SUPPLY CHAIN PERFORMANCE MEASUREMENT IN TEXTILE AND APPAREL INDUSTRIES

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CERTIFICATE OF ORIGINALITY

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Abstract

In this thesis, one important issue of Supply Chain Management (SCM), that is Supply Chain Performance Measurement (SCPM) in textile and apparel industries has been addressed. The final objective of the study is to provide a practical tool for SCPM in textile and apparel industries. To achieve this objective, a hierarchical system for SCPM was firstly set up. A combined fuzzy multiple attributes evaluation (CFMAE) method was then developed to obtain the index value of supply chain performance.

Multiple methodologies were utilized in this study. Based on literature review, the modified Delphi technique was employed to solicit best thinking from supply chain related managers and experts in textile or apparel companies or related organizations. The result was used to construct the SCPMS in textile and apparel industries. A CFMAE method was then developed. A comprehensive questionnaire for a mail survey was conducted to assist in the evaluation model. The questionnaire survey was completed by 77 senior managers related to SCM, who were from Hong Kong and mainland China. Based on above two stages, a SCPM online system was developed for application in reality. PHP and MySQL were employed for the online system development.

The SCPMS developed in this study have two hierarchies. The first level include eight attributes, which are supply chain product development, supply chain cost, supply chain time, supply chain quality, supply chain flexibility, supply chain information sharing, supply chain innovativeness and supply chain profitability. The eight attributes for the first level are further decomposed into 35 operational metrics in the second level, respectively. Three stages comprise the CFMAE method. The first stage was to obtain the evaluation values for the eight attributes, and fuzzy measure and fuzzy integral were employed. The second stage was to obtain the weights of the first-level attributes, employing fuzzy analytical hierarchy process (FAHP). The weight of supply chain profitability is the highest with the number of 0.2087. Followings are supply chain cost, 0.1863; supply chain time, 0.1565; supply chain product development, 0.1321; supply chain quality, 0.1179; supply chain information sharing, 0.0987; supply chain flexibility, 0.0626; and supply chain innovation, 0.0373. A MATLAB program was developed for the process of fuzzy measure and fuzzy integral. The third stage was simple additive weight (SAW). The online SCPMS is then developed for practical use.

LIST OF PUBLICATIONS

Referred Journal Papers

1. Cao, N., Zhang, Z. M., To, K. M. and Ng, K. P. (2005), "Structures of Textile-apparel Supply Chain: Concepts and Cases", *Journal of Dong Hua University*, Vol. 22 No. 2, pp. 130-134.

2. Zhang, Z. M., To, K. M. and Cao, N. (2004), "How do industry clusters success: a case study in China's textiles and apparel industries", *Journal of Textile and Apparel, Technology and Management,* Vol. 4, Iss. 2.

3. Cao, N., Zhang, Z. M., To, K. M. and Ng, K. P. (2005), "Several structures of textile-apparel Supply Chain", *Supply Chain Research*, *Peking University Luen Tai Center for Supply Chain System Research & Development,* Vol. 1, pp.14-17.

4. Cao, N., Zhang, Z. M., To, K. M. and Ng, K. P., "How are supply chains coordinated: An empirical observation in textile-apparel businesses", *Journal of Fashion Marketing and Management (Accepted).*

5. Zhang, Z. M., Lei, J. S., Cao, N., To, K. M. and Ng, K. P., "Evolution of Supplier Selection Criteria and Methods", *Chinese Journal of Management Science. (Submitted)*

Conference Papers

6. Cao, N., Zhang, Z. M., To, K. M. and Ng, K. P., "Structures of Textile-apparel Supply Chain: Concepts and Cases", 4th AUTEX Conference 2004, June 22-24, Roubaix, France.

7. Zhang, Z. M., To, K. M. and Cao, N., “Industrial Clustering of Textiles and Apparel in China: A Case Study”, 4th AUTEX Conference 2004, June 22-24, Roubaix, France.

8. Zhang, Z. M., Cao, N., and Ng, K. P., “Information search behaviors of apparel shoppers in Hong Kong”, 4th AUTEX Conference 2004, June 22-24, Roubaix, France.

9. Zhang, Z. M., Lei, J. S., Cao, N., To, K. M. and Ng, K. P., “Evolution of Supplier Selection Criteria and Methods”, Globelics Conference 2004, Innovation Systems and Development: Emerging opportunities and Challenges, October 16-20, Beijing, China.

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Chapter 1 Introduction

1.1 Research Background

No one can dispute the fact that today's textile and apparel industries are still making a significant contribution to many national economies both in the developing and developed world (Abernathy *et al.*, 2004; Dickerson, 1995; Dicken, 1998; Jones, 2002). In 2003, international trade in textile and apparel industries reached US$395 billion, representing 5.4% of world trade, and it has been growing faster than world trade as a whole (Singhal *et al.*, 2004). And in 2004, the global textile and apparel industries grew by 4.1% to reach a value of US$2,378 billion at retail selling price (Datamonitor, 2005).

However, the textile and apparel supply chain—from fibre to retail—is experiencing deflationary price trends, making cost reduction the key to survival (Singhal *et al.*, 2004). It is due to three main trends since the new millennium. Firstly, consumers are becoming more demanding, but are also more value driven. They are sometimes whimsical and their demand is unpredictable. Secondly, the industrial structure is changing. Mega-retailers and mega-brands are emerging, and their growth is accelerating. Their expanding global reach is putting increased pressure on local traditional textile and apparel retailers, as well as on traditional supply channels. Thirdly, international textile and apparel trade became quota-free on January 1, 2005—at least in the case of trade between members of the WTO. Apparently, sourcing will occur from the most competitive countries in terms of cost, quality and productivity. For suppliers, the ability to offer a full package service, from product development to delivery to smooth the operations of the supply chain, is critical to increase their competitive advantages. The above trends are having a profound impact on how and where textiles and apparel are produced, and how the supply chain is managed. No longer will firms compete against each other individually but rather they will compete with their respective supply chains (Schorr, 1998). The competition of different supply chains in textile and apparel industries will be even more intense, and managing the whole supply chain together by all participants is no doubtfully an essential prerequisite for the competition.

"Supply chain management" (SCM), which refers to the integrated management of a network of entities, that starts with the suppliers' suppliers and ends with the customers' customers, for the production and delivery of goods and services to the final consumers (Lee and Ng, 1997), has, in recent years, been receiving increasing attention from academics, consultants and operational managers. According to SCM, companies do not seek to achieve cost reductions or profit improvements at the expense of their supply chain partners, but rather seek to make the supply chain more competitive as a whole (Romano and Vinelli, 2001).

One of the fundamental topics of SCM is measuring the performance of the whole supply chain, because no one can manage what he/she can not measure (Sink and

Tuttle, 1989). Someone's or something's ***performance*** is how successful they are or how well they do something (Collins Cobuild English Dictionary: 1226, 1995). ***Measurement*** of something is the process of measuring it in order to obtain a result expressed in numbers (Collins Cobuild English Dictionary: 1034, 1995). Measuring the performance of textile and apparel supply chain, in this project, is to help managers in textile and apparel supply chain understand how their supply chain is performing now, and enable managers to make informed decisions and to take appropriate actions to improve the performance, so as to sustain their competitive advantages. This thesis is focusing on the issues of supply chain performance measurement (SCPM) in textile and apparel industries.

1.2 Framework of Performance Measurement System (PMS)

An individual performance measure, which is also termed as metric, includes name of the measure, which reflects the nature of the measure; performance indicator, which describes the unit of the measure; and the performance measurement data, which shows the result of the performance measure and performance indicator (Browne *et al.*, 1997). Hatry (1999) shows a live example of the performance measures with the dashboard in an automobile. He referred that speed would be a performance measure; a calibrated dial would be a performance indicator; and the data recorded over time would give feedback to the driver about the speed. All these performance measures, like speed in the above example, make up the performance measurement system.

After reviewing about 150 published articles, Neely *et al.* (1995) also proposed that performance measurement system should include individual measures and the grouped performance measures. The individual measures contain the actual measures and essentially the rules and procedures for measurement. The ways in which these individual measures are categorized constitute the second level, which can be analyzed by exploring issues, such as "have all the appropriate elements (internal, external, financial, non-financial) been covered?".

Once a performance measurement system has been developed it has to be implemented. In the story of dashboard of the automobile, only data recorded over time, which would give feedback to the driver about the speed, is valuable. How to get the result of the individual measures and the measurement system and what the result means concerns the third element of performance measurement system—evaluation method.

Synthesizing the literatures about performance measurement system, the framework of a performance measurement system used in this study is shown in Figure 1.1, which is comprised of three components—individual measures, categorized individual measures, and evaluation method.

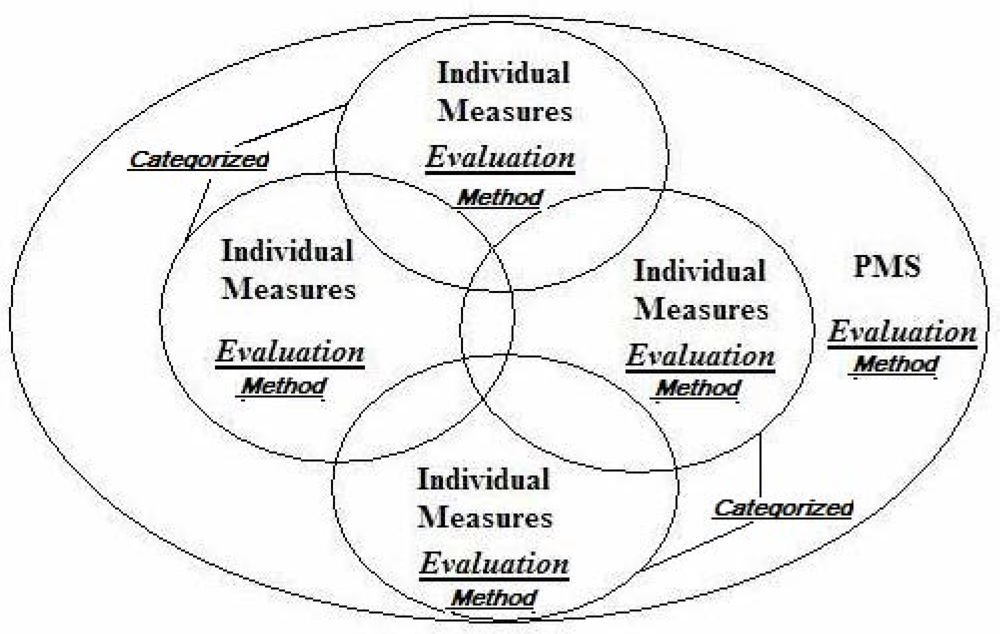


Figure 1.1 Framework of PMS

1.3 Current State of Supply Chain Performance Measurement (SCPM)

As stated before, the issue of SCPM is one of the most fundamental and important topics in the research of SCM. Lee and Billington (1992) in their research presented 14 pitfalls of SCM. They argued that lack of the supply chain's overall performance measurement was the first and the most serious one. After that, Beamon (1996) pointed out that the construction of an appropriate performance measurement is certainly one of the most important parts of efficient SCM, since obviously a credible performance measurement system can be helpful to evaluate the effectiveness of SCM system. Shah and Singh (2001) also suggested that for an improvement to take place, it is essential for a firm to use performance measures appropriate to its SCM. From the management perspective, performance measurement provides necessary information of management feedback for decision makers and managers. It plays the important role of monitoring performance, enhancing motivation, improving communications and diagnosing problems (Chan and Qi, 2003).

Many academicians and practitioners have devoted their efforts to supply chain performance measurement (SCPM) in recent years. And some supply chain performance measurement systems (SCPMSs) have been developed and presented in the literature (for example, Beamon, 1999; Brewer and Speh, 2000; Bullinger *et al.*, 2002; Chan and Qi, 2003; Gunasekarn *et al.*, 2001; Gunasekaran *et al.*, 2004; Holmberg, 2000; Lau *et al.*, 2002; Morash, 2001; Otto and Kotzab, 2002; Supply Chain Council's Supply Chain Operations Reference Model, 2001; Tan *et al.*, 2002).

Despite this attention, inter-organizational SCPM appears to be limited. Keebler *et al.* (1999) surveyed 3,100 logistics executives regarding their supply chain logistics measurement activities as a part of measurement focused research initiative sponsored by the University of Tennessee and the Council of Logistics Management (CLM). Three hundred and fifty five usable responses were received. The authors summarized the results of their survey as follows:

> *The survey and case study research conducted for this book found many companies measuring their logistics operations. Most companies that responded to the survey were measuring performance within their organizations in customer service, order fulfillment, procurement, and other logistics areas. A small number of companies were measuring logistics performance with customers and/or*

> *suppliers. Few, if any, were measuring full supply chain network performance. (p.52)*

Their conclusion that few firms were measuring full supply chain network performance is significant. It implies that the existence of comprehensive supply chain performance measurement system is perhaps more the ideal than the reality. Though several years have passed, there is no evidence to suggest that the situation has improved.

The following generalizations can be made from the literature to-date regarding supply chain performance measurement:

- Many articles in the literature are prescriptive in nature; however, the attributes that "good" metrics and measurement system should possess have been identified.
- More attention has been placed on individual measures rather than on PMSs.
- Little empirical research has been undertaken concerning the holistic SCPMSs. Most extant research focuses on individual firms' perspectives or only buyer-seller relationships as opposed to a holistic supply chain perspective.
- Few, if any, models suggest the detailed method of evaluating supply chain performance.
- Different models were employed in general SCPM, not specific in different supply chain contexts. There is no research relating to SCPM in textile and

apparel industries.

In summary, recent studies indicate that few firms are measuring holistic supply chain performance. Current research, in relation to SCPM, has been mainly based on relatively limited system perspective. In essence, “links” have been the focus as opposed to “chains”. The metrics are prescriptive in nature and the concrete evaluation method is not presented. Very little empirical research exists concerning SCPM from a broader and integrated system perspective. And in the textile and apparel industries, no related research about SCPM has been found. The initiatives of this research arise from the above observations.

1.4 Research Objectives and Methodologies

Via literature review and empirical investigation and analysis, it was expected that the following objectives would be achieved in this study.

- Through literature review and expert interviews and questionnaire (Modified Delphi Technique), an index evaluation system that assessed supply chain performance in textile and apparel industries would be established, which is a hierarchical structure including metrics and categorized measures.
- With the questionnaire survey and a Combined Fuzzy Multiple Attributes Evaluation (CFMAE) method, the evaluation process to obtain the index would be developed.
- Employing PHP as the programming language and MySQL as the database, an

online SCPMS in textile and apparel industries would be developed to guide the decision maker in actual evaluation.

1.5 Organization of Thesis

This thesis consists of six chapters, including this first one. In Chapter 2, the related literature, which includes SCM in textile and apparel industries, SCPM, methodologies of multiple criteria decision making (MCDM) are reviewed. The research methodologies are described in Chapter 3. In Chapter 4, the results of the first two research objectives are illustrated. In Chapter 5, a practical SCPM online system in textile and apparel industries is developed and presented. Conclusions of this study, contributions and limitations, and future research, are provided in the last chapter.

Chapter 2 Literature Review

2.1 Introduction

As discussed in Chapter 1, SCPM in textile and apparel industries is the main point of this study. To investigate the issue, related literatures should be reviewed to make clear the extant research progress and find the research gaps. In this chapter, we firstly surveyed literatures on textile and apparel supply chain management, and explored the unique attributes of SCM in textile and apparel industries. Issues related to SCPM, including SCPM design, supply chain performance measures, and evaluation methods in multiple attribute decision making (MADM), are followed respectively. These constitute the theory base for this study.

2.2 SCM in Textile and Apparel Industries

2.2.1 Much Attention Paid on SCM in Textile and Apparel Industries

The term “supply chain management” was originally introduced by consultants in the early 1980s, and then analyzed by the academic community in the 1990s (Oliver and Webber, 1992). Nowadays, SCM has become such a “hot topic” that it is difficult to pick up a periodical on manufacturing, distribution, marketing, customer management, or transportation without seeing an article about SCM or SCM-related topics (Ross, 1998). The general knowledge of supply chain and SCM, which includes the concepts and evolution of SCM, is summarized in Appendix A. The following generalizations can be made from the literature to-date regarding the definition of supply chain and

SCM:

- Supply chains are autogenetic in nature, whereas managed supply chains are artificially organized with collective efforts of supply chain members;
- A supply chain should consist of multiple firms, at least three, in both upstream (i.e., supply) and downstream (i.e., distribution) operation;
- SCM is a system approach to viewing the channel as a whole, as a single entity, rather than a set of fragmented parts;
- The implementation of SCM needs the integration of processes from sourcing, to manufacturing, and to distribution across supply chain;
- A minority of the entities in the supply chain controls the power in the supply chain; and
- To provide the timely release of product， information and product flows must be accounted for at all levels of the supply chain.

As discussed in Chapter 1, the textile and apparel industries are facing three main changes since the new millennium. The first one is consumers' rigorous demand and rational consumption. The second one is the dominant status of mega-retailers and mega-brands. And the third one is the influence of quota-free in international trade. The three macro trends make SCM an essential prerequisite for the competition. On the other hand, as the final product of textile and apparel supply chain, fashion products are unique, dynamic, emotional and cyclical, which makes change the lifeblood of the fashion industry and the rate of the change in the apparel industry much faster than in other businesses (Stone, 1994). Because of the synergy SCM can generate, it has been given much attention by textile and apparel industries.

The fact can be proved from the following result. The author conducted a search experiment with two databases that are often used in textile and apparel industries, Textile Technology Index and World Textiles. The key word is set as "supply chain". The result is shown in Figure 2.1. Before 1990s, relevant literature was nearly non-existent; after that, in the 5 year intervals, the number of relevant papers grew exponently. It is apparent that supply chain and supply chain management has been paid far more attention in textile and apparel industries in recent years.

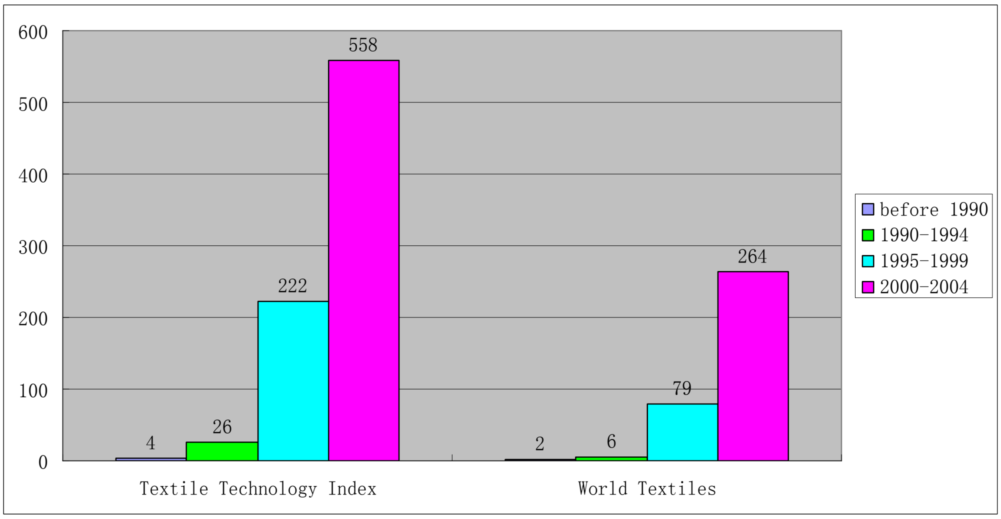


Figure 2.1 Search Results in Textile Technology Index and World Textiles

2.2.2 SCM Research in Textile and Apparel Industries

The textile and apparel supply chain is complex. Often the supply chain is relatively long, with a large number of cross-country enterprises involved (Jones, 2002). Forza and Vinelli (1997) described the main participants in the textile-apparel supply chain, which is shown in Figure 2.2. Consequently, careful management of the supply chain is required in order to reduce lead times and achieve quick responsive actions to changing market environments.

