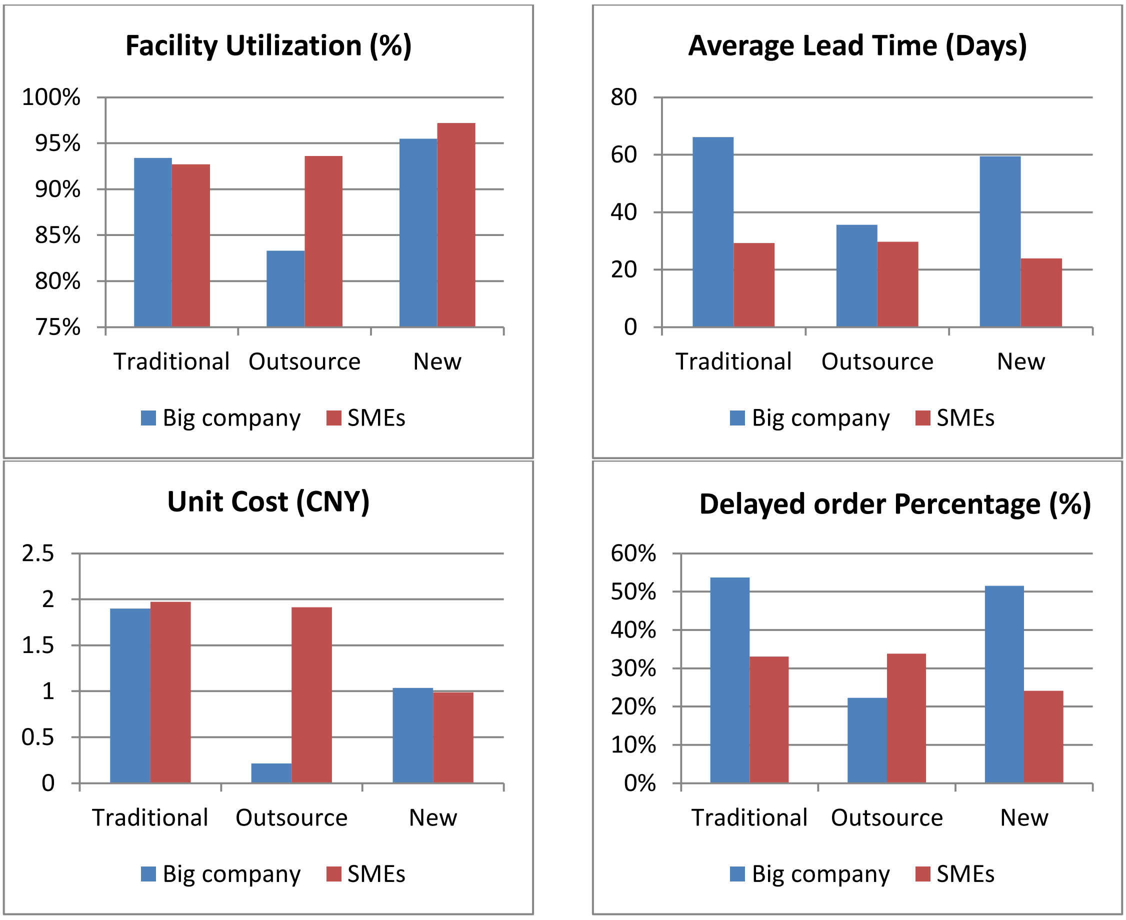


Figure 5.8. KPIs of big garment manufacturer and garment manufacturing SMEs

According to Figure 5.9, the influence of outsourcing mechanism and CCSP on dyeing manufacturers of different scales was obtained. Similar pattern was found as the comparison for big garment manufacturer. Remarkable improvements were obtained with outsourcing mechanism in terms of average lead time (a 46.11% decrease), unit cost (an 88.8% decrease) and delayed order percentage (a 58.47% decrease). However, there is also a 10.81% decrease in facility utilization and 16.20% decrease in yield of big dyeing manufacturer compared to traditional SC model, which are unexpected. Even though there is no dramatic difference between new collaborative model and traditional model, every checked KPI was improved to some extent in the new model. For dyeing SMEs, same conclusion could be got as outcome for garment manufacturing SMEs. SC performances of dyeing SMEs are almost the same in outsourcing mechanism and traditional model. Improvements in all aspects (from 4.85% to 49.87%) were achieved in the new model for dyeing SMEs. Therefore, CCSP is the optimal scenario for dyeing SMEs in textile SC.