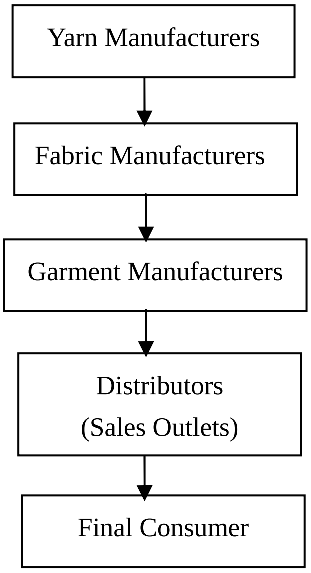


Figure 2.2 Participants in the textile-apparel supply chain

The well known supply chain initiative in apparel industry was the quick response (QR) program (Lummus and Vokurka, 1999). Owing to intense competition in the world-wide textile and apparel industries, leaders in the US apparel industry formed the Crafted With Pride in the USA Council in 1984 (Kurt Salmon Associates, Inc., 1993). In 1985, Kurt Salmon Associates were commissioned to conduct a supply chain analysis. The results of the study showed the delivery time for the apparel supply chain, from raw material to consumer, was 66 weeks long. About 40 weeks of 66 weeks were spent in warehouses or in transit. The long supply chain resulted in undesirable losses of resource and lack of right products launched in right place at the right time. QR is a phenomenon or process of partnership where retailers and suppliers work together to respond more quickly to consumer needs by sharing information. Significant changes as a result of the study were industry adoption of the Universal Product Code (UPC) and a set of standards for electronic data interchange (EDI) between companies. Retailers began installing point of sale (POS) scanning systems to transfer sales information rapidly to distributors and manufactures. QR incorporates marketing information on promotion, discounts, and forecasts into the manufacturing and distribution plan.

In recent years, there is still much research on QR. Forza and Vinelli (1997) underlined the importance of QR strategy in the textile and apparel industries and presented some considerations concerning the organizational, management and technological conditions necessary for its achievement. The support of information technologies was specially analyzed. Perry *et al.* (1999) described the processes that occurred as part of the Australian government funded QR program in the textiles, clothing and footwear industry. Birtwistle *et al.* (2003) surveyed fashion retailers in the UK about their implementation of QR. The study revealed that information technology is particularly important to the large, multiple “own brand” fashion retailers as it enables the various parties in the supply chain to communicate and to respond to demand. Yet, the results also indicated that retailers had not fully understood the benefits of implementing a QR strategy and perceived it more often as a strategy for internal supply chain rather than an external supply chain strategy.

In different stages of textile-apparel supply chain, more attention has been paid to garment manufactures. Au and Ho (2002) presented a business-to-business electronic commerce model for enabling SCM, using a leading clothing manufacturer in Hong Kong as an illustrative case. Lee and Kincade (2003) found that US apparel manufacturer groups, based on their SCM activity levels, showed statistically differences in company characteristics including product fashion level, fabric supplier delivery performance, relationship with fabric suppliers and retail customers and relative size of retail customers. Bheda *et al.* (2003) evaluated the productivity levels achieved by Indian apparel manufacturers vis-à-vis their counterparts from the rest of the world.

Case study was a common used method in the research of SCM in textile and apparel industries. Magretta (1998) described the innovative SCM activities of Li & Fung, Hong Kong's largest export trading company, through interviewing chairman of Li & Fung, Victor Fung. Leung (2000) proposed a model of world-class sourcing enterprises for the purpose of promoting sourcing centers to develop skills in SCM, using the case of skiwear supply chain. Chandra and Kumar (2000) used a five-member textile garment supply chain to propose a system analysis methodology to manage logistics in a textile supply chain.

There also exist some gaps between theory and practice. For example, relationship management encompasses the management of the chain and the building of partnership between different parties within the chain. Throughout the literature, collaborative relationships and partnerships are described as preferential situations, and as beneficial to all parties involved (Dossenbach, 1999; Wong, 1999). However, in reality, it is questionable. The textile industry tends to be dominated at the end of the chain by large, powerful high-street retailers with multiple and often internationally dispersed outlets. Further back down the chain, the manufacturing sector of the industry consists of large numbers of small companies with a limited power. Although it may be argued that partnership agreements exist between these companies in the textile and apparel industries, it is questionable whether these are actually partnerships with benefits for all parties or whether they are a means by which the retailer sector is able to exert power over the smaller suppliers in order to push down prices. With the intensification of globalization and the quest to achieve greater profits through reduced purchase prices, the industries have moved away from partnership between organizations (Bruce *et al.*, 2004).

2.2.3 Attributes of SCM in Textile and Apparel Industries

Empirically viewed, a textile-apparel supply chain can be divided into the several main functional role players. Putting them in operational sequence, there includes end consumers, retailers, distributors, brand owners, garment manufacturers, fabric manufacturers, yarn manufacturers and fibre suppliers. In the industries, an independent entity may be in charge of more than one functional role. For example, Nike, who is a brand owner, can also be recognized as a distributor and a retailer. Another example is that a garment manufacturer may also own woven or knitting factories. That means, a garment manufacturer can also be a fabric manufacturer, or even a yarn manufacturer.

Apparel is the final products of the textile-apparel supply chain. The creation and development of apparel items into a matching collection or a product line involves a series of steps. Each step is closely related to and influenced by all the other steps in the process.

Burns and Bryant (2002) presented an eight-step workflow model of creating and marketing an apparel line, which is shown in Figure 2.3.

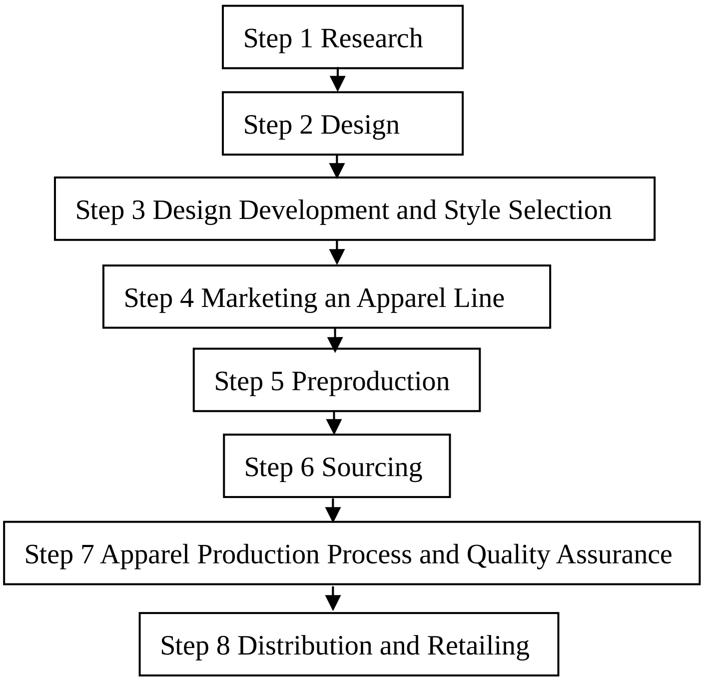


Figure 2.3 Model of creating and marketing an apparel line

The flowchart can be more generic, further combining the eight steps into four, namely product development, sourcing and buying, production and distribution and retailing. The textile-apparel supply chain at least involves four functional participants, which are retailers, brand owners, garment manufacturers and material converters. With the globalization of textile and apparel operations, the brand owner such as Nike is often the key player in product development and distribution in a supply chain. The production process is always outsourced to garment manufacturers. Generally speaking, the responsibilities of each participant in the four steps are shown in Table 2.1.

Table 2.1 Responsibilities of participants in textile-apparel supply chain

	Retailers	Brand Owners	Garment Manufacturers	Suppliers
Product Development	*	**	*	*
Sourcing and Buying	*	**	*	*
Production		*	**	*
Distribution and Retailing	**	*		

*Note: ** Main player(s) taking the coordination role * Supporting participant*

As shown in Table 2.1, in today's business environment, it is difficult for a single entity to integrate the whole processes of textile-apparel supply chain. The participants are generally connected closely. Thus, it is apparent that information sharing is a basic enabler for SCM. Many researchers have emphasized the importance of information sharing in SCM practice. Lanlonde (1998) considers sharing of information as one of five building blocks that characterize solid supply chain relationships. According to Stein and Sweat (1998), supply chain partners that exchange the information on a regular basis are able to work effectively as a single entity. Together, they have a greater understanding of the end consumers and are better able to respond to change in the marketplace. Moreover, Yu *et al.* (2001) point out that the negative impact of the bullwhip effect on a supply chain can be reduced or eliminated by sharing information with trading partners. Tompkins and Ang (1999) suggest that the key competitive and distinguishing factor for the 21st century is the proficient use of relevant and timely information by all functional teams/units within the supply chain to meet organizational objectives. For example, sharing information with TAL, J. C. Penny can obtain the benefits of faster cycle times, reduced inventory, and improved forecasts. At the same time, the customers get a higher-quality product at a lower price. Thus, information sharing should be considered as an important attribute of SCM in textile and apparel industries.

Based on Burns and Bryant's (2002) model, the starting point of creating and marketing an apparel line is product design and development. Apparel product development is the design and engineering of apparel products that are serviceable, producible, marketable, and profitable (Glock and Kunz, 2000). The apparel product development process focuses on the following areas: perfect style and fit, produce pattern, test material and assembly methods, developing style and quality specifications, detail cost, and grade pattern (Wickett *et al.*, 1999). The design team should be comprised of members from different entities. In each step of the process, it is critical for team members to be interdependent (Gaskill, 1992). According to

Pitimaneeyakul (2001), the apparel product development team members who participate in the process are from the areas of marketing, design, and merchandising. Apparel product development team members collaborate throughout the phases of idea/concept development, problem definition/research, creative exploration, and implementation. As to the ultimate consumers of apparel, the attributes of apparel, such as style, color, material, fiber content, are all determined in the process of product design and development. Hence, product development is an important attribute of SCM in textile and apparel industries.

Another attribute was found in Kaplan and Norton’s (1992) balanced scorecard. In their balanced model, innovation and learning is one of the four perspectives. It recognizes that firms must continually learn and innovate to ensure future profitability. In textile and apparel industries, innovation, such as new technology and new material, is a sustainable factor for the supply chain to achieve advantages from the competitive supply chains. It should also be an attribute of SCM in textile and apparel industries.

The objective of textile-apparel supply chain is to provide the right fashion products to market, with the lowest cost and in the fastest speed, and to achieve the maximum profit. Thus, other important attributes of SCM in textile and apparel industries include supply chain cost, supply chain time, supply chain quality, supply chain flexibility and supply chain profitability. These attributes are mentioned in many SCPM models described in 2.3.3.

2.2.4 Summary

With the macro trends of textile and apparel industries since the new millennium, and micro characteristics of textile apparel supply chain, SCM in textile and apparel industries has been paid much more attention both in academia and in industries in recent years. The well known supply chain initiative in textile and apparel industries emerged in 1980s with the philosophy of QR as mentioned earlier. Some basic measures, such as supply chain cycle time, appeared to measure the implementation of QR. Except for QR, the other issues, such as logistics and production, in textile and apparel supply chain, are also studied using multiple methodologies. Unfortunately, no specific record of SCPM in textile and apparel industries is found in extant literatures.

SCM in textile and apparel industries has its unique attributes. For example, product design and development plays an important role in SCM in textile and apparel industries. Summarizing the related literature, eight most important attributes of SCM in textile and apparel industries are obtained. They are: supply chain product design and development, supply chain information sharing, supply chain innovation, supply chain cost, supply chain time, supply chain quality, supply chain flexibility and supply chain profitability. The eight attributes would construct the foundation for the SCPM in textile and apparel industries in the current research.

2.3 SCPM System Design

2.3.1 Generic Performance Measurement System Design Process

Sink and Tuttle (1989) focused on designing performance measurement systems specifically in relation to process improvement initiatives. They have defined their design and implementation process in terms of several steps or phases:

- Preparation.
- Determination of what to measure (the what?)—consensus-building techniques are advocated.
- Determination of measurement techniques to process data and create information needed (the how?)
- Determination of what data to collect and how to source it.
- Process and output validation.
- Linkage of measurement to improvement.
- Feedback and control for measurement system improvement.

Sink and Tuttle's (1989) model is highly detailed, and they recognize that the derivation of a measurement system is more than simply the choice of metrics. Their model explicitly acknowledges the need for consensus building with regard to defining appropriate metrics. Although their model is not supply chain specific, it provides attributes, which could be of value in defining a supply chain specific model.

Adams *et al.* (1995) defined a generic model for "performance metric development".

The model is strategy driven and process focused. Their approach contains five primary steps which are shown in Figure 2.4.

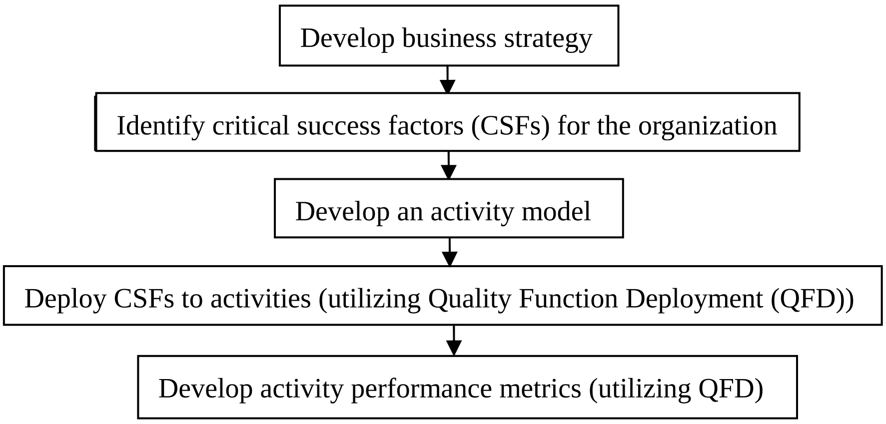


Figure 2.4 Performance metric development model by Adam et al. (1995)

CSFs are defined as those few goals that must be accomplished by the organization to successfully execute its strategy. Adams *et al.* (1995) describe QFD as follows:

> *It is essentially a design approach that begins with establishing objectives, separating those objectives into segments, and identifying specific solutions for each segment. It uses charts, or matrices, on which the objectives to be satisfied are displayed on the vertical axis. Through a series of formalized participative routines, solutions are developed along the top, horizontal axis. (p.28)*

The authors define a five-step process for the development of an activity model:

- Define the boundaries of the activity under study.
- Identify internal and external customers.
- Identify internal and external suppliers.
- Identify product sets and customer-defined product attributes.

- Identify the process characteristics required to produce the customer-defined product attributes.

The process for the deployment of global CSFs to specific activities with an activity model is defined as follows:

- Identify customer requirements.
- Identify critical product attributes by relating customer requirement and global CSFs to current products.
- Identify product attributes and deficiencies by comparing existing product attributes to critical product attributes.
- Develop activity CSFs that address product attribute deficiencies utilizing QFD.

A three-step process is defined for the development of activity performance measures:

- Identify process attributes.
- Identify critical process attributes by correlating process attributes with activity CSFs.
- Develop activity performance metrics to address critical process attributes utilizing QFD.

The above model has the following positive attributes:

- It emphasizes the linkages of “global” CSFs for the organization to “activity”

CSFs. Activity CSFs are then linked to metrics. This approach is hierarchical and systems based. The linkage of the metrics is explicit.

- A transformational process perspective is utilized.
- The model utilizes customer perspective as the arbiter of success.
- The model is, in general, detailed and systematic.

The model which Adams *et al.* (1995) offer as described above does not define itself as a comprehensive performance measurement design system. It is primarily an approach for developing “strategic” performance measures. It is not supply chain focused, but contains characteristics that could have utility in deriving a supply chain measurement design model.

Eccles and Pyburn (1992) offer guidance on “Creating a comprehensive system to measure performance”. They state the following:

> *One significant stumbling block to accomplishing improved measurement is that too often managers ignore a crucial step. Before a comprehensive system of performance measurement can be developed, senior management needs to agree on the business performance model of the firm—their understanding of the relationships between management action and results, which often are implicit, that affect important decisions. (p.42)*

The authors define a five-step model for developing a comprehensive performance measurement system, starting with the development of a "business performance model":

- Develop and agree on a business performance model.
- Develop methodologies for taking new measures.
- Decide on the format and frequency of performance measurement reports, including who receives which measures.
- Change the personnel evaluation and compensation processes to reinforce behaviors that improve performance on relevant activities.
- Recognize that the performance measurement system is not cast in concrete and that it should evolve over time as conditions dictate.

Eccles and Pyburn (1992) point that the business performance model is valid and can be reviewed in terms of understanding "cause and effect" and identifying CSFs in relation to business strategy and measurement development. However, what they offer is by no means a blue print for the design of a comprehensive performance measurement system.

Kaplan and Norton (1992, 1993, and 1996) developed what is arguably the most prominent model for the development of performance measurement systems in their Balanced Scorecard Model (BSC). The BSC translates a business unit's mission and strategy into objectives and measures. The objectives and measures are focused on the following perspectives: financial, customer, internal processes, and learning and growth. The financial measures are framed in terms of outcomes. The measures from the other perspectives are framed in terms of drives of performance. Measures contained in the BSC are balanced along the following dimensions:

- Outcomes vs. Drives of Performance
- Objective Measures vs. Subjective Measures
- Short-term Measures vs. Long-term Measures

A key consideration in the implementation of BSC is the establishment of a cause-and-effect action linkage starting with strategy down through the organization utilizing the financial, customer, internal business process, and learning and growth perspectives. Kaplan and Norton state that the BSC "… should be based on a series of cause-and-effect relationships derived from the strategy, including estimates of the response times and magnitudes of the linkages among the scorecard measures." They further state, "every measure selected for a Balanced Scorecard should be an element in a chain of cause-and-effect relationships that communicates the meaning of the business unit's strategy to the organization" (1996, p.31). The cause-and-effect linkage is essentially the "business performance model" that Eccles and Pyburn (1992) required in their performance measurement system model.

The BSC, as mentioned earlier, is arguably the most widely recognized approach to the development of performance measurement systems. The focus on cause-and-effect with strategy as the departure point in the measurement development process is straight-forward and rational. The model also addresses the issue of balancing perspectives when developing measures. It is also one of the most comprehensive approached offered.

Hronec (1993) defined separate processes for developing process performance measures and output performance measures. He developed a matrix of performance measures to assist in the selection of performance measures appropriate to a given set of circumstances. A six-step process was also defined for performance measure implementation. Hronec (1993)'s model is neither comprehensive nor systems based. It emphasizes metric selection and ignores other significant design considerations.

Sharman and gurowas (1999) defined a "performance measurement framework". They state that the design of this framework is a necessary first step for the design of an integrated measurement system. Their framework is based on information derived through the application of a series of analytical measurement tools. The listing of the analytical activities that they provide is an extensive checklist that is relevant from the standpoint of gaining understanding of the operating context of the measurement system.

In conclusion, the existing models for performance measurement system design generally focus on individual business units. The majority of the models focus on metric selection as opposed to a holistic system design and implementation process.

Various authors emphasized the need to recognize a cause-and-effect linkage to strategy in defining performance measurement systems. Kaplan and Norton's BSC is the most comprehensive generic model offered for the design of performance measurement systems.

2.3.2 SCPM System Design Process

Holmberg (1997) defined what he termed a "supply chain measurement system development cycle". This was the only model identified in the literature that dealt explicitly with measurement system development in the inter-organizational supply chain context. Holmberg's (1997) supply chain measurement development cycle consists of the following steps:

- The definition of measures at the supply chain level.
- The definition of cause-effect relationship between/among supply chain measures.
- The linkage of output measures for each of the organizations in the supply chain to the supply chain measures defined.
- The definition of organizational process (activity) measures and links to organizational output measures.
- The definition of measurement protocols.

Holmberg's (1997) model addresses the supply chain context specifically. It also emphasizes the vertical integration of measurements, which is a key consideration. He does not address inter-organizational consensus building and conflict reconciliation with regard to the system development process. Goal resonance among the supply chain members is assumed as a given.

Keebler *et al.* (1999) provide what they refer to as a "logistics measurement implementation approach". They define their process as linked to and driven by corporate strategy. Their measurement development process contains seven steps:

- Record the existing measures.
- Determine potential future measures.
- Evaluate and prioritize desired measures.
- Develop a prototype of new measures.
- Implement and test the prototype.
- Refine and reiterate.
- Train the organization and roll out the new measure.

The above seven steps address system planning, evaluation, and implementation, but only at a very high conceptual level. The model does not address measurement system design from an inter-organizational supply chain perspective.

2.3.3 SCPM System Design Philosophies—Several Models

2.3.3.1 BSC Model

Brewer and Speh (2000) recommend the use of modified version of the BSC as a framework for SCPM. They suggest that more effective supply chain measures can be developed by relating supply chain goals to the four perspectives (Financial, Customer, Business Process, and Innovation/Learning) defined in the BSC framework. They state, "The shift in philosophy that takes place when a supply chain point of view is embedded within the balanced scorecard framework is that the internal perspective of the scorecard is expanded to include both the 'inter-functional' and 'partnership' perspective." They further state, "…the balance scorecard advocated here incorporates integrated measures, in addition to non-integrated measures, that motivate employees to view their firm's success as being predicated upon the success of the entire supply chain of which they are a part, rather than solely upon their firm itself."(p.84). Their recommendations provide a departure point and rationale for the linkage of the BSC and the SCM concept.

The SCM performance framework developed by Brewer and Speh (2000) from four perspectives is shown in Figure 2.5. The framework relates the goals of SCM to customer satisfaction, firm financial performance, and the ways in which firms continue to learn, innovate and grow. The linkage of SCM framework to the BSC framework is shown in Figure 2.6.

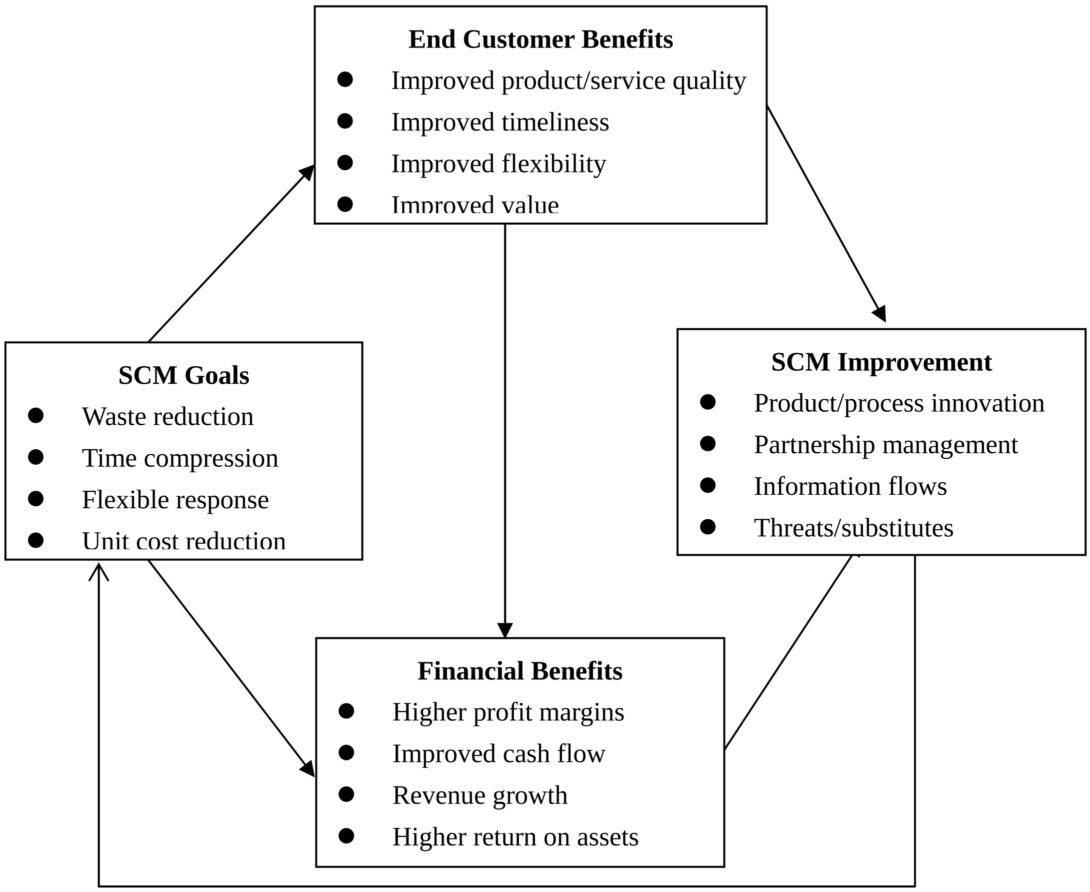


Figure 2.5 SCM performance framework

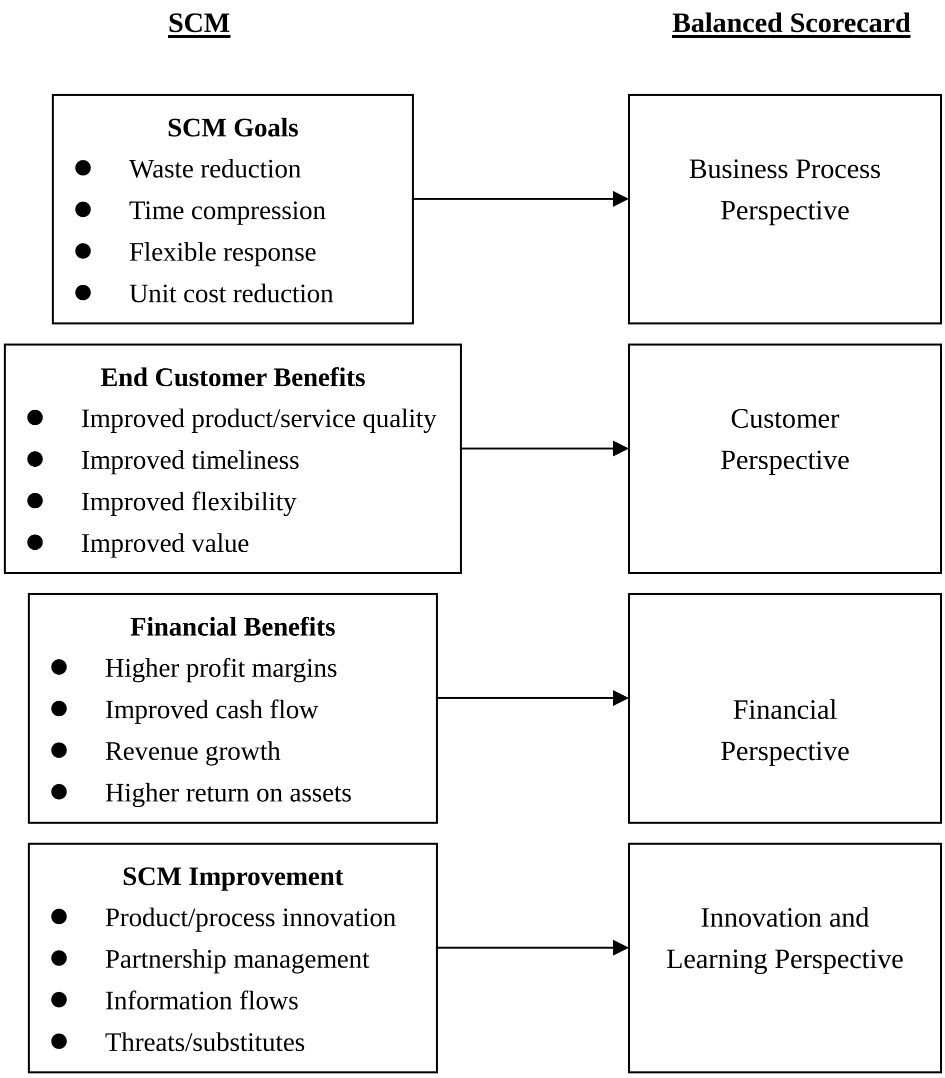


Figure 2.6 Linking SCM framework to the balanced scorecard

2.3.3.2 Supply Chain Operation Reference (SCOR) Model

In April, 2001, the Supply Chain Council (SCC) released Version 5.0 of the Supply Chain Operations Reference (SCOR) model. The SCOR Model is a business process reference model which provides a comprehensive toolset linking business processes to metrics, best practice and technology (Stephens, 2001).

The SCOR Model is based on five distinct management processes which are Plan, Source, Make, Delivery, and Return. These five management processes are decomposed into three levels of detail. At Level 1 (Plan, Source, Make, Delivery, and Return) supply chain performance can be directly tied to the business objectives of the organization. At Level 2 and Level 3, processes elements are used to describe more and more detailed activities to provide greater insight into the operation of the supply chain. Because it is a cross-industry model and because each organization’s operations are unique, the model must be extended by the implementing organization to Level 4. For each of the SCOR processes, the model provides several performance measures in five dimensions: reliability, responsiveness, flexibility, cost, and efficiency. Table 2.2 describes these performance attributes, identifies the Level 1 metrics.

Table 2.2 Performance attributes and level 1 metrics

Performance attribute	Performance attribute definition	Level 1 metrics
Supply chain delivery reliability	The performance of the supply chain in delivering: the correct product, to the correct place, at the correct time, in the correct condition and packaging, in the correct quantity, with the correct documentation, to the correct customer.	Delivery performance Fill rates Perfect order fulfillment
Supply chain responsiveness	The velocity at which a supply chain provides products to the customer.	Order fulfillment lead time
Supply chain flexibility	The agility of a supply chain in responding to marketplace changes to gain or maintain competitive advantage.	Supply chain response time Product flexibility
Supply chain Costs	The costs associated with operating the supply chain.	Cost of goods sold Total supply chain management costs Value-added productivity Warranty/returns processing costs
Supply chain asset management efficiency	The effectiveness of an organization in managing assets to support demand satisfaction. This includes the management of all assets: fixed and working capital.	Cash-to-cash cycle time Inventory days of supply Asset turns

2.3.3.3 Beamon's ROF Model

After studying the former supply chain models and PMSs, Beamon (1999) thought that current supply chain performance measurement systems were inadequate because they relied heavily on the use of cost as a primary (if not sole) measure. They were not inclusive, often inconsistent with the strategic goals of the organization, and the effects of uncertainty were not taken into consideration. Strategic goals involve key elements that include the measurement of resources, output and flexibility. Based on this thread, Beamon (1999) proposed his ROF Model of SCPM.

The model places emphasis on three separate types of performance measures: resource measures (R), output measures (O), and flexibility measures (F). Each of the three types of performance measures has different goals, as illustrated in Table 2.3. The PMS must measure each of the three types (R, O and F) and must contain at least one individual measure from each of the three identified types. The individual measurers chosen from each type must coincide with the organization's strategic goals.

Table 2.3 Goals of performance measure types

Performance measure type	**Goal**	**Purpose**
Resources	High level of efficiency	Efficient resource management is critical to profitability
Output	High level of customer service	Without acceptable output, customers will turn to other supply chains
Flexibility	Ability to respond to a changing environment	In an uncertain environment, supply chains must be able to respond to change

Resource measures include: inventory levels, personnel requirements, equipment utilization, energy usage, and cost. Resources are generally measured in terms of the minimum requirements or a composite efficiency measure. Efficiency measures the utilization of the resources in the system that are used to meet the system's objectives. Examples of resource measures are total cost, distribution costs, manufacturing cost, inventory, and return on investment (ROI). Output measures include: customer responsiveness, quality, and the quantity of final product produced. Output performance measures must not only correspond to the organization's strategic goals, but must also correspond to the customers' goals and values, since strategic goals generally address meeting customer requirements. Examples of output measures are sales, profit, fill rate, on-time deliveries, backorder/stockout, customer response time, manufacturing lead time, shipping errors, and customer complaints. Flexibility can measure a system's ability to accommodate volume and schedule fluctuations from suppliers, manufactures, and customers. Beamon (1999) defined four types of flexibility measures quantitatively based on Slack (1991)'s definition. They are volume flexibility, delivery flexibility, mix flexibility, and new product flexibility.

2.3.3.4 Otto and Kotzab's Goal-oriented Approach

Discussing the question "Does supply chain management really pay", Otto and Kotzab (2003) presented a goal-oriented approach to measure the supply chain performance. They suggested differentiating between six perspectives on SCM. Each perspective follows a particular set of goals, which consequently leads to a particular set of performance metrics. The different metrics refer to the main disciplines, which contributed to the field of SCM the most: System Dynamics, Operations Research/ Information Technology, Logistics, Marketing, Organization, and Strategy. The perspectives to derive the goals of SCM are summarized in Table 2.4.

Table 2.4 Perspectives to derive the goals of SCM

Perspectives	**Purpose of SCM**	**Focal area of improvement**
System Dynamics	Managing trade-offs along the complete supply chain	Order management
Operations Research	Calculating optimal solutions within a given set of degrees of freedom	Network configuration and flow
Logistics	Integrating generic processes sequentially, vertically, and horizontally	Integration of processes
Marketing	Segmenting products and markets and combine both using the right distribution channel	Fit between product, channel and customer
Organization	Determining and mastering the need to coordinate and manage relationships	Intra-enterprise segmentation
Strategy	Merging competencies and re-locating into the deepest segment of the profit pool	Ability to partner; positioning in the chain

For each of the perspective, Otto and Kotzab identified the standard problems and then standard solutions. The performance metrics are dependent on the unique notions and problems. For “System Dynamics” perspective, capacity utilization, cumulative inventory level, stock-outs, time lags, time to adapt, and phantom ordering are used as performance metrics. For “OR/IT” perspective, logistics cost per unit, service level, and time to deliver are chosen. For “Logistics” perspective, integration, lead time, order cycle time, inventory level, and flexibility are the metrics. For “Marketing” perspective, metrics are composed of customer satisfaction, distribution costs per unit, and market share/channel costs. For “Organization” perspective, metrics include transaction costs, time to network, flexibility, and density of relationship. For “Strategy” perspective, metrics include time to network, time to market and ROI of focal organization. Otto and Kotzab also claimed that from the SCM holistic requirements, the different performance metrics should be combined.

2.3.3.5 Chan and Qi's Process-based Approach

After literature review, Chan and Qi (2003) noted that most of the current PMSs of supply chain in place were harassed by too many defects to meet the requirements of SCM. The defects include: lack of balanced approach to integrating financial and non-financial measures; lack of system thinking; and loss of supply chain context. Then, they proposed a process-based approach to mapping and analyzing the practically complex supply chain. Via this approach, a process-based PMS is presented.

The tasks done before measuring the performance is to analyze and break down the processes to be measured. Chan and Qi (2003) suggest seven steps to do so.

- Identify and link all the involved processes of inter- and intra- organization.
- Define and confine the core processes.
- Derive the missions, responsibilities, and functions of core processes.
- Decompose and identify the sub-processes.
- Derive and identify the sub-processes.
- Decompose and identify the elementary activities of sub-processes.
- Link goals to each hierarchy from process to elementary activity.

The process framework of hierarchical structure provides the base of measuring process performance, through the method of performance of activity (POA).

POA includes a board of performance metrics, each of which represents one of the dimensions of activity performance. They cover inputs and outcomes, and both tangible items and intangible ones. The board of performance metrics, called metrics board, is suggested summarily by the authors as follows:

- Cost—the financial expense to carry out one event or activity.
- Time—the time between the beginning and completion of one specific event or activity.
- Capacity—the ability of one specific activity to fulfill a task or perform a required function.
- Capability—a talent or ability of one activity to be used, treated, or developed for the specific purpose and required functions. Capability contains the following 4 more specific measures:
    - Effectiveness—the ability of one specific event or activity to achieve an intended or desired effect in performing the functions or taking the responsibilities.
    - Reliability—the ability of one specific event or activity to perform a required function under stated period of time.
    - Availability—the ability to bring about effective or beneficial results or the degree to which one specific functional activity is ready when needed.

- Flexibility—the ability of one specific activity to adapt to the varying functional requirements or respond to the changes.

- Productivity—the rate at which one specific event or activity adds value at the cost of resources.
- Utilization—the utilizing rate of the resource to carry out one specific activity.
- Outcome—the results or value added of one specific activity and event.

When measuring the supply chain performance, not all the dimensions in the metrics board need to be used; the selection of the dimensions is based on the actual requirements.

An example of implementing the POA method is shown in Figure 2.7.

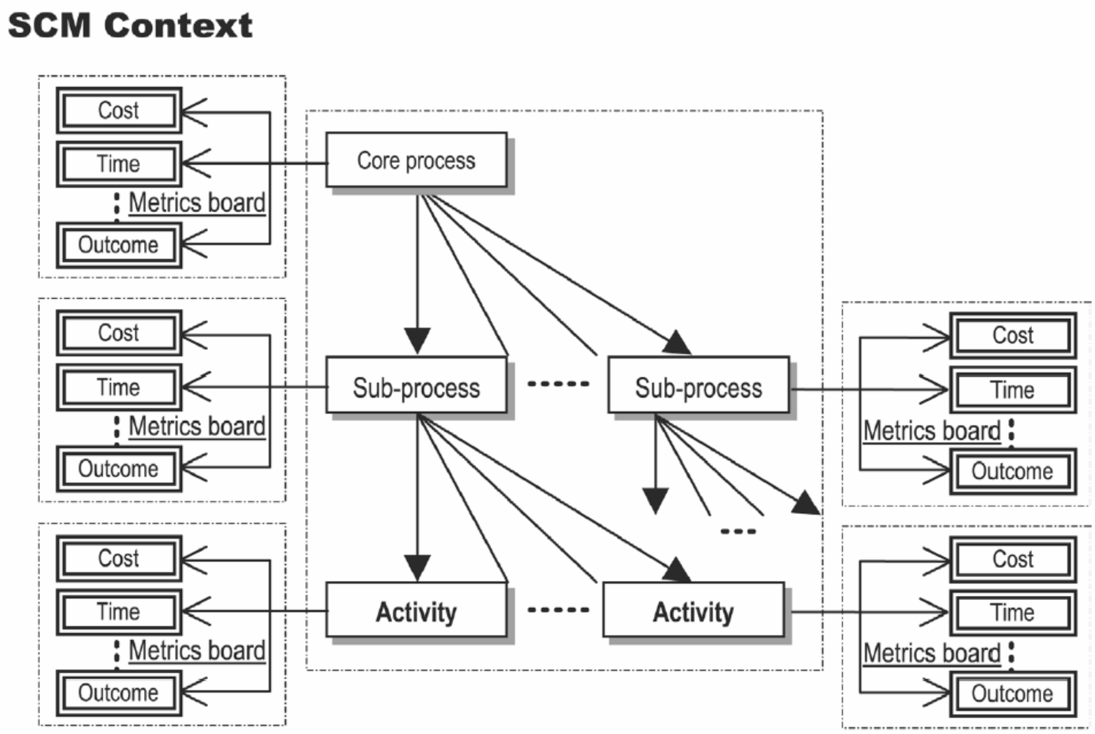


Figure 2.7 The general structure of applying POA

2.3.3.6 Tridimensional Model

Gunasekaran *et al.* (2001) proposed frameworks of PMSs from three perspectives. One is to classify the performance metrics to strategic level, tactical level, and operational level. This has been done so as to assign them where they can be best dealt with by the appropriate management level, and for fair decisions to be made. Another is to classify the performance metrics as financial metrics and non-financial ones so that a suitable costing method based on activity analysis can be applied. The last is to classify the measures from the four basic links that constitute the supply chain: plan, source, make, and delivery. Such a classification signifies which metric should be used where, and which can together act as a fair indication of the problems persistent in respective links. The so called tridimensional model is presented in Table 2.5.

Table 2.5 Tridimentional model

Level	Performance Metrics	Financial	Non-financial	Process
Strategic	Total supply chain cycle time		√	Plan
	Total cash flow time		√	Plan
	Customer query time		√	Service
	Level of customer perceived value of product		√	Service
	Net profit vs. productivity ratio	√		Plan
	Rate of return on investment	√		Plan
	Range of product and services		√	Plan
	Variations against budget	√		Plan
	Order lead time		√	Plan
	Flexibility of service systems to meet particular customer need		√	Service
	Buyer-supplier partnership level	√	√	Source
	Supplier lead time against industry norm		√	Source
	Level of supplier's defect free deliveries		√	Source
	Delivery lead time		√	Delivery
	Delivery performance	√	√	Delivery
Tactical	Accuracy of forecasting techniques		√	Plan
	Product development cycle time		√	Plan
	Order entry method		√	Plan
	Effectiveness of delivery invoice methods		√	Delivery
	Purchase order cycle time		√	Source
	Planned process cycle time		√	Plan
	Effectiveness of master production schedule		√	Make
	Supplier assistance in solving technical problems		√	Source
	Supplier ability to respond to quality problems		√	Source
	Supplier cost saving initiatives	√		Source
	Supplier's booking in procedures		√	Source
	Delivery reliability	√	√	Delivery
	Responsiveness to urgent deliveries		√	Delivery
	Effectiveness of distribution planning schedule		√	Delivery
Operational	Cost per operating hour	√		Make

Information carrying cost	√	√	Plan
Capacity utilization		√	Make
Total inventory as:	√		Make
-Incoming stock level			
-Work-in-process			
-Scrap level			
-finished goods in transit			
Supplier rejection rate	√	√	
Quality of delivery documentation		√	Delivery
Efficiency of purchase order cycle time		√	Source
Frequency of delivery		√	Delivery
Driver reliability for performance		√	Delivery
Quality of delivered goods		√	Make
Achievement of defect free deliveries		√	Source

2.3.3.7 Summary of SCPM System Models

The above six models for SCPM are the most typical ones. In the literature, many scholars have also proposed other SCPM systems in their research work. For example, Bullinger *et al.* (2002) developed a tailored balanced measurement methodology which is a hybrid measurement approach integrating SCOR measurement and adapted balanced scorecards. Tan *et al.* (2002) proposed six performance measures which are market share, return on assets, average selling price, overall product quality, overall competitive position, and overall customer service level in their surveying research of firms' supply chain management practices, supplier evaluation practices, and firms' supply chain performances. Morash (2001) proposed SCPM system from demand-side aspect and supply-side aspect. However, these are less influential than the six ones discussed above. The comparisons of the models are listed in Table 2.6.