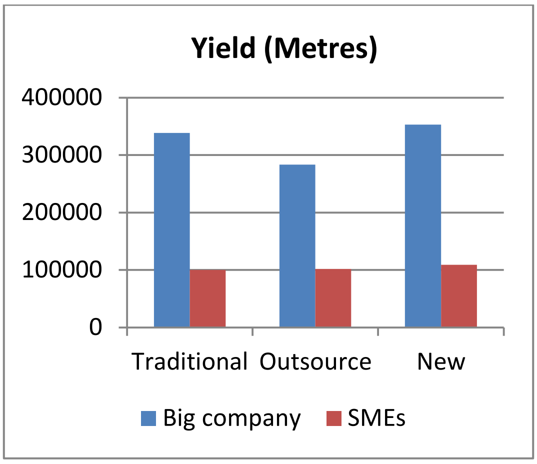


Figure 5.9. KPIs of big dyeing manufacturer and dyeing SMEs

5.5 Conclusions

In this sub-study, a collaborative cloud service platform was developed to create a collaborative make-to-order textile SC model. A service provider selection heuristic was designed for the platform to select optimal supplier corresponding to each demand received by the platform. Multi-agent-based simulation technology was utilized to build the proposed platform and to evaluate new collaborative SC model. Simulation experiment was also conducted to compare the new model to traditional textile make-to-order SC model and SC model with outsourcing mechanism. Based on simulation experiment results, the remarkable advantage of the proposed collaborative SC model with CCSP was demonstrated. The following conclusions were also obtained:

- In general, CCSP can bring comprehensive benefits to companies in every echelon of textile SC, namely dyeing manufacturing echelon and garment manufacturing echelon. CCSP integrates information sharing, resource sharing, joint decision-making and profit sharing into one novel SCC model, which is an innovative approach to enhance SC performance and overcome defects in current make-to-order textile SC.

- The SPSH heuristics can provide optimal solution in decision-making for service provider selection. Therefore, optimal resource allocation was achieved in textile SC, leading to significant improvements in multiple aspects of SC performance.
- Outsourcing, as a widely used mechanism in textile industry currently, is not an optimized choice in terms of SC performance for the whole cluster in textile industry. There is no significant difference in terms of SC performance of whole cluster between make-to-order textile SC model with outsourcing mechanism and traditional make-to-order textile SC model.
- Outsourcing mechanism is still an outstanding scenario for big company in textile industry. Although the proposed new model can, to some extent, improve SC performance of big companies, outsourcing mechanism can bring much higher improvements in some aspects, e.g., average lead time, unit cost and delayed order percentage.
- The new model with CCSP helps textile SMEs obtain dramatically enhanced performance in make-to-order textile SC. It provides a service platform for small businesses in textile industry to collaborate and share with each other for increasing both overall and individual competitive power. It is the optimal and desirable choice for textile companies, especially textile SMEs, to survive and become competitive in the future trend of textile SC.

6. Discussions, conclusions and future perspectives

6.1 Summary of the thesis

The results of the systematic literature review on supply chain collaboration provided directions and theoretical base for the research, it also forms the basis for the research questions that guide this research. Three sub-studies are conducted in this thesis to address the three formulated research questions respectively. The relationship between each sub-study is illustrated in figure 6.1 below.

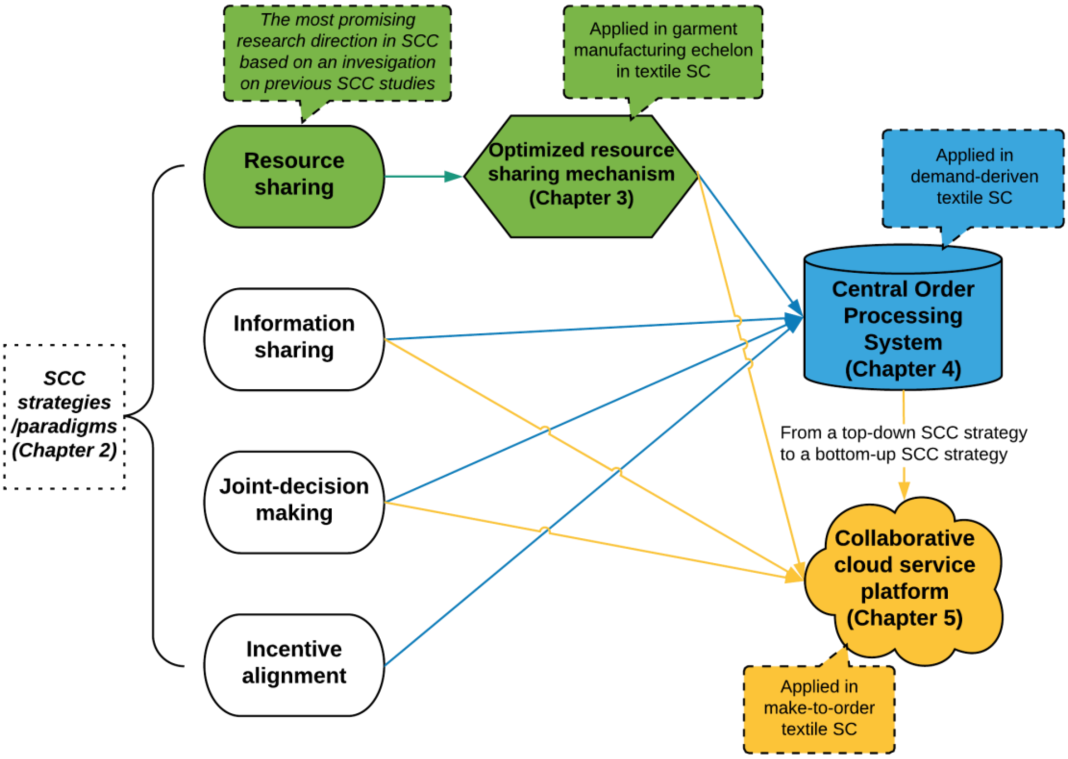


Figure 6.1 SCC strategies, sub-studies and their relations

The first sub-study (green colour in Figure 6.1) proposed a resource sharing mechanism and employed it as the main supply chain collaboration approach on garment manufacturing echelon. The motivation for conducting this sub-study is considering resource sharing as the most promising research direction in supply chain collaboration, which is concluded in the literature review regarding supply chain collaboration (Chapter Two). A simulation-based heuristic was designed for generating the optimal resource sharing scenario based on multi-criteria objective. A discrete-event simulation model was built to experiment the novel mechanism. Finally, the benefit of proposed resource sharing mechanism was demonstrated.

Based upon the result of sub-study 1, the implementation of supply chain collaboration strategy was then extended to the whole supply chain. A collaborative model in the second sub-study (blue colour in Figure 6.1) was developed for optimizing demand-driven textile supply chains. Under a top-down structure, a central order processing system was designed by merging the resource sharing mechanism proposed previously and other supply chain collaboration strategies identified in the review study. Discrete-event simulation technology was utilized to experiment the new collaborative model under different conditions. Based on simulation experiment results, the advantages of the central system were demonstrated. The conditions for pursuing better performance of its application were also presented.

Finally, the last sub-study (yellow colour in Figure 6.1) developed a collaborative cloud service platform, aiming at optimizing make-to-order textile supply chain. For the sake of the characteristic of make-to-order supply chain, the platform was built based on a bottom-up method. Supply chain collaboration strategies identified in the literature review, such as resource sharing, information sharing and joint decision making were included in the platform. A service provider selection heuristic was developed for the platform to select optimal supplier corresponding to each demand received by the platform. Multi-agent-based simulation technology was employed to realize the platform and experiment the new model. Supply chain performances of the textile supply chain model with cloud platform were compared to two existing typical make-to-order supply chain models, viz. traditional model and outsourcing model. On the basis of simulation experiment, the advantages of this model were demonstrated. The collaborative cloud service platform can bring remarkable benefits to textile SMEs.

6.2 **Discussion**

- RQ1: What are effects of resource sharing mechanism on garment manufacturing?

Table 6.1 Summary of sub-study 1

Sub-study	**Sub- research question**	**Experiment outcome**
Sub-study on Resource sharing (RS) mechanism in garment manufacturing echelon	RQ 1-1: What are effects of resource sharing mechanism on garment manufacturing in terms of efficiency, financial aspect and customer satisfaction? RQ 1-2: What is the optimal RS scenario?	• In general, RS mechanism can bring comprehensive improvement in garment manufacturing for individual garment manufacturers and whole garment manufacturing cluster. • Scenario with highest KPI was different for each multi-criteria objective

The first research question addresses the effects of recourse sharing mechanism on garment manufacturing, as summarized in the table 6.1 above. Based on the results of the simulation experiment, resource sharing mechanism can bring comprehensive improvement in garment manufacturing for individual garment manufacturers and whole garment manufacturing cluster. It aligns with successful resource sharing models/applications in previous research, e.g. a collaborative procurement and sharing model (Keskinocak and Savasaneril, 2008), a capacity sharing model in semiconductor manufacturing industry (Shirodkar and Kempf, 2006) and an energy sharing model in energy supply chain (Soylu et al., 2006).