Table 2.6 Comparisons of models for SCPM

Model/Author/Year	Design Philosophy	Level 1 Metrics
SCOR/SC Council/2001	Process based	SC delivery reliability
		SC responsiveness
		SC flexibility
		SC cost
		SC asset management efficiency
BS/Brewer and Speh/2000	Balanced thinking	SC goals
		End customer benefits
		Financial benefits
		SCM improvement
ROF/Beamon/1999	Process based	Resource measures
		Output measures
		Flexibility measures
Goal-oriented/ Otto and Kotzab/2002	Goal oriented	System dynamics
		Operations research/IT
		Logistics
		Marketing
		Organization
		Strategy
Process-based/ Chan and Qi/2003	Process based	Cost
		Time
		Capacity
		Capability
		Productivity
		Utilization
		Outcome
Tridimentional model/ Gunasekaran *et al.*/2001	Tridimentioanl	Strategic/Tactical/Operational
		Financial/Non-financial
		Processes

The typical characteristics for the SCPM systems are:

- They are hierarchically structured. Generally, the top level of the hierarchy is the ultimate performance of measured supply chain. The second level of the hierarchy is the multiple attributes to reflect total performance. For example, resource measures, output measures and flexibility measures in Beamon (1999)'s ROF model comprise the second level hierarchy.

- Multiple attributes are employed in the second level. Kenney and Raiffa (1993) provide a number of important characteristics of good attributes. The set of attributes should be "complete, so that it covers all the important aspects of the problem; operational, so that it can be meaningfully used in the analysis; decomposable, so that aspects of the evaluation process can be simplified by breaking it down into parts; nonredundant, so that double counting of impact can be avoided; and minimal, so that the problem dimension is kept as small as possible" (p.50).
- They are process based method or balanced method. The process based method and balanced thinking are the basic design methods for SCPM.

2.3.4 Summary

Although there exist models for performance measurement system design process, the specific ones for SCPM system is not sufficient. The most reasonable deficiency of the extant literature of the SCPM system design process is that it is not from an inter-organizational supply chain perspective. The existing SCPM models illustrate some characteristics, which are hierarchically structured, employing multiple attributes, and process based or of balanced thinking. These give some hints for this research. Firstly, the SCPM system design process should be from the inter-organizational supply chain perspective. Secondly, complete, operational, decomposable, nonredudant, and minimal attributes to reflect the holistic supply chain performance in textile and apparel industries should be employed. Thirdly, the attributes employed should be balanced.

2.4 Supply Chain Performance Measures

System thinking and system theory have had a fundamental impact on business logistics. Business logistics has undergone an evolution, going from a task and activity focus toward a cross-function process focus. A higher system level perspective has been introduced through the SCM concept. The aforementioned evolution has prompted the need for logistics measures that support and are compatible with the evolving broader system perspective. Metric usage recommendations have gone from a task/ activity perspective, to a process perspective, and more recently to an inter-organizational supply chain perspective.

2.4.1 From Task/ Activity Focused Measures to Supply Chain Measures

2.4.1.1 Logistics Task and Activity Focused Measures

Most of the articles related to business logistics metrics published in the 1980s and early 1990s focused primarily on logistics metrics at the task and activity level. Various papers have been written outlining and recommending task and activity focused logistics measures. Mentzer and Konrad (1991) and two studies sponsored by the CLM and conducted by A. T. Kearney (1984 and 1991) provide excellent coverage of logistics performance metrics form this perspective. This is not the focus of this study.

2.4.1.2 Logistics Process Focused Measures

Keebler *et al.* (1999) made the following statement in relation to the logistics process metrics:

> *While there are hundreds of measures logistics managers could use, research has shown that less than two dozen process measures are critical to evaluating and improving the performance of the logistics process. (p. 131)*

The authors cite four process measure categories: time, quality, cost and other/ supporting. Table 2.7 provides a summary of their recommended process measures.

Table 2.7 Recommended logistics process metrics

Time	Cost
- On-time Delivery/ Receipt	- Finished Goods Inventory Turns
- Order Cycle time	- Days Sales Outstanding
- Response Time	- Cost to Serve
- Forecasting/ Planning Cycle Time	- Cash-to-Cash Cycle Time
- Planning Cycle Time Variability	- Total Delivered Cost
Quality	Cost of Goods
- Overall Customer Satisfaction	Transportation Cost
- Processing Accuracy	Inventory Carrying Costs
- Perfect Order Fulfillment	Material Handling Costs
On-Time Delivery	All Other Costs
Complete Order	Information Systems
Accurate Product Selection	Administrative
Damage-free	- Cost of Excess Capacity
Accurate Invoice	- Cost of Capacity Shortfall
- Forecast Accuracy	**Other/ Supporting**
- Planning Accuracy	- Approval Exceptions to Standard
Budgets and Operating Plans	Minimum Order Quantity
- Schedule Adherence	Change Order Timing
	- Availability of Information

2.4.1.3 Supply Chain Focused Measures

The evolution of logistics toward a cross-functional and cross-organizational focus has prompted the need for more integrative and boundary spanning measures. In 1994, a multi-industry consortium reported the results of their efforts at deriving an integrated supply chain metric framework (Pittiglio and McGrath, 1994). The consortium derived an extensive set of metrics that spanned the total supply chain and focused on four general metric types: (1) customer satisfaction, (2) quality, (3) costs, and (4) assets. Table 2.8 summarizes the metrics included in their framework.

Table 2.8 A multi-industry consortium recommendation—integrated supply chain performance metrics

1. Perfect Order Fulfillment	
2. Customer Satisfaction	
3. Product Quality	
4. Total Order Fulfillment Cycle Time	
5. Total Supply-Chain Costs	
Order Fulfillment Costs	Logistics-related Finance & MIS Costs
New Product Release & Maintenance	Finance Costs
Customer Order Creation Costs	MIS/ Systems
Order Entry & Maintenance	Supply-chain Support Costs
Contract/ Program Management	Manufacturing Labor & Inventoriable OH Costs
Installation Planning Costs	Direct Labor & Fringes
Order Fulfillment	Indirect Labor & Management
Distribution Costs	Manufacturing & Quality Engineering
Installation Costs	Information System for Production
Customer Accounting Costs	Scrap & Rework
Material Acquisition Costs	Depreciation
Commodity Management & Planning	Lease Expense
Supplier Quality Engineering	Plant Occupancy
Inbound freight & Duties	Equipment Maintenance
Receiving	External Support
Incoming Inspection	Environmental Expenses
Component Engineering	
Tooling	
Total Inventory Carrying Costs	
Cost of Capital/ Opportunity Costs	
Shrinkage	
Insurance & Taxes	
Obsolescence	
6. Cash-to-Cash Cycle Time	
7. Inventory Days of Supply	

The multi-industry consortium mentioned above later evolved into the Supply Chain Council (SCC). The SCC is an independent, not-for-profit corporation, established in 1996 with the goal of applying and advancing "state-of-the-art supply chain management systems and priorities." The SCC has developed and endorsed a Supply Chain Operations Reference model (SCOR), which is described in 2.2.3.2. Supply chain delivery reliability, supply chain responsiveness, supply chain flexibility, supply chain costs, and supply chain assets management efficiency are the five categories of measures for SCOR model.

2.4.2 Supply Chain Metric Utilization Based on Empirical Studies

Keebler et al. (1999), in their survey and case study research on logistics measurement in the supply chain, also surveyed metric utilization practices. Table 2.9 summarizes their results in the following areas:

- Most often used measures.
- Least used measures.
- Percent of respondents utilizing popular measures.
- Most important measures for the logistics function.
- Most important logistics measures to the company.
- Top measures used by customers and suppliers to measure performance.

Table 2.9 Logistics Metric Utilization Summary

Note: the percentage represents percentage of survey respondents

Most Often Used Measures		**Most Important measures for the Logistics Function**	
Outbound Freight Costs	87%	On-time Delivery	66%
Inventory count Accuracy	86%	Order Fill	61%
Order Fill	81%	Customer Compliance	57%
Finished Goods Inventory Turns	80%	Outbound Freight Costs	53%
On-time Delivery	79%	Inventory Count Accuracy	51%
Customer Compliance	77%		
Least-Used Measures		**Most Important Logistics Measures to the Company**	
Cost to Serve	37%	On-time Delivery	61%
Units Processed Per Time Unit	37%	Order Fill	56%
Orders Processed Per Time Unit	36%	Customer Compliance	55%
Labor Utilization vs. Capacity	36%	Inventory Count Accuracy	38%
Cash to Cash Cycle Time	32%	Outbound Freight Costs	33%
Inquiry Response Time	30%		
Percent of Respondent Not Utilizing Popular Measures		**Top Measures Used by Customers and Suppliers to Measure Performance**	
On-time Delivery	21%	On-time Delivery	64%
Line Item Fill	31%	Order Fill	59%
Back Order	36%	Invoice Accuracy	56%
Cycle Time	38%	Order Cycle Time	45%
Invoice Accuracy	48%	Line Item Fill	42%

The authors also highlighted the following significant observations with respect to their survey responses:

- Cost continues to get the greatest emphasis.
- Measures that are of a more boundary-spanning nature are among the least-used.

- A significant number of companies still fail to calculate or utilize some of the most fundamental measures. (A full of 21% of respondents did not capture on-time delivery on a regular basis in their companies.)
- Most companies that responded to the survey were measuring performance within their organizations in customer service, order fulfillment, procurement, and other logistics areas. A smaller number of companies were measuring logistics performance with customers and/or suppliers. Few, if any, were measuring full supply chain network performance.

2.4.3 Summary

In this sector of literature review, we explore the evolution of supply chain measures from the perspective of logistics task and activity focused, through logistics process focused, to supply chain focused. The empirical study revealed that cost continues to get the greatest emphasis, and measures that are of a more boundary-spanning nature are among the least-used. At the same time, a significant number of companies still fail to calculate or utilize some of the most fundamental measures, and most companies are measuring performance within their organizations in customer service, order fulfillment, procurement, and other logistics areas. A smaller number of companies were measuring logistics performance with customers and/or suppliers. Few, if any, were measuring full supply chain network performance.

2.5 Evaluation Methods in Multiple Attribute Decision Making (MADM) Issues

2.5.1 Introduction of MADM

Multiple Attribute Decision Making (MADM) refers to making preference decisions (e.g. evaluation, prioritization, selection) over the available alternatives that are characterized by multiple, usually conflicting, attributes (Hwang and Yoon, 1981). MADM is a branch of the field of Multiple Criteria Decision Making (MCDM), which also includes Multiple Objective Decision Making (MODM) (Hwang and Masud, 1979). In contrast to MADM problems, MODM problems involve designing the best alternative given a set of conflicting objectives. The characteristics of MADM issues are:

- *Alternatives*: A finite number of alternatives, from several to thousands, are screened, prioritized, selected, and/or ranked.
- *Multiple Attributes*: Each problem has multiple attributes. A decision maker must generate relevant attributes for each problem setting. The number of attributes depends on the nature of the problem.
- *Incommensurable Units*: Each attribute has different units of measurement.
- *Attribute Weights*: Almost all MADM methods require information regarding the relative importance of each attribute, which is usually supplied by an ordinal or cardinal scale. Weights can be assigned directly by the decision makers or developed by the methods described in 2.4.2.
- *Decision Matrix*: A MADM problem can be concisely expressed in a matrix format, where columns indicate attributes considered in a given problem and

rows list competing alternatives.

The issue of SCPM in textile and apparel industries is definitely a MADM problem. The measured supply chain or supply chains constitutes the alternative(s). Multiple attributes are generated to evaluate the different aspects of supply chain performance. The units of the attributes are different. And attribute weights are needed to reflect the importance of each attribute. In the following parts of literature review, some common used MADM methods are reviewed.

2.5.2 Common Used MADM Methods

2.5.2.1 Simple Multi-Attribute Rating Technique (SMART)

The Simple Multi-Attribute Rating Technique (SMART) has emerged in recent years as a popular technique for analyzing problems with multiple attributes. One advantage of this method is that it is so “transparent” that decision makers usually develop a greater understanding of the problem being faced. The stages of SMART defined by Goodwin and Wright (1998) are as follows:

- Identify the decision maker(s).
- Identify the alternative courses of action.
- Identify those attributes that are relevant to the decision maker.
- For each attribute being evaluated, assign values to measure the performance of the individual alternatives relative to that attribute.
- Determine a weight for each attribute that reflects how important that attributes

is to the decision maker.

- For each alternative, take a weighted average of the values assigned to that alternative.
- Make a provisional decision.
- Perform sensitivity analysis to see how robust the decision is to changes in the figures supplied by the decision maker.

Although simple, the underlying assumption of SMART method is that attributes are preferentially independent. Less formally, this means that the contribution of an individual attribute to the total score is independent of other attribute values. In addition, these scoring models are easy to use and construct, but their results are often misunderstood.

2.5.2.2 Multiattribute Utility Theory (MAUT)

The MAUT approach, chiefly developed by Keeney and Raiffa (1976), is a theoretically sound approach based on the assumptions of rationality underlying the classic paradigm of expected utility created by von Neumann and Morgenstern (1944). The theory’s basic idea is that the selection issue can be broken down into alternative attributes. Based upon the user’s tradeoff among attributes, importance weights are quantified and single-attribute utilities are measured. Finally, single-attribute utilities are combined to develop with one single aggregate utility index for each alternative. The main consideration is how to structure and assess an aggregate utility function such that

$$u(x_1, x_2, \cdots, x_n) = f[u_1(x_1), u_2(x_2), \cdots, u_n(x_n)]$$

where $u_i(x_i)$ designates a utility function over single attribute x_i.

MAUT can be used to model the unique preference of a decision making group using utility functions that must be derived (Keeney and Raiffa, 1976). Practical applications have been limited due to the difficulties in constructing utilities functions for an individual of group. Specifically, individuals must evaluate a sequence of artificially constructed lotteries to calibrate the utility function for each attribute. In addition, MAUT's view of rationality in decision making requires perfect consistency of judgments. However, in the real world, some inconsistency is acceptable and even natural.

2.5.2.3 Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP), one of the major MADM models in the current literature, has been applied to various decision areas since its introduction by Satty (1977, 1980). It is based on three principles (Arbel and Vargas, 1993): 1) Decomposition, 2) Measurement of preferences and 3) Synthesis. Decomposition breaks the problem down into manageable elements that are treated individually. This process starts from the implicit descriptors of the problem (e.g., general objectives) and proceeds in a logical manner to identify more explicit and detailed descriptors. And according to the hierarchical descriptors, one can later compare the alternatives.

An example of a simple 3-level hierarchy is given in Figure 2.8. "Best Overall Alternative" is placed at the top level of the hierarchy, symbolizing the goal of the analysis (level 1). The hierarchy is then divided into the difficult-to-quantify as well as the quantified criteria (level 2). At the third level of the hierarchy we have the mutually exclusive alternatives that are under consideration.

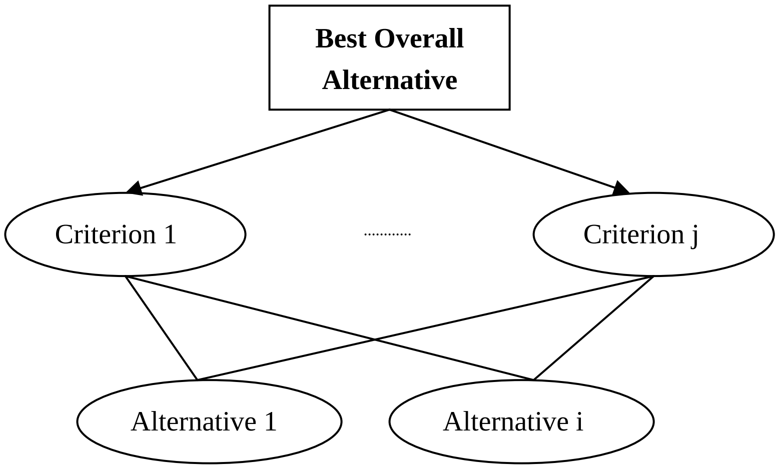


Figure 2.8 3-Level hierarchy for AHP

Measurement is used in comparing elements in a level of the hierarchy with respect to an element in a level immediately above them. The comparison is done in a pairwise manner with judgments provided as numerical statements utilizing an established comparison scale of one-to-nine and their reciprocals. When n elements are being compared to each other, these judgments are summarized in a $n \times n$ reciprocal matrix, that requires $n(n-1)/2$ comparisons. They are then used to derive a priority vector as an estimate of the underlying preferences associated with the elements being compared by the help of the principal eigenvector technique.

Using the Eigenvector and Eigenvalues method, the importance weights among the considered factors can be derived from the pairwise comparison matrix. Suppose that we wish to compare a set of k factors in pairs according to their relative weights. Denote the factors by $F_1,......,F_k$ and their weights by $W_1,......,W_k$. If $W=(W_1,......,W_k)^T$ is given, the pairwise comparisons may be represented by a matrix A of underlying ratios as follows:

$$A=\begin{array}{c} \\ F_1 \\ \vdots \\ F_i \\ \vdots \\ F_k \end{array}\begin{array}{c} \begin{array}{ccccc} F_1 & \cdots & F_j & \cdots & F_k \end{array} \\ \begin{bmatrix} \frac{w_1}{w_1} & \dots & \frac{w_1}{w_j} & \dots & \frac{w_1}{w_k} \\ \vdots & & \vdots & & \vdots \\ \frac{w_i}{w_1} & \dots & \frac{w_i}{w_j} & \dots & \frac{w_i}{w_k} \\ \vdots & & \vdots & & \vdots \\ \frac{w_k}{w_1} & \dots & \frac{w_k}{w_j} & \dots & \frac{w_k}{w_k} \end{bmatrix} \end{array}$$, and

$$\begin{array}{c} \\ F_1 \\ \vdots \\ F_i \\ \vdots \\ F_k \end{array}\begin{array}{c} \begin{array}{ccccc} F_1 & \cdots & F_j & \cdots & F_k \end{array} \\ \begin{bmatrix} \frac{w_1}{w_1} & \dots & \frac{w_1}{w_j} & \dots & \frac{w_1}{w_k} \\ \vdots & & \vdots & & \vdots \\ \frac{w_i}{w_1} & \dots & \frac{w_i}{w_j} & \dots & \frac{w_i}{w_k} \\ \vdots & & \vdots & & \vdots \\ \frac{w_k}{w_1} & \dots & \frac{w_k}{w_j} & \dots & \frac{w_k}{w_k} \end{bmatrix} \end{array}\begin{bmatrix} w_1 \\ \vdots \\ w_j \\ \vdots \\ w_k \end{bmatrix}=k\begin{bmatrix} w_1 \\ \vdots \\ w_j \\ \vdots \\ w_k \end{bmatrix}$$

$AW=kW \Rightarrow (A-kI)W=0$. But if we only had A and wanted to recover W, we would have to solve the system $(A-kI)W=0$ in the unknown W. This has a nonzero solution if, and only if, k is the eigenvalue of A and W is an eigenvector with respective to k. Thus all the eigenvalues $\lambda_i, i=1,......k$ of A are zero except one. Also it is known that: $\sum_{i=1}^{k}\lambda_i = tr(A) =$ sum of the diagonal elements= k . Therefore only one of the λ_i, which is called $\lambda_{\max}$, equals k, and $\lambda_i=0$, $\lambda_i=\lambda_{\max}$ and if $\hat{A}$ is the matrix of pairwise comparison values from intuitive rank order to pairewise comparisons, in order to find the priority eigenvector, we must find the eigenvector $\hat{W}$ with respective $\lambda_{\max}$ which satisfies $\hat{A}\hat{W} = \lambda_{\max}\hat{W}$. Observe from intuitive judgments that since small changes in elements of matrix $\hat{A}$ imply a small change in λ_i, the deviation of the latter from k is a measure of consistency. That is, $C.I. = (\lambda_{\max} - k)/(k-1)$, the consistency index, is the indicator of "closeness to consistency". In general, if this number is less than 0.1, the result is satisfied.

When comparisons are completed for all the elements of the hierarchy, one proceeds to synthesize the local priorities derived for each of the comparison matrices into a global measure of priority used in making the final decision. These global priorities are obtained by applying the principle of hierarchic composition. In mathematical format, the final weight of each alternative is given by:

$$R_i = \sum_j v_{ij} c_j$$

where

R_i = the overall weight of alternative *i*;

c_j = the weight assigned to criterion *j* to reflect its importance relative to the other criteria;

v_{ij} = the weight of alternative *i* in criterion *j*.