In current textile supply chain, resource sharing mechanism is rarely applied in the echelons of manufacturing. Garment manufacturers seldom share their resources for the production with other manufacturers due to the intense competitiveness in textile industry. That is even if they may have idle capacity for a short period. Garment manufacturers are reluctant to share their orders to their competitors as well. They always desire to keep orders even though no sufficient resource left to complete the order in time under some circumstances, which would incur penalty for late delivery or low quality. Based on the result of sub-study 2, the more types of orders on which resource sharing is applied, the higher performance is obtained in garment manufacturing, which is contrary to the situation in the real industry. Therefore, garment manufacturers should be opener to the resource sharing strategy with proper partners, even among so-called competitors, as they can achieve more benefits according to this study.

Additionally, scenario with highest KPI is different for each multi-criteria objective. For the time oriented objective, the application of resource sharing mechanism on the production of order type 1,3,5,6 (see Table 3.1 for the representation of each order type) can obtain the optimal supply chain performance. For the efficiency oriented objective, the application of resource sharing mechanism on the production of order type 1,3,4,5,6 can obtain the optimal supply chain performance. For the customer oriented objective, the application of resource sharing mechanism on the production of all order types can obtain the optimal supply chain performance. It is means that the configuration of optimized resource sharing scenario for garment manufacturers depends on the optimization purpose.

- RQ 2: What are effects of application of a combination of identified supply chain collaboration strategies, e.g. information sharing, joint-decision making, resource sharing and profit sharing, on demand-driven textile supply chain?

Table 6.2 Summary of sub-study 2

Sub-study	**Sub-research question**	**Experiment outcome**
Sub-study on Central Order Processing System (COPS) in demand-driven textile supply chain (SC)	RQ 2-1: What advantages are brought to textile SC through COPS? RQ 2-2: If COPS is applied under high workload condition or low workload condition, what is the difference in terms of SC performance? RQ 2-3: If COPS is applied in one SC echelon, what is the difference in terms of SC performance?	• The new proposed collaborative model with COPS got significant improvements in multiple key performance indicators. • COPS provided more significant improvements under high workload condition than under low workload condition. KPIs were significantly improved in new collaborative model under overload condition, while only lead time was significantly improved under low workload condition. • Generally, improvements were achieved in terms of all checked KPIs no matter which echelon applied COPS. Applying COPS in earlier SC echelon could lead to higher improvements in SC performances.

The second research question addresses the effects of the combined application of multiple supply chain collaboration strategies (e.g. information sharing, joint-decision making, resource sharing and profit sharing) on demand-driven textile supply chain, as summarized in the table 6.2 above. A number of previous studies present the benefits of these supply chain strategies. Kuo et al. (2014) improves sustainability in textile and apparel industry by efficiently sharing related information. Zhang (2006) demonstrates the importance of horizontal information sharing between suppliers on inventory status. Chen et al. (2010) proposes a profit sharing contract for the reduction of lead time. In the sub-study 2, these strategies are merged into a Central Order Processing System (COPS), aiming at improving the supply chain performance of demand-driven textile supply chain. Its effect is examined though simulation experiment, showing that the new collaborative model with COPS gets significant improvements in multiple key performance indicators. In finance perspective, COPS could help the whole supply chain gain more profits and reduce cost for each unit of product. Productivity and facility utilization is also increased; thus the efficiency of involved suppliers is improved significantly. Lead time is decreased as well while order completion rate is increased, so that higher customer satisfaction could be obtained. The performances of new collaborative model under different workload conditions are different. On the basis of simulation experiment results, COPS can provide more significant improvements under high workload condition than under low workload condition. The idea of COPS could be regarded as a special temporary strategy in peaking season for textile supply chain. If COPS is only applied in one supply chain echelon, generally, improvements are achieved in terms of all checked KPIs no matter which echelon applied COPS. Applying COPS in earlier SC echelon could lead to higher improvements in supply chain performances.

In demand-driven supply chain, collaboration plays a vital role. Without strong collaboration among suppliers, it would be impossible to implement the core process improvements in a demand-driven supply network (Hadaya and Cassivi, 2007). Demand-driven supply chain has been applied and discussed in several textile studies, e.g. textile supply chain coordination under with energy consumption constraints (Shen *et al.*, 2017) and optimal scheduling and coordination in garment manufacturing with RFID technology (Choi *et al.*, 2018). Studies regarding collaborations in a demand-driven supply chain mainly focus on vertical collaboration, e.g. joint decision making (Hadaya and Cassivi, 2007) and information sharing (Cao, Xiao and Sun, 2017) among players from different echelons of demand-driven supply chains. Thus, the main barrier of previous collaboration practice in textile industry mainly laid on the horizontal collaboration aspect. Horizontal collaborations are hardly implemented in textile supply chain due to the potential competitive relationship among companies in the same supply chain stage. The result of sub-study 2 demonstrates that, in the context of optimizing the whole performance of the supply chain, collaborations must be realized among two or more directly competitive firms in order to maximize the total production capacity and total benefits and fully make use of their complementarity.

- RQ 3: What are effects of application of a combination of identified supply chain collaboration strategies, e.g. information sharing, joint-decision making, resource sharing and profit sharing, on make-to-order textile supply chain?

Table 6.3 Summary of sub-study 3

Sub-study	**Sub-research question**	**Experiment outcome**
Sub-study on Collaborative Cloud Service Platform (CCSP) in make-to-order textile supply chain (SC)	RQ 3-1: What advantages are brought to the whole textile SC through CCSP? RQ 3-2: What is the different effect brought to big companies and SMEs through CCSP?	• In general, CCSP can bring comprehensive benefits to companies in every echelon of textile SC, namely dyeing manufacturing echelon and garment manufacturing echelon. • The new model with CCSP helps textile SMEs obtain dramatically enhanced performance in make-to-order textile SC. It provides a service platform for small businesses in textile industry to collaborate and share with each other for increasing both overall and individual competitive power. It is the optimal and desirable choice for textile companies, especially textile SMEs, to survive and become competitive in the future trend of textile SC.

The second research question addresses the effects of the combined application of multiple supply chain collaboration strategies (e.g. information sharing, joint-decision making, resource sharing and profit sharing) on make-to-order textile supply chain, as summarized in the Table 6.3 above. The successful experiences of these strategies are discussed above. Thus, with similar ideas applied on demand-driven textile supply chain, these state-of-art supply chain collaboration strategies are also considered combined for optimizing make-to-order supply chain It is realized in the developed Collaborative Cloud Service Platform (CCSP) in sub-study 3. The effects of its application are examined through agent-based simulation experiments, addressing the last research question in this research. Based on the simulation result, CCSP can bring comprehensive benefits to companies in every echelon of textile supply chain. The new model with CCSP helps textile SMEs obtain dramatically enhanced performance in make-to-order textile supply chain. It provides a service platform for small businesses in textile industry to collaborate and share with each other for increasing both overall and individual competitive power. It is the optimal and desirable choice for textile companies, especially textile SMEs, to survive and become competitive in the future trend of textile supply chain.

6.3 **Theoretical contributions**

In general, the theoretical contributions of this PhD research are manifold novel inter-organizational collaboration strategies for optimizing existing textile SC model from multiple aspects. In summary, this thesis proposes three novel SCC models and explores their implementations. Relevant research gaps were addressed by the three models with corresponding mechanism, system or platform.

The first proposed SCC model is a garment production model with resource sharing mechanism. Resource sharing is a common SCC strategy and it was a common method applied in horizontal collaboration for better resource utilization and hence for further improvements in supply chain performance. As shown in the literature review (chapter 2), resource sharing was an under-explored theme in previous SCC research. However, resource sharing presents itself as the most promising direction in future SCC research and practice. Resource sharing has been applied in various industries, e.g. transportation sharing (Vilkelis and Jakovlev, 2014) or inventory pooling (Kurata, 2014). However, an extensive literature review has not located any research considered or discussed resource sharing in the textile supply chain. A production model that included a resource sharing mechanism was proposed in this PhD research to bridge the gap. The implementation effect of such mechanism was examined through discrete-event simulation technology.