The primary advantage of the AHP is its use of pairwise comparisons to obtain a ratio scale of measurement. Ratio scales are a natural means of comparison among alternatives and enable us to measure both tangible and intangible factors. An AHP analysis uses pairwise comparisons to measure the impact of items on one level of the hierarchy on the next higher level. Another important advantage of the AHP is that it allows for inconsistency in judgment. However, AHP also measures the degree to which the judgments are inconsistent and establishes an acceptable tolerance level for the degree of inconsistency.

Despite the strengths and wide spread applications of AHP (Arbel and Seidman, 1984; Boucher and Gogus, 1995; Chandra and Schall, 1988; Lootsma, 1980; Wabalickis, 1988), it has received much criticism in the literature. Recent research outcomes indicate that there are pitfalls associated with the AHP approach suggested by Satty. They are summarized as follows.

- The AHP is mainly used in nearly crisp decision applications (Chen, 1996; Hauser and Tadikammlla, 1996).
- Although the use of the discrete scale of 1 to 9 has the advantage of simplicity, the AHP does not take into account the uncertainty associated with the mapping of one's judgment to a number (Cheng and Mon, 1994).
- The subjective judgment, selection and preference of decision-makers exert a strong influence in the AHP method (Cheng and Mon, 1994).
- AHP is known as an additive pairwise weights identification method, which may cause the evaluation results departure from the experts' opinions. In other words, using AHP to evaluate a system is an operation of Simple Additive Weight (SAW) that sums the importance of individual criteria and their

efficient values. Very often, however, each individual criterion is not completely independent of the others, which does not comply with the characteristics of this additivity type (Chen, 2000; Ralescu and Adams, 1980).

2.5.3 Fuzzy Logic in Decision Making

Decision making may be characterized as a process of choosing or selecting 'sufficiently good' alternative(s) or course(s) of action, from a set of alternatives, to attain a goal or goals. Much decision making involves uncertainty. Hence, one of the most important aspects for a useful decision aid is to provide the ability to handle imprecise and vague information, such as 'large' profits, 'fast' speed and 'cheap' price. According to Bellman and Zadeh (1970) 'much of the decision-making in the real world takes place in an environment in which the goals, the constraints and the consequences of possible actions are not known precisely'.

A useful decision model must handle incomplete and uncertain knowledge and information. Different views, attitudes and beliefs must also be acknowledged. A decision model should include processes for identifying, measuring and combining criteria and alternatives to create a conceptual model for decisions and evaluations in fuzzy environments.

In 1965, L. A. Zadeh introduced the theory of fuzzy sets. Fuzzy sets are based on the concept that the boundaries of sets involving approximate data are not precisely defined and that membership within the set is not a matter of absolute truth, but rather, a matter of degree. Zadeh (1965) defined a fuzzy set as “a class of objects with a continuum of grades of membership.” A fuzzy set can be defined mathematically by assigning each element in the set a value which represents the grade of membership in the set. The membership grades are represented by real number values in the closed interval from zero to one. In essence, a fuzzy number can be regarded as a special fuzzy subset of a real number. Classical sets, usually distinguished as “crisp sets”, can be viewed as special cases of fuzzy sets in which the associated function maps each element of the set to the binary set {0,1}. Crisp sets only allow full membership or no membership at all, while fuzzy sets allow partial membership (Yager and ZadehB, 1992). The basic knowledge of theory of fuzzy sets is illustrated in Appendix B.

The application of fuzzy set theory has several advantages in comparison with the crisp sets (Klir, 1995). First, fuzzy set theory is capable of handling a higher degree of uncertainty than regular crisp set method. Second, it requires fewer assessments than other methods such as Bayes’ theorem or evidential theory. Third, it requires that very few assumptions be satisfied. Fourth, fuzzy set theory has realistic means of including degrees of importance for decision makers.

2.5.4 Summary

In this section of literature review, we make sure that SCPM in textile and apparel industries is definitely a MADM problem. Three common used MADM techniques, SMART, MAUT and AHP, are described. Most real world decision making takes place in an environment in which the states of nature, feasible actions and outcomes, and available information are only imprecisely known. Hence, fuzzy logic are more and more used in decision making problems. All these constitute the theory foundation for a Combined Fuzzy Multiple Attribute Evaluation (CFMAE) model developed for SCPM in textile and apparel industries in this study.

Chapter 3 Research Methodology

3.1 Introduction

As stated in Chapter 1, the final result of the research is to build up a practical tool, which is an online system, for SCPM in the textile and apparel industries. To achieve the goal, three detailed objectives are presented step by step. The objective of the first stage is to put forward a hierarchical structure of SCPMS in textile and apparel industries. The objective of the following stage is to develop a mathematical evaluation model to evaluate SCPMS in textile and apparel industries. The objective of the final stage is the online SCPM in textile and apparel industries to guide the decision maker in actual evaluation. As shown in Figure 3.1, multiple methodologies, which are accordingly comprised of three stages, are employed to these three objectives.

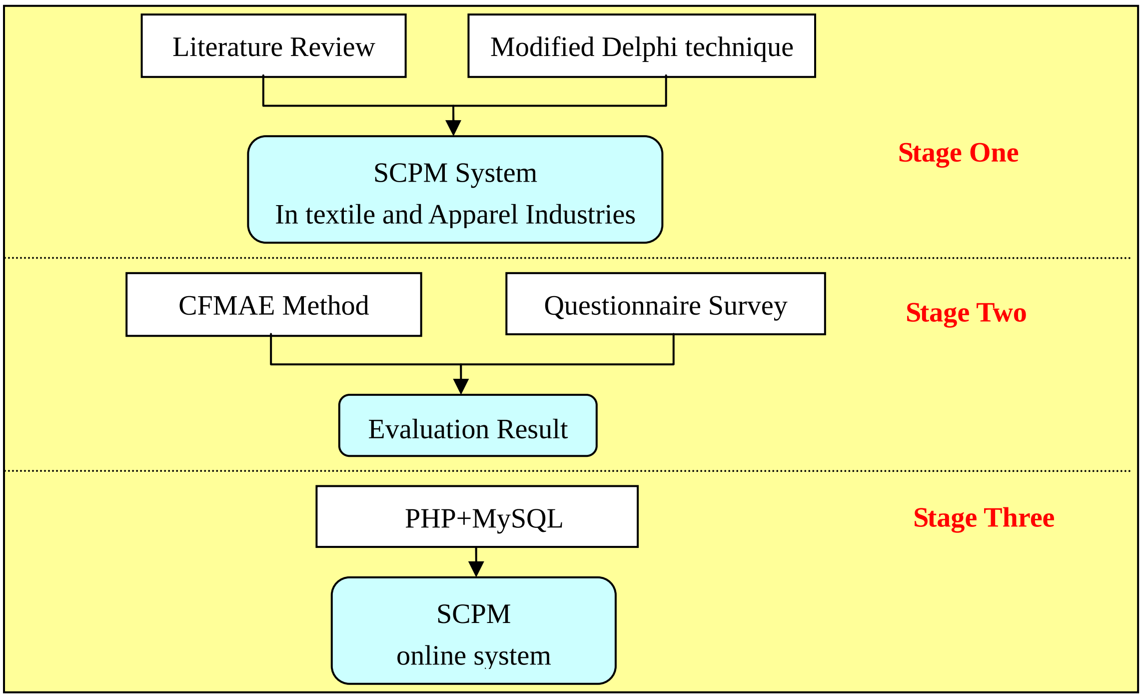


Figure 3.1 Research methodology

In the first stage, based on literature review, the modified Delphi technique was employed to solicit best thinking from supply chain related managers and experts in textile or apparel companies or related organizations. The result of this stage is to construct the SCPMS in textile and apparel industries. In the second stage, a Combined Fuzzy Multiple Attribute Evaluation (CFMAE) method was developed. A comprehensive questionnaire for a mail survey was conducted to assist in the evaluation model. The questionnaire survey was completed by 77 senior managers related to SCM, who were from Hong Kong and mainland China. Based on above two stages, a SCPM online system was developed for application in reality. PHP and MySQL were employed for the online system development.

3.2 Methodologies in Stage One

3.2.1 Literature Review

An extensive search of both academic and practitioner press database was conducted to identify literature pertaining to SCPM and attributes of SCM in textile and apparel industries. Over 200 articles were identified mainly from the four databases: Social Sciences Citation Index (1970+), Science Direct-Online Journals by Elsevier Science (1996+), Emerald Fulltext (1994+) and Business Source Premier (1965+). Database searches on a combination of approximately 20 key words relating to SCPM. These studies were reviewed, categorized and synthesized to determine what research has been done and to identify gaps in the literature. This relevant body of knowledge, discussed in Chapter 2, provides antecedent justification for theory building or theory-extension on the subject of SCPM in textile and apparel industries.

3.2.2 Modified Delphi Technique

3.2.2.1 Introduction of Delphi Technique

The Delphi is the best known qualitative, structured, and indirect interaction featured method in use today (Woudenberg, 1991). Created by Olaf Helmer and Norman Dalkey in 1953 at RAND Corporation to address a future military issue, the technique became popular when it was applied a decade later on large scale forecasting and corporate planning (Helmer, 1983).

According to the literature, the Delphi technique has several advantageous features, which include (1) anonymity, (2) written responses, (3) controlled feedback, and (4) statistical group responses (Dalkey, 1967; Delbecq *et al.*, 1975). Among its advantages is the fact that participants do not have to meet face to face; respondents may remain anonymous, and adequate time is provided for thinking and reflection. Domination by individuals is prevented. Participants are granted flexibility in responding, and conformity issues are avoided (Linstone and Turoff, 1975; Ruhland, 1993; Weaver, 1988). According to Sackman (1975), the Delphi method is generally fast, inexpensive, easy to understand, and versatile in the sense that it can be applied wherever expert opinion is believed to exist.

The process of Delphi consists of a series of rounds of survey questionnaires. In a traditional Delphi study, the first round would consist of participants responding to a broad question, while each additional round would build upon the responses gleaned from earlier rounds. The process is terminated when consensus is reached (Delbecq *et al.*, 1975). According to Linstone and Turoff (1975), most commonly, three rounds should prove sufficient to attain stability in the responses; further rounds tended to show very little change and excessive repetition was unacceptable to participants.

The detailed steps suggested by Allen (1978) should be followed when implementing and utilizing the Delphi technique:

- Selection of a panel of experts, the panel needs to be aware of the issues surrounding the problem. The size of the panel should be between ten and thirty. Because of the time involved in the process, a smaller panel of ten was recommended.
- First round Delphi questionnaire development, where an open ended format was utilized and responses of the panel were not limited by the researcher.
- Analysis of the first questionnaire, the responses were coded and put into categories.
- Development of the second round questionnaire, the responses from the first round were reviewed and ranked for feedback to the panel.
- Development of the third round questionnaire, the panel was asked to look at the median scores from round two and rate the statements again. Whenever their individual rating different from the group median they were asked to write

an explanation.

- Analysis in the final round, the median scores were used to determine if consensus was reached.
- Final report preparation, median, mean scores and ranges were exhibited to report the degree of agreement and consensus.

3.2.2.2 Modified Delphi Technique Employed in Stage One

In this research, a modified Delphi technique was employed. Three phases were conducted. The modification emerged mainly in the first phase. Ten experts were selected in the panel, which is comprised of 6 top executives of companies in textile and clothing industries and 4 secretaries of local associations of textile and apparel. They are from Hong Kong and Mainland China. The experts in Mainland China were recommended by China Garment Association, and those in Hong Kong were recommended by The Hong Kong General Chamber of Textile Ltd. At first, 20 candidates were recommended. After communicating with them about their availability and interest, 10 were finally selected into the panel.

In the first phase, instead of traditional questionnaire survey to panel experts, face-to-face in-depth interviews were conducted to communicate with the experts. The reason to modify is that from literature review, we know that little research is found on SCPM in textile and apparel industries. SCPM in textile and apparel industries lacks both theoretical and practical bases. That means even for experts, the issue is out of considerations to some extent. And textile and apparel supply chain is complicated, which encompasses multiple members. SCPMS design philosophy and the concrete meaning of each SCPM metrics are also very difficult to be delivered thoroughly and accurately through questionnaire survey. For such a complicated issue, it is not reasonable to start the discussion just through questionnaire. The face-to-face interview is more thorough and accurate. It can be controlled by the interviewer. The unified terms and explanations can be used to all the interviewees. Different understanding between panel members can also be avoided. The difficult of the face-to-face in-depth interview is that it is hard to arrange the time of interview with the experts because they are generally busy, and it needs relatively long time to communicate with them about the issues of SCPM in textile and apparel industries. In-depth interviews of at least one hour each were conducted. Before the interview, the author prepared a detailed interview plan with open ended questions based on the literature review. In the first round in-depth interviews, experts were asked to provide the related opinion on both SCM in textile and apparel industries and SCPM in textile and apparel industries.

The interviews were conducted from June, 2004 to August, 2004. The results were compiled and were sent with the second survey to the 10 experts in the beginning of September, 2004 via Email. Responses from the second survey were received in about four weeks. Two weeks after the email, telephone calls were made to remind the experts to complete the questionnaires. All of the questionnaires were completed and valid.

After summarizing the result of the second survey, the final SCPMS in textile and apparel industries employed in this study is determined. The result was sent to the experts via Email to make confirmation for the third round.

A list of experts included in the panel is found in Appendix C as Exhibit C1, the outline of the interview as Exhibit C2, the second round questionnaire as Exhibit C3, and the last email as Exhibit C4.

3.3 Methodologies in Stage Two

3.3.1 Why Fuzzy Logic Used in Stage Two

There exists much ignorance and imprecision when measuring the supply chain performance in textile and apparel industries, using the SCPMS developed in stage one of this study. They are:

- Unquantifiable information. In the SCPMS in textile and apparel industries, quantitative and qualitative metrics are in concurrence. Qualitative information in linguistic terms, such as “knowledge management” for supply chain development, cannot be quantified precisely.
- Incomplete information. Some exact information cannot be assessed due to the lack of tools for measuring it in SCPMS in textile and apparel industries. For example, the timeliness of information sharing is “about” 5 days; it is estimated

information, limited by the unavailability of a precise instrument for measuring it.

- Nonobtainable information. It needs all supply chain members to take part in the SCPM in textile and apparel industries. Hence, sometimes the crisp data is difficult to obtain due to high cost, limited time constraint or unavailability because of sensitive issues. The typical example is to measure all of the supply chain cost. It needs all related members to set up a concrete accounting system, such as Activity Based Costing (ABC) to record it. An approximation of information is usually used in a decision-making process.
- Partial ignorance. Some fuzziness is attributed to partial ignorance of the phenomenon when only part of the fact is known.

As stated in Chapter 2, fuzzy set theory is capable of handling a higher degree of uncertainty than regular crisp set method; it requires fewer assessments information; it requires very few assumptions to be satisfied; and, it has realistic means of including degrees of importance for decision makers. Fuzzy multiple attribute decision making is thus employed in stage two.

3.3.2 Foundations of CFMAE Method

3.3.2.1 Fuzzy Measure

The concept of fuzzy measure is first introduced by Sugeno (1974) in his Ph.D thesis. The fuzzy measure generalizes the usual definition of a measure by replacing the usual additivity property by a monotonicity property with respect to set inclusion. Similar attempts regarding nonadditive measures were also made almost simultaneously by Shafer (1976) and Zadeh (1978). As Sugeno (1974) suggested, fuzzy measures are suitable to express grades of fuzziness, i.e., the quantities depending on human subjectivity.

Fuzzy measures are the generalization of the classical measures. By a measurable space we mean a pair (X, Ω) consisting of a set *X* and a σ-algebra of subset of *X*. A subset *A* of *X* is called measurable (or measurable with respect to Ω) if $A \in \Omega$. A measure μ on a measurable space (X, Ω) is a real nonnegative set function defined for all sets of Ω such that $\mu(\phi) = 0$, and if $(A)_{i=1}^{\infty}$ is a disjoint family of sets with $A_i \in \Omega, i \geq 1$, then

$$\mu(\bigcup_{i=1}^{\infty} A_i) = \sum_{i=1}^{\infty} \mu(A_i)$$

It can be shown that a measure μ has the following properties.

1) $\mu(A) \leq \mu(B)$ if $A \subset B$
2) if $(A)_{i=1}^{\infty}$ is an increasing sequence of measurable sets, then $\lim_{i \to \infty} \mu(A_i) = \mu(\lim_{i \to \infty} A_i)$

An important example of such a measure is the probability measure, *P*, where $P(X) = 1$. Within the frame work of a human reasoning model, the additivity hypothesis of this measure is too restrictive. In the seventies, alternative models were proposed by different researchers (Shafer, 1976; Sugeno, 1977; Terono and Sugeno, 1975; Zadeh, 1978) who all share the following intuitively reasonable axioms.

Sugeno (1974) defined fuzzy measure as follows.

Let $g:\Omega \to [0,1]$ be a set function with

1) $g(\phi)=0, g(X)=1$
2) $g(A) \le g(B)$ if $A \subset B$
3) If $(A)_{i=1}^{\infty}$ is an increasing sequence of measurable sets, then $\lim_{i\to\infty} g(A_i) = g(\lim_{i\to\infty} A_i)$

By the nature of the definition of a fuzzy measure *g*, the measure of the union of two disjoint subsets can not be directly computed form the component measures. In light of this, Sugeno (1974) introduced the so called λ-fuzzy measures satisfying the following additional property:

for all $A, B \subset X$ and $A \cap B = \phi$,

$$g(A \cup B) = g(A) + g(B) + \lambda g(A)g(B) \qquad \text{for some } \lambda > -1 \qquad (3.1)$$

A λ-fuzzy measure is indeed a fuzzy measure, and the λ-fuzzy measure for $\lambda = 0$ is probability measure (Banon, 1981).

Let $X = \{x_1, x_2, \cdots x_n\}$ be a finite set and let $g_i = g(\{x_i\})$. The mapping $x_i \to g_i$ is called a fuzzy density function. Suppose $A = \{x_{i_1}, x_{i_2}, \cdots x_{i_m}\} \subseteq X$. A has m elements, x_{i_1} is the first element of the classifier *i*, and x_{i_m} is the element *m* of the classifier *i* (*i* is the general name given for the classifier). One can write

$$g(A)=\sum_{j=1}^{m} g_{i_j}+\lambda\sum_{j=1}^{m-1}\sum_{k=j+1}^{m} g_{i_j}g_{i_k}+\cdots+\lambda^{m-1}g_{i_1}g_{i_2}\cdots g_{i_m}=\frac{1}{\lambda}\left|\prod_{j=1}^{m}(1+\lambda g_{i_j})-1\right| \quad (3.2)$$

for $-1<\lambda<\infty$

Equation 3.2 is the generalization of the equation 3.1 which indicates the union of only two subsets A and B. The first section of equation 3.2 ($\sum_{j=1}^{m} g_{i_j}$) is the summation of all the fuzzy densities from element *1* to *m* of the classifier *i* (*m* is the number of elements in subset *A*). The second section of the equation 3.2 ($\sum_{j=1}^{m-1}\sum_{k=j+1}^{m} g_{i_j}g_{i_k}$) means the inter-influence of every two fuzzy densities, where g_{i_j} is the *j*th fuzzy density of the classifier *i* and g_{i_k} is the *k*th fuzzy density of the classifier *i*. The third section of equation 3.2 ($\lambda^{m-1}g_{i_1}g_{i_2}\cdots g_{i_m}$) means multiplying λ by λ for *m-1* times (number of elements in subset *A* minus 1) and then multiply the result with $g_{i_1}g_{i_2}\cdots g_{i_m}$ which are the fuzzy density value of every element of the subset *A* for classifier *i*.

Equation 3.2 calculates the λ-fuzzy measure for *A* which is the subset of the finite set *X*. Thus the value of λ can be found from the equation $g(X)=1$. This is equivalent to solving the equation $\lambda+1=\prod_{i=1}^{n}(1+\lambda g_i)$. Hence if we know the fuzzy densities, g_i, for *i=1,2,…,n*, we can construct the λ-fuzzy measure.

Consider the following simple case of three knowledge sources, $X=\{x_1,x_2,x_3\}$ together with density value $g_1=0.1, g_2=0.3, g_3=0.2$. Using the Sugeno's measure *g* must have a parameter λ satisfying $0.006\lambda^2+0.11\lambda-0.4=0$.

The unique root greater than -1 for this equation is $\lambda = 3.109$, which produces the following fuzzy measure on the power set of X (calculated from the definition of Sugeno measueres). Table 3.1 shows the results obtained.