The second model developed in this research is the collaborative demand-driven textile SC model with Central Order Processing System (COPS). The concept or idea of central planning has been proposed and discussed in previous SC research, e.g. the introduction of Advanced Planning and Scheduling Systems in the first wave of supply chain management. However, such central system suffered many drawbacks. For instance, the optimization was only based on a single objective (Hvolby & Steger-Jensen 2010), individual benefits were less considered and system failed to take the priorities among different partners into account (Lin et al. 2007). The COPS combined both vertical and horizontal collaborations for the demand-driven textile supply chain, integrating information sharing, joint-decision making, resource sharing and profit sharing. In COPS, a classification concept was introduced to take priority among companies into considerations, several supply chain performances were considered so that to achieve comprehensive improvement, and a profit sharing mechanism was also proposed to guarantee individual benefit.

The third SCC model proposed in this research is the collaborative make-to-order textile SC model with Collaborative Cloud Service Platform (CCSP). In recent years, the concept of cloud manufacturing was raised (Xu 2012), although it is still under development. In a nutshell, the idea of cloud manufacturing refers to that customers send orders to a cloud manufacturing central system, and the central system selects the service provider for the customer. However, cloud manufacturing is only concentrated on manufacturing sector (one echelon in SC) but not from a series of SC echelons perspective. Cloud manufacturing is a totally centralized structure; the company can hardly maintain their own decision rights (Zhang et al. 2017), which is hardly accepted in the highly competitive textile industry. In this research, a “service to business to customer” (S2B2C) structure was developed by the designed CCSP. Although the SCC level among companies is enhanced, companies maintain their individual right to make decision of whether to keep an order or use the cloud service.

In addition to the theoretical contributions above, this thesis also develop and use different methods for data analysis and optimization. These methods - listed below - contribute, and can be applied, to research domains also outside that of textile supply chain management, e.g. supply chain in general and operations research.

- The comprehensive KPI based on extended-ANP approach is developed for multi-criteria evaluation of resource sharing scenarios. The KPI balanced the financial factor and manifold SC performances. It could be utilized in future research to evaluate the overall SC performance of a model, a mechanism or a strategy.
- The simulation-based optimization heuristic is an innovative method. It could reduce the running time and iterations for simulation-based optimization, it helps to derive the optimal scenario faster. The idea of such method could be used in future SC research, especially for research employed simulation-based optimization.
- In COPS, the algorithm for order distribution is novel method in order management. Based on defined criteria (capacity and priority), the algorithm could help COPS distribute every received textile production order to the most appropriate supplier. The

principle of this algorithm could be extended to other SC research regarding SC arrangement by defining appropriate criteria.

- To process collected data regarding orders, an order classification approach is designed in this research. Garment production orders are initially classified into fashion-forwarded type and daily basic type. On the basis of the production time, three levels are defined for each type. Thus, six types of orders are defined. The classification method could be used in future textile research.
- In the collaborative cloud service platform, a service provider selection heuristic (SPSH) is developed for the decision-making system. SPSH is an original method for selecting the optimal supplier corresponding to each received demand on the basis of capacity, raw material inventory and profit level. The principle of SPSH could be employed for similar purpose in other SC research by defining appropriate screening criteria.

6.4 Practical contributions

The effects of each proposed SCC models under different conditions for textile industry were examined based on simulation-based experiments in this research. They formed the practical contributions of this PhD research. This will give managers in the textile industry an understanding of the criteria and conditions for implementation of each SCC mechanism, system or platform. The conclusions of this research can help managers making decision on the utilization of SCC strategy. For example, the most suitable garment type which should apply resource sharing mechanism in production, or the season which should implement central order processing system in textile SC. Practically, the outcome of this thesis could be applied in the whole textile SC. Textile companies, especially SMEs, could benefit from the suggested SCC models with corresponding mechanism, system and platform proposed in this research. Textile companies can increase their multiple SC performances, e.g. reduction of lead time and cost, growth of productivity and flexibility, so that to improve their competences in future textile industry with the trend of sustainable production, mass customization, small-series production.

Although this research is aiming at textile industry, the conceptual models with corresponding evaluation outcomes can also be instructive to other industries, especially to those which have similar SC structure, e.g. footwear industry. Companies from other industries can implement the models proposed in this PhD research for optimization by slightly modifying parameters or structures to meet the characteristics of their industry.

6.5 Limitations and perspectives in future research

Three SCC models are proposed for optimizing textile supply chain in this research. Their advantages under distinct environments are all demonstrated through simulation models. Nonetheless, to see the realistic and practical effect of all models on real industry, the proposed system or platform would be required to develop in real-world system. However, it also requires more time and resources. Therefore, to build the real systems/platforms and to implement them in real industry is the most interesting direction for future research based upon the contributions of this thesis.

The three SCC models proposed in this research also have some limitations. The resource sharing mechanism only concentrates on collaborations between garment manufacturing SMEs. It would be beneficial to explore the influence of RS on organizations with different scales and for different types of resource in future SC research, such as joint raw material inventory or joint transportation. The COPS proposed in this thesis distributes orders/selects supplier mainly depending on the capacity and priority of candidate suppliers, more criteria are expected to be included to improve current system. The priority of suppliers is determined in COPS; to improve the system's performance, the definition of the dynamic priority of suppliers could be extended to include e.g. their collaborative experiences or number of collaborative times. As the change of ratio for profit sharing has opposite influence on the profits of suppliers with relatively high capacity and suppliers with relatively low capacity, it becomes "a game" between supply chain players with different capacities when collaborating through COPS. Therefore, a dynamic selection of ratio may improve current system so that to guarantee all individual companies can always get an increase of profit. The influence of CCSP on logistics activities is not considered. Also, future research could focus on the effect of CCSP on logistics aspects under distinct conditions, as logistics is one of the most important parts in SC. Besides, CCSP only provides a platform for companies to share their redundant resource and orders which they cannot complete. Finally, additional intelligent functions could be integrated into the platform, e.g., collaborative raw material purchase.

Supply Chain Collaboration is the ontology of this PhD research. “Sharing economy” has become an important concept in business model nowadays, gradually changing our society structure from individual lifestyles to industrial supply chains in the past decade. Based on the systematic investigation and analysis on literatures regarding SCC, resource sharing is a salient direction for future research in SCC. It is anticipated to have more studies concentrating on resource sharing considering it to be still less explored area, but at the same time showing higher level of inter-organizational collaboration in SCs and businesses. As aforementioned in Section 6.3, although this research is focused on textile supply chain, the designed system and corresponding collaborative model can also have implications in supply chain of other industries. These models can be modified and implemented in other industries based on characteristics of the applied industry. These are expected to be discussed in future research.

The concept, structure and heuristic used in the three SCC models in this research provides direction for future research in SC and textile management; it can also be useful in current industry trends such as Internet of Things, industry 4.0, intelligent system and mass customization. Those models could also be a starting point for the ideal C2B model in future textile SC. In general, the content presented in this thesis has a wide scope, it concerns current issues and topics of high interest for the field of supply chain and textile management, and it will hopefully inspire future research in multiple directions.

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Appendix: Publications

1. Ma, K., Thomassey, S. and Zeng, X., 2018. A collaborative platform with negotiation mechanism for make-to-order textile supply chain: a study based on multi-agent simulation. Accepted by the 13th International FLINS conference on Data Science and Knowledge Engineering for Sensing Decision Support.

2. Ma, K., Thomassey, S. and Zeng, X., 2018. A new collaborative model for demand-driven supply chains：a case study on textile industry. Presented on the conference Functional Textiles and Clothing Conference 2018

3. Ma, K., Wang, L. and Chen, Y., 2017. A Collaborative Cloud Service Platform for Realizing Sustainable Make-To-Order Apparel Supply Chain. Sustainability, 10(1), p.11.

4. Ma, K., Wang, L. and Chen, Y., 2017. A Resource Sharing Mechanism for Sustainable Production in the Garment Industry. Sustainability, 10(1), p.52.

5. Ma, K., Thomassey, S. and Zeng, X., 2017. Simulation modelling of central order processing system under resource sharing strategy in demand-driven garment supply chains. In IOP Conference Series: Materials Science and Engineering (Vol. 254, No. 20, p. 202004). IOP Publishing.

6. Ma, K., Gustafsson, E. and Pal, R., 2016. Simulation modelling of resource sharing in inter-organizational supply chain collaboration within garment industry. In Uncertainty Modelling in Knowledge Engineering and Decision Making: Proceedings of the 12th International FLINS Conference (pp. 770-777).

7. Ma, K., Gustafsson, E. and Pal, R., 2015. Identifying inter-organization collaboration types and research advancements in supply chain context. In Proceedings of the 20th International Symposium on Logistics (pp. 165-172). Centre for Concurrent Enterprise, Nottingham University Business School.