Table 3.1 Fuzzy measure on the power set of *X*

Subset A	$g_{3.109}(A)$
ϕ	0
$\{x_1\}$	0.1
$\{x_2\}$	0.3
$\{x_3\}$	0.2
$\{x_1, x_2\}$	0.493
$\{x_1, x_3\}$	0.362
$\{x_2, x_3\}$	0.687
$\{x_1, x_2, x_3\}$	1

As expected, the subset of the criteria $\{x_2, x_3\}$ is considerably more important for confirming the hypothesis than either subset $\{x_1, x_2\}$ or $\{x_1, x_3\}$.

3.3.2.2 Fuzzy Integral

Using the notion of fuzzy measures, Sugeno (1974) defined the concept of the fuzzy integral. Fuzzy integrals are non-linear functional, very similar to Lebesque integrals, where the integral is defined over measurable sets (Halmos, 1950; Pfeffer, 1977). Let (X, Ω) be a measurable space and let $h: X \to [0,1]$ be a Ω-measurable function. The fuzzy integral over $A \subset X$ of the function h with respect to a fuzzy measure is defined as follows:

$$\oint_A h(x) \circ g(\cdot) = \sup_{E \subseteq X}[\min(\min_{x \in E} h(x), g(A \cap E))] = \sup_{\alpha \in [0,1]}[\min(\alpha, g(A \cap F_\alpha))]$$

where $F_\alpha = \{x : h(x) \geq \alpha\}$

The following is the interpretation of the fuzzy integral. Suppose that an object is evaluated from the point of view of a set of sources *X*. Let $h(x) \in [0,1]$ denote the decision for the object when source $x \in X$ is considered and let $g(\{x\})$ denote the degree of importance of this source. Now, suppose the object is evaluated using sources from $A \subseteq X$. It is reasonable to consider a quantity

$$W(A) = \min_{x \in A} h(x)$$

as the best security decision that the object provides and $g(A)$ expresses the grade of importance of this subset of sources. The value obtained from comparing these two quantities in terms of the min operator is interpreted as the grade of agreement between real possibilities, $h(x)$, and the expectations, *g*. Hence fuzzy integration is interpreted as searching for the maximal grade of agreement between objective evidence and the expectation.

The following are the properties of fuzzy integral (Wierzchon, 1976).

1) If $h(x) = c$, for all $x \in X$, $0 \le c \le 1$, then $\oint_X h(x) \circ g(\cdot) = c$

2) If $h_1(x) \le h_2(x)$, for all $x \in X$, then $\oint_X h_1(x) \circ g(\cdot) \le \oint_X h_2(x) \circ g(\cdot)$

3) If $A \subset B$, then $\oint_A h(x) \circ g(\cdot) \le \oint_B h(x) \circ g(\cdot)$

4) Let $\{A_i : i = 1,2,\cdots n\}$ be a portion of the set X, then $\oint_X h(x) \circ g(\cdot) \ge \max(e_1, \cdots, e_n)$, where e_i is the fuzzy integral of *h* with respect to *g* over A_i. The interpretation of all these properties related to the fuzzy integral as an information fusion technique should be obvious.

The calculation of the fuzzy integral when X is a finite set is easily given. Let $X = \{x_1, x_2, \cdots x_n\}$ be a finite set and let $h: X \to [0,1]$ be a function. Suppose $h(x_1) \ge h(x_2) \ge \cdots \ge h(x_n)$ (if not, X is rearranged so that this relation holds). Then a fuzzy integral, *e*, with respect to a fuzzy measure *g* over X can be calculated by

$$e = \max_{i=1}^{n}[\min(h(x_i), g(A_i))] \qquad \text{where } A_i = \{x_1, \cdots, x_i\}.$$

Note that when g is λ-fuzzy measure, the value of $g(A_i)$ can be determined recursively as

$$g(A_1) = g(\{x_1\}) = g_1$$

$$g(A_i) = g(\{x_1, \cdots x_{i-1}, x_i\}) = g_i + g(A_{i-1}) + \lambda g_i g(A_{i-1}) \quad \text{for } 1 < i \le n$$

Thus the calculation of the fuzzy integral with respect to a λ-fuzzy measure would only require the knowledge of the density function, where *i*th density, g_i, is interpreted as the degree of importance of the source x_i, for $i = 1,2,\cdots n$.

A more general equation of fuzzy integral deifined as follows (Sugeno, 1974).

Assuming that $h(x_1) \ge h(x_2) \ge \cdots \ge h(x_n)$, then the fuzzy integral is:

$$(C)\int hdg = h(x_n)g(H_n) + [h(x_{n-1}) - h(x_n)]g(H_{n-1}) + \cdots + [h(x_2) - h(x_1)]g(H_1)$$

$$= h(x_n)[g(H_n) - g(H_{n-1})] + h(x_{n-1})[g(H_{n-1}) - g(H_{n-2})] + \cdots + h(x_1)g(H_1) \qquad (3.3)$$

where $H_1 = \{x_1\}, H_2 = \{x_1, x_2\}, \cdots H_n = \{x_1, x_2, \cdots x_n\} = X$

The basic concept of Equation 3.3 can be illustrated as shown in Figure 3.2.

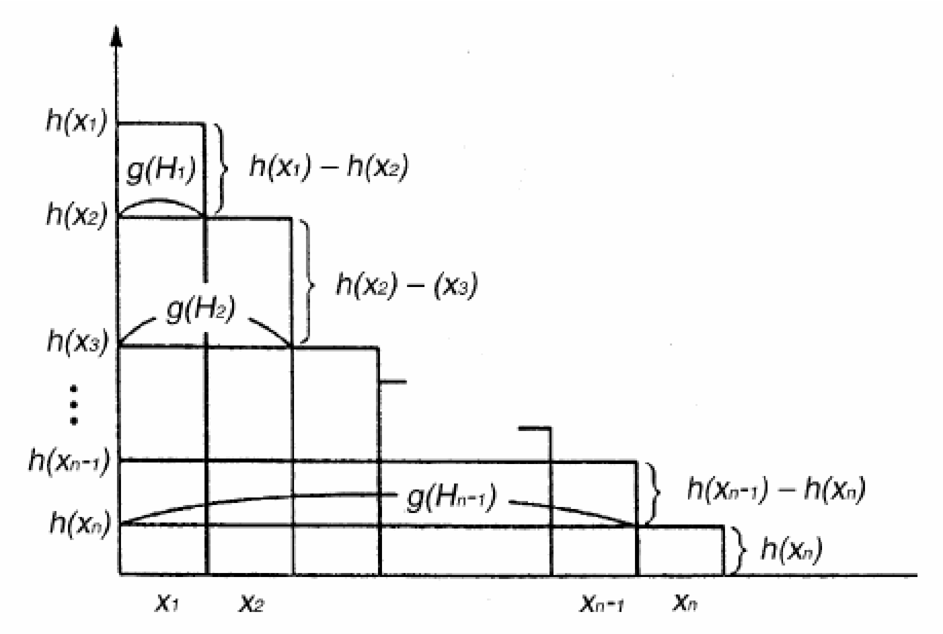


Figure 3.2The basic concept for fuzzy integral

Furthermore, if $\lambda = 0$ and $g_1 = g_2 = \cdots = g_n$, then $h(x_1) \geq h(x_2) \geq \cdots \geq h(x_n)$ is not a necessary condition.

3.3.2.3 FAHP

As stated in Chapter 2, AHP is one of the extensive used MADM methods. One of the main advantages of this method is the relative ease with which it handles multiple criteria. In addition to this, AHP is easier to understand and it can effectively handle both qualitative and quantitative data. The use of AHP does not involve cumbersome mathematics. However, the conventional AHP cannot reflect the human thinking style because of uncertainty and vagueness.

In order to deal with the uncertainty and vagueness from the subjective perception and the experience of human decision process, many fuzzy AHP methods are proposed by various authors. Decision makers are usually more confident to give interval judgments than fixed value judgments. This is because usually he/she is unable to be explicit about his/her preferences due to the fuzzy nature of the comparison process.

The advantages for the fuzzy AHP method against Satty's (1980) classical AHP method are as follows:

- Fuzzy numbers are preferable to extend the range of a crisp decision matrix in the classical AHP method insofar as human judgment in comparison is never precise.
- Fuzzy numbers allow decision makers to have freedom of estimation regarding the overall goal. Judgment can go from optimistic to pessimistic.
- The combination judgment from sub-criteria to major criteria is better than the traditional single eigenvector method, which forms a square comparison matrix for all the criteria.

Table 3.2 gives the comparison of several fuzzy AHP methods in the literature, which have important differences in their theoretical structures.

Table 3.2 Comparisons of different fuzzy AHP methods

Sources	*The main characteristics of the method*	*Advantages (A) and disadvantages (D)*
Van Laarhoven and Pedrycz (1983)	● Direct extension of Satty's AHP method with triangular fuzzy numbers ● Lootsma's Logarithmic least square method is used to derive the fuzzy weights and fuzzy performance scores	(A)The opinions of multiple decision makers can be modeled in the reciprocal matrix (D) There is not always a solution to the linear equations (D) The computational requirement is tremendous, even for a small problem (D) It allows only triangular fuzzy numbers to be used
Buckley (1985)	● Extension of Satty's AHP method with trapezoidal fuzzy numbers ● Uses the geometric mean method to derive fuzzy weights and performance scores	(A) It is easy to extend to the fuzzy case (A) It guarantees a unique solution to the reciprocal comparison matrix (D) The computational requirement is tremendous
Boender *et al.* (1989)	● Modifies van Laarhoven and Pedrycz's method ● Presents a more robust approach to the normalization of the local priorities	(A) the opinions of multiple decision makers can be modeled (D) The computational requirement is tremendous
Chang (1996)	● Synthetical degree values ● Layer simple sequencing ● Composite total sequencing	(A) The computational requirement is relatively low (A) It follows the steps of crisp AHP. It does not involve additional operations. (D) It allows only triangular fuzzy numbers to be used
Cheng (1996)	● Builds fuzzy standards ● Represents performance scores by membership functions ● Uses entropy concepts to calculate aggregate weights	(A) The computational requirement is not tremendous (D) Entropy is used when probability distribution is known. The method is based on both probability and possibility measures

3.3.3 Introduction of CFMAE Method

An attribute-based SCPMS in textile and apparel industries is put forward after stage one, which will be described in the result part of the thesis. A three level hierarchical model is obtained. The top level is the final performance of the evaluated textile-apparel supply chain. The second level is the eight attributes, which are independent. The eight attributes in the second level are comprised of several metrics respectively, which are interdependent, in the third level. These metrics are interdependent. The hierarchical evaluation model is shown in Figure 3.3.

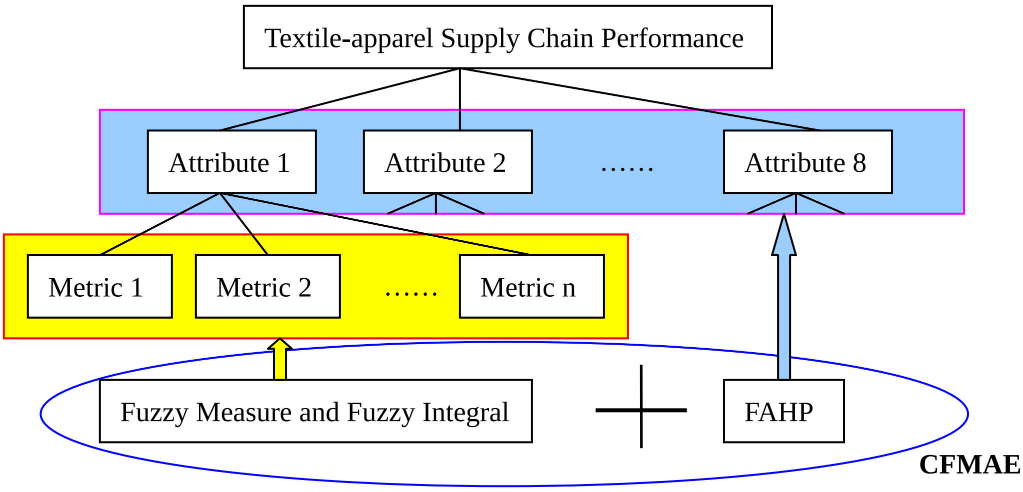


Figure 3.3 Evaluation process using fuzzy logic approach

As stated before, the evaluation of SCPM in textile and apparel industries is a MADM problem. In this study, a Combined Fuzzy Multiple Attribute Evaluation (CFMAE) method is developed for the evaluation process. Also three stages constitute the CFMAE method. The first stage is to calculate the evaluation value of each first-level attribute, which is reflected by the corresponding second-level metrics. Fuzzy measure and fuzzy integral are employed in this stage. The reason to employ fuzzy measure and fuzzy integral is that the metrics of the first-level attribute are interdependent. Hence, nonadditivity measures are appropriate. Fuzzy measure and fuzzy integral is a reasonable solution for this kind of problem. The second stage is to get the weight of each first-level attribute, employing FAHP. The eight first-level attributes are independent. Hence, the additivity method, especially AHP is proper for this kind of problem. The third stage is to get the overall performance value, which is an operation of Simple Additive Weight (SAW) that integrates the score of each attribute.

Questionnaire survey is employed to assist in calculating the responding weights of the metrics and attributes, which will be described in the following part.

3.3.4 Terms Used in CFMAE Method

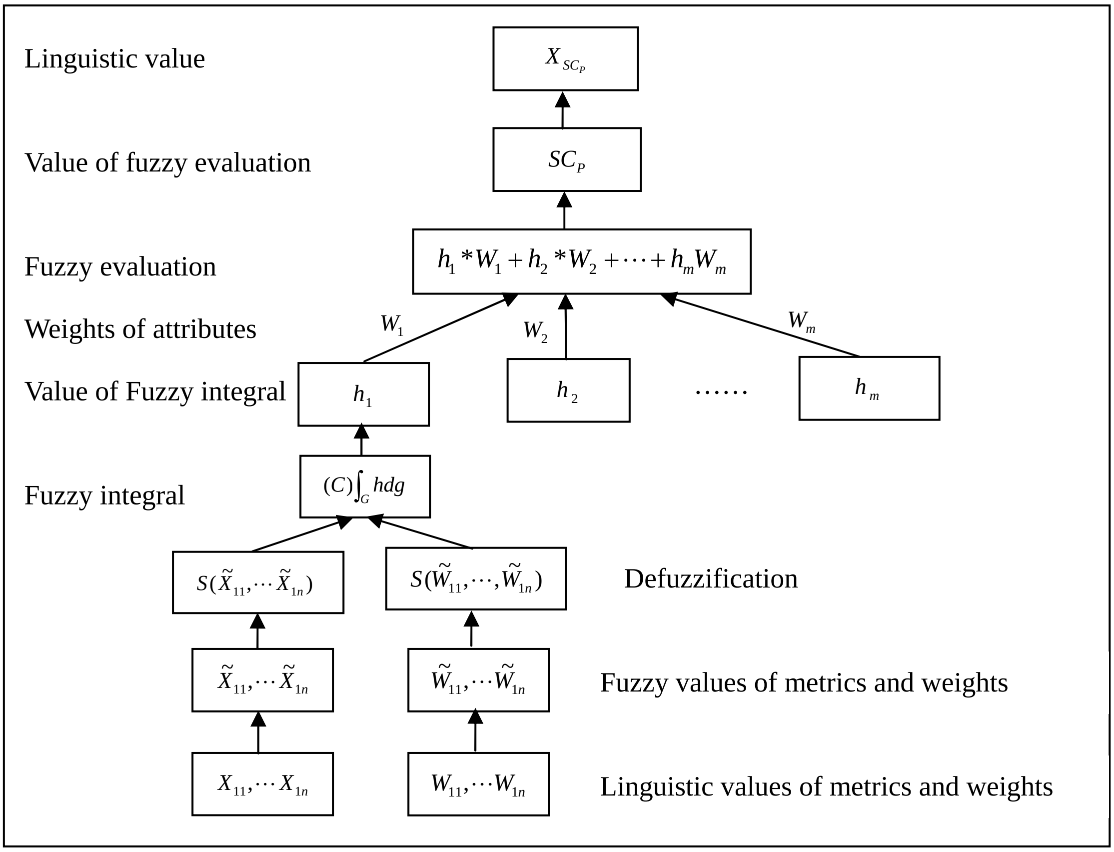


Figure 3.4 Processes of CFMAE Method

Figure 3.4 shows the detailed processes of CFMAE method. The terms used in this method are interpreted as following.

X_{ij} : Linguistic evaluation value of *j*th metric for *i*th attribute for a given textile apparel supply chain;

W_{ij} : Linguistic weight value of *j*th metric for *i*th attribute;

$\tilde{X}_{ij}$: Fuzzy evaluation value of *j*th metric for *i*th attribute for a given textile apparel supply chain;

$\tilde{W}_{ij}$: Fuzzy weight value of *j*th metric for *i*th attribute;

$S(\tilde{X}_{i1},\cdots,\tilde{X}_{in})$: Defuzzification vector of evaluation value for *i*th attribute for a given textile apparel supply chain;

$S(\tilde{W}_{i1},\cdots\tilde{W}_{in})$: Defuzzification vector of weight value for *i*th attribute;

h_i : Evaluation value after fuzzy integral for *i*th attribute;

W_i : Weight value after FAHP for *i*th attribute;

SC_P : Evaluation value after SAW for the whole supply chain performance;

X_{SC_P} : Linguistic value for the whole supply chain performance.

3.3.5 First Stage of CFMAE Method—Fuzzy Measure and Fuzzy Integral

There are four steps for the first stage of CFMAE method in this study.

Step 1 Define the membership functions of fuzzy linguistic sets

The first step is to define the membership functions for both X_{ij} and W_{ij} . In this real evaluation process, respondents were asked to evaluate the performance and the importance of the metric with a 7-point scale. Accordingly, linguistic variable for

X_{ij} is defined consisting of 7 elements. X_{ij} ={EP, VP, LP, N, LG, VG, EG}, where EP=Extremely Poor, VP=Very Poor, LP=Little Poor, N=Normal, LG=Little Good, VG=Very Good, EG=Extremely Good. Linguistic variable for W_{ij} contains 7 elements too. W_{ij} ={EUI, VUI, LUI, N, LI, VI, EI}, where EUI=Extremely Unimportant, VUI=Very Unimportant, LUI=Little Unimportant, N=Normal, LI=Little Important, VI=Very Important, EI=Extremely Important.

There are many approaches to define membership functions (Dombi, 1990), in which the piecewise linear (trapezoidal-shaped) has been used by many authors (Bortolan and Degani, 1985; Chen, 1985). The symmetrical trapezoidal-shaped membership functions which are most often used are employed in this study. The linguistic values of X_{ij} are shown in the Table 3.3.

Table 3.3 Linguistic values of X_{ij}

EP: Extremely Poor	(0, 0, 0.1, 0.15)
VP: Very Poor	(0.1, 0.15, 0.25, 0.3)
LP: Little Poor	(0.25, 0.3, 0.4, 0.45)
N: Normal	(0.4, 0.45, 0.55, 0.6)
LG: Little Good	(0.55, 0.6, 0.7, 0.75)
VG: Very Good	(0.7, 0.75, 0.85, 0.9)
EG: Extremely Good	(0.85, 0.9, 1, 1)

The membership functions of X_{ij} are shown in the following:

$$f_{EP}(x) = \begin{cases} 1 & 0 \le x \le 0.1 \\ 3 - 20x & 0.1 \le x \le 0.15 \\ 0 & others \end{cases}$$

$$f_{VP}(x)=\begin{cases}20x-2 & 0.1\le x\le 0.15\\ 1 & 0.15\le x\le 0.25\\ 6-20x & 0.25\le x\le 0.3\\ 0 & others\end{cases}$$

$$f_{LP}(x)=\begin{cases}20x-5 & 0.25\le x\le 0.3\\ 1 & 0.3\le x\le 0.4\\ 9-20x & 0.4\le x\le 0.45\\ 0 & others\end{cases}$$

$$f_{N}(x)=\begin{cases}20x-8 & 0.4\le x\le 0.45\\ 1 & 0.45\le x\le 0.55\\ 12-20x & 0.55\le x\le 0.6\\ 0 & others\end{cases}$$

$$f_{LG}(x)=\begin{cases}20x-11 & 0.55\le x\le 0.6\\ 1 & 0.6\le x\le 0.7\\ 15-20x & 0.7\le x\le 0.75\\ 0 & others\end{cases}$$

$$f_{VG}(x)=\begin{cases}20x-14 & 0.7\le x\le 0.75\\ 1 & 0.75\le x\le 0.85\\ 18-20x & 0.85\le x\le 0.9\\ 0 & others\end{cases}$$

$$f_{EG}(x)=\begin{cases}20x-7 & 0.85\le x\le 0.9\\ 1 & 0.9\le x\le 1\\ 0 & others\end{cases}$$

The graphic presentations of membership functions for the linguistic set X_{ij} are shown in Figure 3.5.

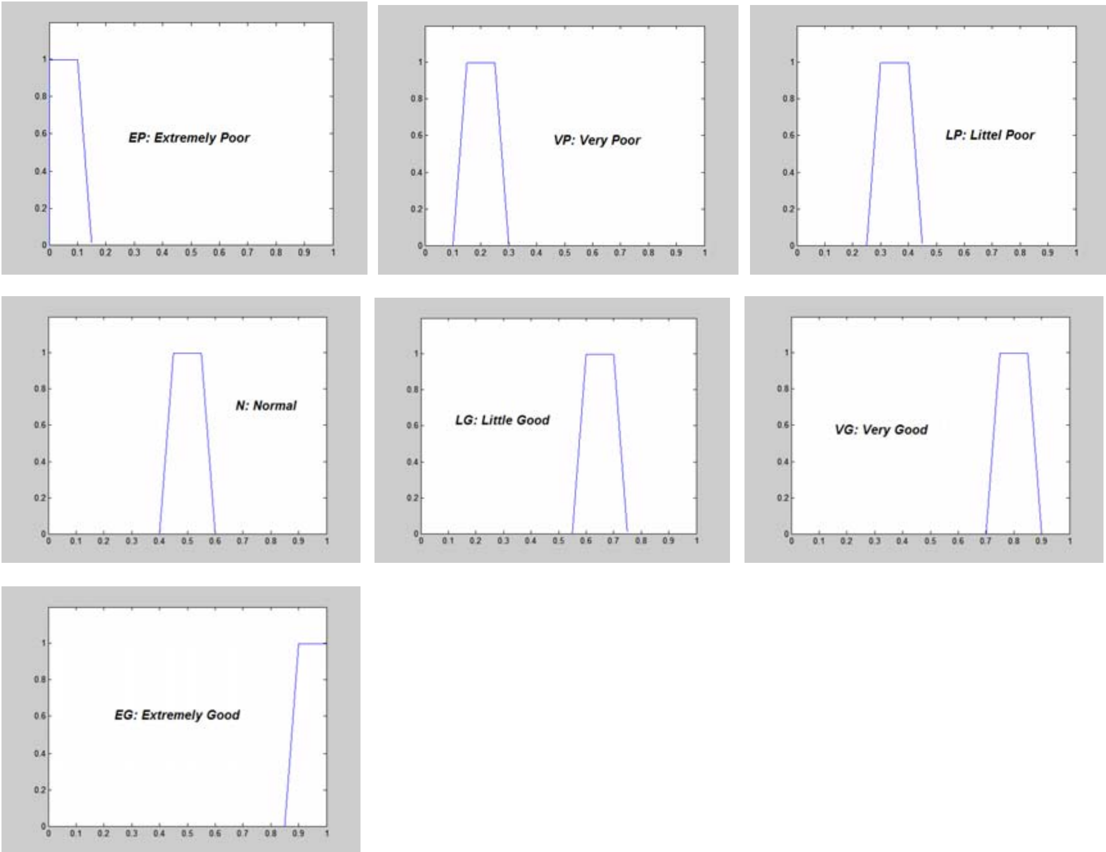


Figure 3.5 Membership function of linguistic variable X_{M_i}

Same with X_{ij}, the linguistic values of W_{ij} are shown in the Table 3.4.

Table 3.4 Linguistic values of W_{ij}

EUI: Extremely Unimportant	(0, 0, 0.1, 0.15)
VUI: Very Unimportant	(0.1, 0.15, 0.25, 0.3)
LUI: Little Unimportant	(0.25, 0.3, 0.4, 0.45)
N: Normal	(0.4, 0.45, 0.55, 0.6)
LI: Little Important	(0.55, 0.6, 0.7, 0.75)
VI: Very Important	(0.7, 0.75, 0.85, 0.9)
EI: Extremely Important	(0.85, 0.9, 1, 1)

The membership functions of X_{ij} are shown in the following:

$$f_{EUI}(x)=\begin{cases}1 & 0\le x\le 0.1\\ 3-20x & 0.1\le x\le 0.15\\ 0 & others\end{cases}$$

$$f_{VUI}(x)=\begin{cases}20x-2 & 0.1\le x\le 0.15\\ 1 & 0.15\le x\le 0.25\\ 6-20x & 0.25\le x\le 0.3\\ 0 & others\end{cases}$$

$$f_{LUI}(x)=\begin{cases}20x-5 & 0.25\le x\le 0.3\\ 1 & 0.3\le x\le 0.4\\ 9-20x & 0.4\le x\le 0.45\\ 0 & others\end{cases}$$

$$f_{N}(x)=\begin{cases}20x-8 & 0.4\le x\le 0.45\\ 1 & 0.45\le x\le 0.55\\ 12-20x & 0.55\le x\le 0.6\\ 0 & others\end{cases}$$

$$f_{LI}(x)=\begin{cases}20x-11 & 0.55\le x\le 0.6\\ 1 & 0.6\le x\le 0.7\\ 15-20x & 0.7\le x\le 0.75\\ 0 & others\end{cases}$$

$$f_{VI}(x)=\begin{cases}20x-14 & 0.7\le x\le 0.75\\ 1 & 0.75\le x\le 0.85\\ 18-20x & 0.85\le x\le 0.9\\ 0 & others\end{cases}$$

$$f_{EI}(x)=\begin{cases}20x-7 & 0.85\le x\le 0.9\\ 1 & 0.9\le x\le 1\\ 0 & others\end{cases}$$

The graphic presentations of membership functions for the linguistic set W_{ij} are shown in Figure 3.6.

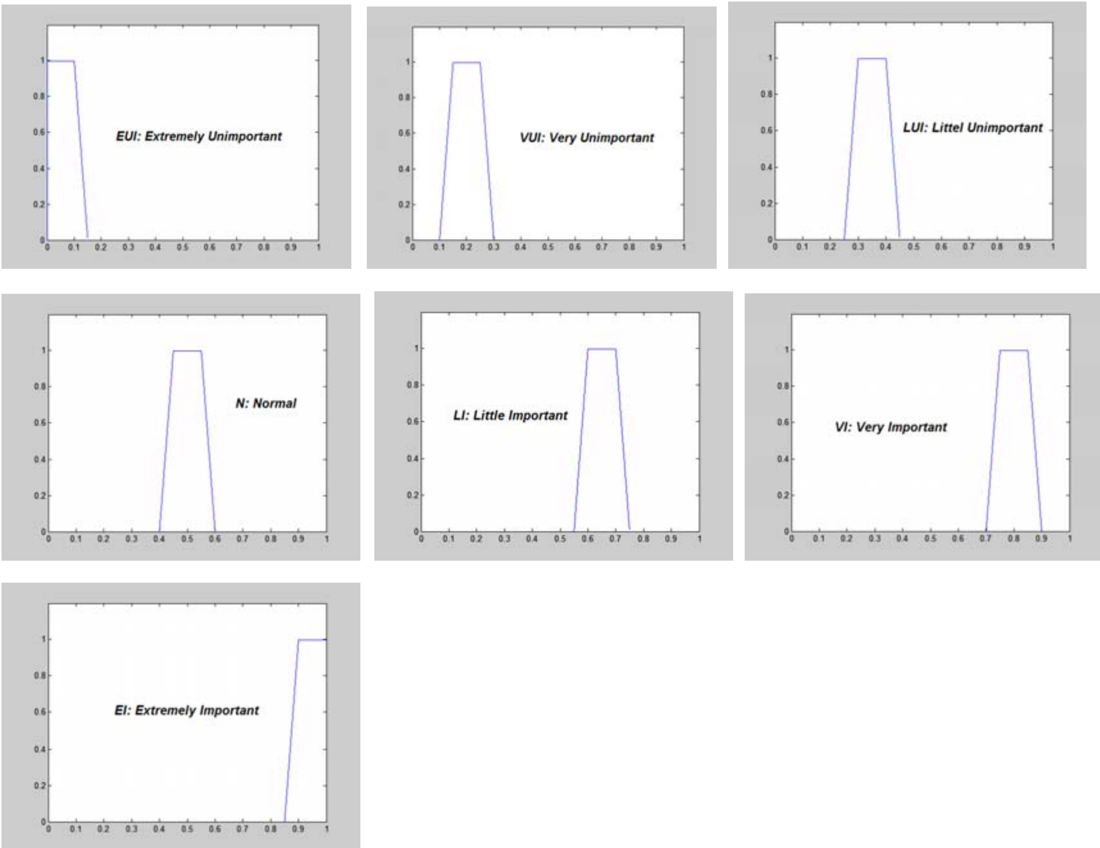


Figure 3.6 Membership function of linguistic variable W_{M_i}

Step 2 Average fuzzy values of both metrics and weights

Suppose there are total *k* experts to evaluate both metrics and weights. According to the linguistic values defined in step 1, after averaging the *k* values, fuzzy evaluation value of *j*th metric for *i*th attribute $\tilde{X}_{ij}$ and fuzzy weight value of *j*th metric for *i*th attribute $\tilde{W}_{ij}$ are shown in the following equations.

$$\tilde{X}_{ij} = \frac{1}{k}(\cdot)\left\{X_{ij_1} + X_{ij_2} + \cdots + X_{ij_k}\right\} \tag{3.3}$$

$$\tilde{W}_{ij} = \frac{1}{k}(\cdot)\left\{W_{ij_1} + W_{ij_2} + \cdots + W_{ij_k}\right\} \tag{3.4}$$

Step 3: Defuzzification

Once calculating the fuzzy evaluation value and fuzzy weight of each metric, the next step is to get the nonfuzzy values. There are many methods of defuzzification (Chen and Hwang, 1992). Delgado *et. al* (1998) pointed out it is not proper to use a single method to transform from linguistic domain to numerical domain. They suggested using multiple transformation functions for defuzzification. In this study, three most frequently used methods are employed.

1) Distance measurement

Chen (2000) proposed the distance measurement method for defuzzification. For

$$M_1(\tilde{W}_{ij}) = \frac{\bar{e}_{ij}}{\bar{e}_{ij} + e_{ij}^{*}} \tag{3.5}$$

$\tilde{W}_{ij} = (a_{ij}, b_{ij}, c_{ij}, d_{ij})$, its defuzzified value $M_1(\tilde{W}_{ij})$ is

where

$$e_{ij}^{*} = \sqrt{\frac{1}{4}[(1-a_{ij})^2 + (1-b_{ij})^2 + (1-c_{ij})^2 + (1-d_{ij})^2)}$$

$$\bar{e}_{ij} = \sqrt{\frac{1}{4}(a_{ij}^{\ 2} + b_{ij}^{\ 2} + c_{ij}^{\ 2} + d_{ij}^{\ 2})}$$

2) Central Value

The central value method for defuzzification suggested by Delgado *et. al* (1998) is as follows. For $\tilde{W}_{ij} = (a_{ij}, b_{ij}, c_{ij}, d_{ij})$, its defuzzified value $M_2(\tilde{W}_{ij})$ is

$$M_2(\tilde{W}_{ij}) = \frac{b_{ij} + c_{ij}}{2} + \frac{[(d_{ij} - c_{ij}) - (b_{ij} - a_{ij})]}{6} = \frac{2b_{ij} + 2c_{ij} + d_{ij} + a_{ij}}{6} \tag{3.6}$$

3) Central of gravity

This method summarizes the meaning of a label, $\tilde{W}_{ij}$, into a numeric value as (Delgado *et al.*, 1998)

$$M_3(\tilde{W}_{ij}) = \frac{\int_V v\mu_{y_{\tilde{W}_{ij}}}(v)dv}{\int_V \mu_{y_{\tilde{W}_{ij}}}(v)dv}$$

For trapezoidal fuzzy numbers $\tilde{W}_{ij} = (a_{ij}, b_{ij}, c_{ij}, d_{ij})$

$$M_3(\tilde{W}_{ij}) = \begin{cases} a_{ij} & a_{ij} = b_{ij} = c_{ij} = d_{ij} \\ \dfrac{d_{ij}{}^2 + c_{ij}{}^2 - b_{ij}{}^2 - a_{ij}{}^2 + c_{ij}d_{ij} - a_{ij}b_{ij}}{3(d_{ij} + c_{ij} - a_{ij} - b_{ij})} & otherwise \end{cases} \tag{3.7}$$

We use the mean of $M_1(\tilde{W}_{ij})$, $M_2(\tilde{W}_{ij})$ and $M_3(\tilde{W}_{ij})$ to get the final defuzzification number $M(\tilde{w}_i)$, which is

$$M(\tilde{W}_{ij}) = \frac{M_1(\tilde{W}_{ij}) + M_2(\tilde{W}_{ij}) + M_3\tilde{(}W_{ij})}{3} \tag{3.8}$$

Step 4 Fuzzy measure and fuzzy integral

According to equation 3.2

$$g(A) = \sum_{j=1}^{m} g_{i_j} + \lambda \sum_{j=1}^{m-1} \sum_{k=j+1}^{m} g_{i_j} g_{i_k} + \cdots + \lambda^{m-1} g_{i_1} g_{i_2} \cdots g_{i_m} = \frac{1}{\lambda}\left|\prod_{j=1}^{m}(1+\lambda g_{i_j}) - 1\right|$$

and $g(X) = 1$, we can get

$$\lambda + 1 = \prod_{i=1}^{n}(1 + \lambda g_{ij}) \tag{3.9}$$

where $g_{ij} = S(\tilde{W}_{ij})$

Thus, the value of λ can be reached.

Then, $g_\lambda(\{\tilde{X}_{i1}, \tilde{X}_{i2}, \cdots \tilde{X}_{il}\}) = \frac{1}{\lambda}\left|\prod_{j=1}^{l}(1 + \lambda S(\tilde{W}_{ij})) - 1\right|$ (3.10)

Suppose $h(X_{ij}) = S(\tilde{X}_{ij})$, if $S(\tilde{X}_{il}) > S(\tilde{X}_{i(l-1)}) > \cdots > S(\tilde{X}_{i1})$ then

$$h_i = h(X_{il})[g_\lambda(\tilde{X}_{i1},\cdots,\tilde{X}_{il}) - g_\lambda(\tilde{X}_{i1},\cdots\tilde{X}_{i(l-1)})] + \cdots + h(X_{i1})g_\lambda(\tilde{X}_{i1})$$
$$= g_\lambda(\tilde{X}_{il})[h(X_{il}) - h(X_{i(l-1)})] + \cdots + g_\lambda(\tilde{X}_{i1})h(X_{i1}) \quad (3.11)$$

In this stage, MATLAB was also employed as a mathematical tool to help the calculation. The name MATLAB stands for Matrix Laboratory. It is a high performance language for technical computing and is a well-known scientific simulation package. The MATLAB system consists of five main parts, which are, namely: development environment, MATLAB mathematical function library, MATLAB language, graphics and MATLAB application program interface. MATLAB also has a variety of optional programs such as control system toolbox, fuzzy logic toolbox, etc., to be used for solving a particular class of problem. To calculate the results of the questionnaire survey for the weights of second-level metrics, and further calculate the evaluation results of the first-level attributes, a program using MATLAB is developed.

3.3.6 Second Stage of CFMAE Method—FAHP

Five steps in the FAHP model are employed in this study to calculate W_i, which are presented as following steps.

Step 1: Create fuzzy pairwise comparison matrix by questionnaire survey

For the eight attributes in the SCPMS in textile and apparel industries, the decision importance factors converted into the semantic format were used to design polling questionnaires. The data were obtained from the questionnaire survey which is described in 3.3.7. The next phase was to convert the results of the questionnaire into fuzzy pairwise comparison matrix by using Satty's (1980) 9 scales. The details are shown in Table 3.5.

Table 3.5 Scale for comparison

Intensity of importance	Definition	Explanation
1	equal importance	two criteria contribute equally to the objective
3	weak importance	judgment slightly favor one criteria over another
5	strong importance	judgment strongly favor one criteria over another
7	very strong or demonstrated importance	a criteria is favored very strongly over another
9	absolute importance	the evidence favoring one criteria over another is of the highest possible order
2,4,6,8	Intermediate values between adjacent scale values	

Triangular fuzzy numbers can be defined by a triplet (a_1, a_2, a_3) to approach the fuzziness of estimation. The functions for those fuzzy numbers are shown in Table 3.6 from Cheng and Mon's paper (1994).

Table 3.6 Parameters that define the functions of fuzzy numbers

Fuzzy number	Membership function (a_1, a_2, a_3)
$\tilde{1}$	(1, 1, 1)
$\tilde{x}$	(x-1, x, x+1) where x=2,3,4,5,6,7,8
$\tilde{9}$	(9, 9, 9)

Step 2: Group combination

After creating the fuzzy pairwise comparison matrix, the geometric mean of each attribute in the matrix was calculated as Buckley (1985) suggested.

$$\tilde{M}_{ij} = (1/N) \otimes (\tilde{m}_{ij}^{\;1} \oplus \tilde{m}_{ij}^{\;2} \oplus \cdots \oplus \tilde{m}_{ij}^{\;N})$$

$\tilde{M}_{ij}$: Integrated Trigonometric Fuzzy Number

$\tilde{m}_{ij}^{\;N}$: the *i*th to the *j*th attribute pair comparison value by Expert *N*

N: total number of experts

Step 3: Build up the fuzzy positive reciprocal matrix

After Step 3, obtaining the final calculated fuzzy numbers could form the Fuzzy Positive Reciprocal Matrix

$$M = \left[\tilde{M}_{ij}\right]$$

M: Fuzzy positive reciprocal matrix

$$\tilde{M}_{ij} = (L_{ij}, C_{ij}, R_{ij})$$

L_{ij} : the left value of the experts' opinions in the triangular function

C_{ij} : the central value of the experts' opinions in the triangular function

R_{ij} : the right value of the experts' opinions in the triangular function

$$\tilde{M}_{ji} = 1/\tilde{M}_{ij}$$

Step 4: Calculate the attributes' fuzzy weights

Buckley (1985)'s method to calculate the fuzzy weights was employed in this step. The formula is defined below:

$$\tilde{Z}_i = (\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \cdots \otimes \tilde{a}_{in})^{1/n}, \qquad \forall i = 1,2,\cdots n$$

$$\tilde{W}_i = \tilde{Z}_i \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \cdots \oplus \tilde{Z}_n)^{-1}$$

$\tilde{a}_{ij}$: relative importance between attribute i and j

$\tilde{Z}_i$: fuzzy geometric average of attribute i

$\tilde{W}_i$: fuzzy weight corresponding to attribute i

Step 5: Defuzzification and normalization

Equations 3.5 to 3.8 were used in the defuzzification process. Therefore, for $i = 1,2,\cdots,K$, the weight vector is given by

$$W' = (M'(\tilde{W}_1), M'(\tilde{W}_2), \cdots, M'(\tilde{W}_k))^T$$

Via normalization, we get the normalized weight vectors

$$W = (M(\tilde{W}_1), M(\tilde{W}_2), \cdots, M(\tilde{W}_k))^T$$

where W is a nonfuzzy number.

3.3.7 Third Stage of CFMAE Method—SAW

The third stage is to get the overall performance value, which is an operation of Simple Additive Weight (SAW) that integrates the score of each attribute.

The final value of the performance is

$$SC_P = h_1 \cdot W_1 + h_2 \cdot W_2 + \cdots + h_m W_m \qquad (3.12)$$

SC_P is the numerical value for the final performance. Delgado *et al.* (1998) defined a

Numerical Linguistic Transformation Function, which gave a representative label for a given numerical value.

Let $r \in [0,1]$ be a numerical value. Let s_i be a label verifying that

$$h(r, s_i) = \min\{h(r, s_t) | \forall s_t \in S\},$$

with

$$h(r, s_i) = \begin{cases} z & if \quad r \notin Supp(s_t) \\ \sum_{j=1}^{z} (r - G_j(s_t))^2 & if \quad r \in Supp(s_t) \end{cases} \qquad (3.13)$$

where z is the number of dividing point, $G_j(s_t)$ is jth numerical value of the linguistic variable s_i, $Supp(s_i)$ is the scope of numerical value of the linguistic variable s_i.

3.3.8 Questionnaire Survey

Questionnaire survey is employed in this study as a means to obtain the necessary data in the process of CFMAE method. There are three parts of the questionnaire survey, one is for W_i in FAHP process, the other is for W_{ij} in the fuzzy measure and fuzzy integral process. Also the demographics of the respondents are in the third part.

The questionnaire was conducted with textile and apparel firms to get more practical opinions. The survey was conducted in Hong Kong and some provinces in Mainland China. The selected provinces of Mainland China are places where textile and apparel firms are clustered. These clusters, however, are dispersed. They are Guangdong in the south, Zhejiang in the east, Beijing and Tianjin in the north, and Shanxi in the northwest. The survey was sponsored by local associations of textile and apparel. After discussing with the sponsors, they provided the member lists that were suitable for this study. Because top management is assumed to have more knowledge about the company's various strategies and operations, the company's top executives, such as CEO or COO, or director of manufacturing, were targeted as research subjects.

Ten companies were selected for interview as pilot test to verify the understanding of the questionnaire. After their response, the questionnaire was revised to the respondents' better understanding. The survey was conducted mainly by mail with self-addressed envelop. The mailing was followed two weeks later by a telephone reminder. The survey lasted for two months, from November, 2004 to January, 2005. The sampling procedure produced 400 companies as potential respondents. A total of 77 questionnaires were completed and returned to the researcher, resulting in a total response rate of 19.3 percent.

For the FAHP part of the questionnaire, respondents were asked to assess the relative importance between the eight attributes after a simple example. The example in the questionnaire is in Table 3.7.

Table 3.7 Example to describe the pairwise comparison

Example:

When you buy clothing, there are many factors to be considered such as price and style. If you think that price is absolutely more important than style, please tick “absolutely important” in price side.

	AI		DI		SI		WI		EI		WI		SI		DI		AI	
	9		7		5		3		1		3		5		7		9	
Price	√	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	Style

Or if you think that style is more important than price, and the extent is between weakly more important and strongly more important, please tick between SI and WI in style side.

	AI		DI		SI		WI		EI		WI		SI		DI		AI	
	9		7		5		3		1		3		5		7		9	
Price	□	□	□	□	□	□	□	□	□	□	□	√	□	□	□	□	□	Style

AI (9): absolute importance
DI (7): demonstrated importance
SI (5): strong importance
WI (3): weak importance
EI (1): equal importance

For the fuzzy measure and fuzzy integral part, respondents were asked to evaluate the importance of each second-level metric with 7-point scale, from EUI (Extremely Unimportant) to EI (Extremely Important). The demographics of the companies are also investigated. The full version questionnaire can be found in Appendix D.

3.4 Methodology in Stage Three

The online SCPMS in textile and apparel industries to guide the decision maker in actual evaluation is developed in this stage, employing PHP as the developing language and MySQL as the database. In the online system, the weights of first-level attributes are from the calculating results of the second stage, while the importance and performance value of the according second-level metrics are required to evaluate by the decision makers for the consistency. The detail is described in Chapter 5.

Chapter 4 Results

4.1 Introduction

In Chapter 3, the research methodologies of this study, which are comprised of three stages, are presented. After literature review and revised Delphi process, the hierarchical structure of SCPMS in textile and apparel industries is constructed. Following is the process of the evaluation, in which the CFMAE method is employed. FAHP is used to calculate the weights of first-level eight attributes. Fuzzy measure and fuzzy integral are used to calculate the value of the performance for first-level eight attributes, through their corresponding second-level metrics. In this process, questionnaire survey, which is responded by 77 industrial experts, is conducted to collect the related data. A general online SCPMS in textile and apparel industries is then developed, which is described in Chapter 5. Accordingly, in Chapter 4, the results of the study are also presented in three stages. In the first stage, the result is the hierarchical structure of SCPMS in textile and apparel industries. In the second stage, the results are the weights of first-level eight attributes and the mid data in fuzzy measure and fuzzy integral. In the third stage, the real online SCPMS in textile and apparel industries is ready for use, which is also described in Chapter 5.

4.2 Results in Stage One—Construction of SCPMS in Textile and Apparel Industries

4.2.1 Results of Literature Review

After conducting vast of literature review, eight attributes of SCM in textile and apparel industries are selected as the first-level measures in SCPMS of this study. They are supply chain product development, supply chain cost, supply chain time, supply chain quality, supply chain flexibility, supply chain innovation, supply chain information sharing, and supply chain profitability. These selected eight attributes are from inter-organizaional supply chain view. They are balanced in multiple aspects: supply chain information sharing and supply chain flexibility are from business process perspective; supply chain product development, supply chain cost, supply chain time, and supply chain quality are from customer perspective; supply chain innovation is from innovation and learning perspective; and supply chain profitability is from financial perspective. The eight attributes are complete, operational, decomposable, non-redundant, and minimal to reflect the supply chain performance.

Under the eight first-level attributes, the corresponding second-level metrics are presented.

- **Measures Relating to Supply Chain Product Design and Development**

The product design and development process in textile and apparel industries differs from the process used for other generic products in several ways. First, the product development process timeframe is relatively short. It takes approximately 3 to 9 months to develop one fashion apparel product line (Brown and Rice, 2001). And under the intense competition, the timeframe is even shorter. Second, a fashion apparel product development process is needed to respond quickly to the changes of fashion seasons. It requires the coordination with fashion trends, including colors, silhouettes, and yarns, otherwise it will be out-of-date by the time the product is on the market. Third, the final result of the product design and development can be influenced by different stages of textile and apparel supply chain. For example, the product design and development of yarn can directly affect the final product. Due to these characteristics, each firm in the supply chain is under enormous pressure in terms of time and product.

Except for product design and development time and cost, few supply chain measures are available for measuring the performance of product design and development. Here, we present three measures for product design and development according to the characteristics described above and the model of creating and marketing an apparel line described in 2.1.3.

The first one is the adoption rate of initial designs. It is a measure to evaluate the efficiency of product design and development. For a supply chain, if 100 initial designs are made and only 80 are finally adopted and then in market, the adoption rate of initial designs is 0.8. It is quantitative.

The second one is quality of sample making. Sample making is a critical process for the product development. The quality of sample making determines the final quality of the products. It is a qualitative one.

The third is R&D of the whole supply chain, which mainly refers to the resource that is devoted to the design section. It can be simply measured by the input to the design section divided by the income of the total supply chain. It is a quantitative measure.

Measures Relating to Supply Chain Costs

As mentioned before, cost is one of the most emphasized measures in supply chain performance measurement (Neely *et al.*, 1995). In Beamon's (1999) ROF model, resource measures include total cost, distribution costs, manufacturing cost, inventory cost, and return on investment. Cost is also a critical measure in Chan and Qi's (2003) Process-based model. Here, we break down supply chain costs in textile and apparel industries into the following costs: 1) Product development cost, which includes all the direct costs in the process of product development process; 2) Production cost, which refers to total cost of manufacturing; 3) Inventory cost, which is associated with held inventory; 4) Transportation cost, which includes all the related cost in transportation; 5) Quality control cost, which happens when controlling the quality; and 6) information sharing cost, which is related to the process of information sharing. For the six kinds of cost, activity based cost (ABC) method should be employed to further decompose them for accurate record. These should be quantitative, and can be illustrated by proportion to the total supply chain costs.

Measures Relating to Supply Chain Time

Similar to cost, time is also one of the most emphasized measures in supply chain performance measurement (Neely *et al.*, 1995). Breaking down the total supply chain time in textile and apparel industries, six types of times can be obtained. They are: 1) Product design time, which refers to the time from the start of designing the apparel line to the sample making starts; 2) Sample making time; 3) Materials preparing time; 4) Production time; 5) Delivery time; and 6) Waiting time in supply chain, which is an important measure to evaluate the efficiency of the total supply chain.

- **Measures Relating to Supply Chain Quality**

Traditionally quality has been defined in terms of conformance to specification and hence quality-based measures of performance have focused on issues such as the number of defects produced and the cost of quality (Neely *et al.*, 1995). Quality control cost has been categorized to supply chain cost. In supply side of the supply chain, failure rate caused by materials is employed to measure the supply chain quality. In production process, failure rate caused by production is employed. And in logistics side, on time delivery rate and perfect order delivery rate are employed.

- **Measures Relating to Supply Chain Flexibility**

The flexibility measure in Beamon's (1999) ROF model is used for this study. They are: Quantity flexibility, which refers to the ability to change the output level of products produced; Delivery flexibility, which refers to the ability to change planned delivery dates; and product combination flexibility, which refers to the ability to combine different lines of products.

Measures Relating to Supply Chain Information Sharing

Information sharing is without question important, because all the decisions in the supply chain should be made according to the information shared. Here, we employ accuracy of information sharing, timeliness of information sharing, and effectiveness of information sharing to measure the extent of information sharing within supply chain members.

Measures Relating to Supply Chain Innovation

In textile and apparel industries, innovation, such as new technology and new material, is a sustainable factor for the supply chain to achieve advantages from the competitive supply chains. Here, three measures to reflect the supply chain innovation are employed, which are number of new product per season, number of new technology, and number of new materials.

Measures Relating to Supply Chain Profitability

As stated before, real partnership is questionable between the powerful retail sectors and the small manufacturing sectors in textile and apparel supply chain (Bruce *et al.*, 2004). Hence, to measure the supply chain profitability, except for the traditional total supply chain turnover, and total supply chain profit, rationality of profit distribution is also a critical.

The above measures are summarized in Table 4.1. From Table 4.1, the original

SCPMS in textile and apparel industries is illustrated in Figure 4.1. Both quantitative and qualitative measures are included.

Table 4.1 Second-level metrics

First-level Attribute	Second-level Metrics	Definition	Character
① *Supply Chain Product Development*	Adoption rate of initial design	Number of adopted design/total design	Quantitative(↑)
	Quality of sample making	Level of sample making	Qualitative(↑)
	R&D of the whole supply chain	Resources devoted to design section	Quantitative(↑)
② *Supply Chain Cost*	Product development cost	Direct cost in the product development	Quantitative(↓)
	Production cost	Total cost of manufacturing	Quantitative(↓)
	Inventory cost	Cost associated with held inventory	Quantitative(↓)
	Transportation cost	Cost related to transportation	Quantitative(↓)
	Quality control cost	Cost happening in controlling quality	Quantitative(↓)
	Information sharing cost	Cost devoted to improve information sharing	Quantitative(↓)
③ *Supply Chain Time*	Total supply chain lead time	Time from initial point to the products to market	Quantitative(↓)
	Product development time	Start of designing to start of sample making	Quantitative(↓)
	Sample making time	Stat of sample making to sample determined	Quantitative(↓)
	Material preparing time	Time waiting for materials	Quantitative(↓)
	Production time	Time in production	Quantitative(↓)
	Delivery time	Time in delivery	Quantitative(↓)
	Waiting time in supply chain	All time not in any process	Quantitative(↓)
④ *Supply Chain Quality*	Failure rate caused by materials	Number of fails caused by materials/total number of fails	Quantitative(↓)

	Failure rate caused by production	Number of fails caused by production/ total number of fails	Quantitative(↓)
	On time delivery rate	Number of on time deliveries/total deliveries	Quantitative(↑)
	Perfect order delivery rate	Number of perfect deliveries/total deliveries	Quantitative(↑)
⑤ *Supply Chain*	Quantity flexibility	Ability to change the output level of product produced	Qualitative(↑)
Flexibility	Delivery flexibility	Ability to change planned delivery dates	Qualitative(↑)
	Product combination flexibility	Ability to combine different lines of products	Qualitative(↑)
⑥ *Supply Chain*	Accuracy of information sharing	Accuracy of information sharing	Qualitative(↑)
Information Sharing	Timelessness of information sharing	Timelessness of information sharing	Qualitative(↑)
	Effectiveness of information sharing	Effectiveness of information sharing	Qualitative(↑)
⑦ *Supply Chain*	Number of new product per season	Number of new product to market per season	Quantitative(↑)
Innovation	Number of new technology	Number of new technology adopted	Quantitative(↑)
	Number rate of new materials	Number of new materials adopted	Quantitative(↑)
⑧ *Supply Chain*	Total supply chain turnover	The turnover of final product	Quantitative(↑
Profitability	Total supply chain profit	The turnover of final product-all cost in supply chain	Quantitative(↑
	Rationality of profit distribution	Rationality of profit distribution	Qualitative(↑)

Note: (↑) means the bigger the better, (↓) means the smaller the better.

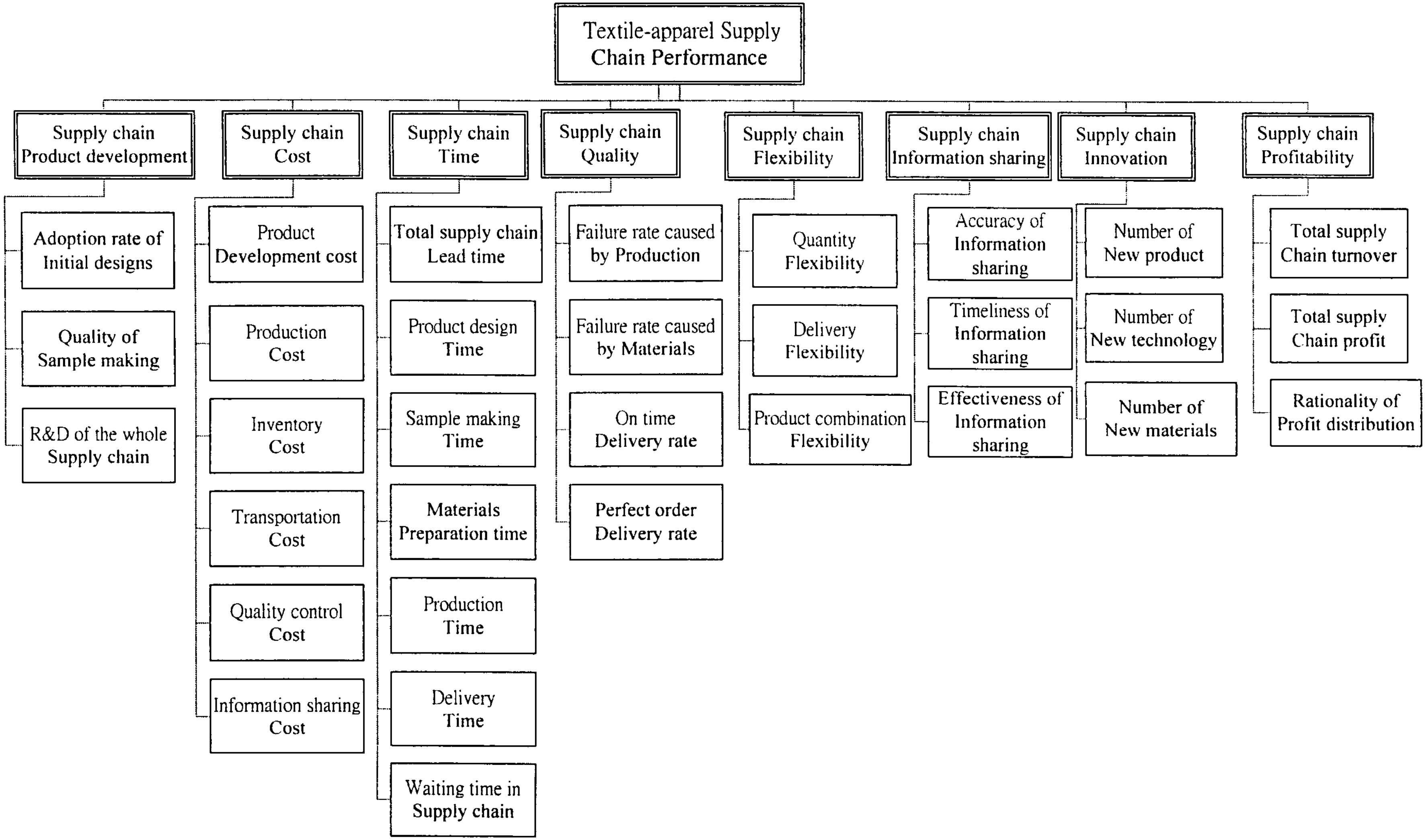


Figure 4.1 Original SCPMS after literature review

4.2.2 Key findings from First Round of In-depth Interviews

As stated in Chapter 3, the first round of Delphi study is modified to be in-depth interview. The interview questions are not just for SCPM in textile and apparel industries, because we need to explore the topic step by step. The interview questions are listed below in bold typeface. The syntheses of responses are listed immediately below the questions, in order of frequency of mention.

1. **What do companies think of SCM in textile and apparel industries?**

   Respondents claimed that not so many companies adopt the philosophy of SCM in textile and apparel industry. But because of increasing competition, companies in textile and apparel industries started to pay attention to SCM and conduct some SCM projects. More specific reasons to adopt SCM are:

   - Low margins and competitive pressure to reduce costs;
   - Lead time pressure/demand;
   - Requirement of powerful member in supply chain such as War-Mart; and
   - More customer service and customer focus.

2. **Please comment on the evolution of the process of measuring activities across firms. What is the current state? How fast is it evolving? How much progress will occur in the next five years?**

   Respondents recognized measurement was deficient today but expected dramatic improvement. Specific comments included:

   - The current state is an awareness that it is necessary, but there is a lack of knowledge regarding how to do it or implement it.

- Many organizations, even today, do not have cross-functional performance measures in place within their own companies;
- Evolution of the measures will be based on collaboration among firms;
- The next five years are expected to see dramatic changes.

3. **What are the barriers that companies face in moving toward a supply chain process orientation?**

   Status quo tendencies and deficient information capability were cited. More specific comments were:

   - Organizational structure and related issues such as resistance to change, lack of infrastructure, lack of leadership commitment, and the lack of trust among partners;
   - I/T infrastructure such as being outdated/obsolete, too expensive to upgrade, no compatibility of IT system between partners;
   - Lack of metrics to measure improvement of use of shared information;
   - Absence of new performance measures and objectives that are process spanning rather than functional based;
   - The range of information sharing.

4. **Which attributes do you think are typical and important for SCM in textile and apparel industries?**

   In this question, the interviewer presented the eight attributes which were found through literature review and asked the interviewees' opinion about them. All of the respondents agreed with the eight attributes. The complementary opinions are:

- The definitions of the eight attributes are not quite clear;
- The eight attributes are not complete, some new ones should be added, two are specially mentioned:
    - Supply chain productivity—the rate at which one specific event or activity adds value at the cost of resources;
    - Supply chain asset management efficiency—the effectiveness of a supply chain in managing assets to support demand satisfaction.

5. **What are the key activity or process measures being used inside companies in textile and apparel industries today?**

Traditional internal metrics were referenced, including:

- Specific functional measurements (case fill, inventory turns, cycle time, inventory levels, days sales outstanding, costs versus budget);
- Performance to expectation/requirement (on time delivery, perfect order delivery rate);
- Process measures are not widely used (cash to cash cycle time).

6. **What metrics should be considered to measure the holistic supply chain performance in textiles and clothing industries?**

Respondents claimed that few measures are used between companies today. The interviewer was discussing with the interviewees about the metrics corresponding to the attributes mentioned above. The metrics that are for the whole supply chain under each attribute are (The Italic typewriters did not emerge in literature review):

- Product development
  - Adoption rate of initial designs;
  - Level of sample making;
  - R&D of the whole supply chain;
  - *Ability of knowledge management.* Some experts mentioned this measure because the apparel product development process combines designing, merchandising, and marketing with production to bring new merchandise into the market on time to meet consumers' demands. And at the same time, it requires the coordination with fashion trends, including colors, silhouettes, and yarns. Hence, managing the related knowledge inside the supply chain is a critical success factor for product design and development. It is a qualitative measure.
- Supply chain total cost
  - Product development cost;
  - Production cost;
  - Inventory cost;
  - Transportation cost;
  - Quality control cost;
  - Information sharing cost.
- Supply chain time
  - Total supply chain lead time;

- Product design time;
- Sample making time;
- Materials preparation time;
- Production time;
- Delivery time;
- Waiting time in supply chain;
- *Inventory turnover on sales*. The metric gives a picture of how quickly inventory turns over, and equals to sales divided by average inventory. It should be categorized to supply chain time. It is a quantitative one.

Supply chain quality

- Failure rate caused by production;
- Fail rate caused by materials;
- On time delivery rate;
- Perfect order delivery rate;
- *Accuracy of forecasting.* For textile and apparel supply chain, the total supply chain lead time is relatively long. Forecasting plays an very important role to maintain the effectiveness of the supply chain operations. Accuracy of forecasting reflects the quality of supply chain operations. With product quality, delivery quality, forecasting quality is also an important part to measure the supply chain quality.

Supply chain flexibility

- Quantity flexibility

- Delivery flexibility
- Product combination flexibility

- Supply chain information sharing
  - Accuracy of information sharing
  - Timeliness of information sharing
  - Effectiveness of information sharing
- Supply chain innovation
  - Number of new product of each season
  - Number of new technology adopted
  - Number of new materials adopted
- Supply chain profitability
  - Total supply chain turnover
  - Total supply chain profit
  - Rationality of profit distribution
- *Supply chain productivity*
  - *Capital productivity*
  - *Labor productivity*
  - *Raw material productivity*
  - *Energy productivity*
- *Supply chain asset management efficiency*
  - *Cash-to-cash cycle time*
  - *Asset turns*

7. **What comments or guidance do you have on what should be the focus of research in this area?**

   Respondents were clearly thinking about the needs for supply chain performance measurement. Specific comments included:

   - Supply chain performance in textile and apparel industries should be defined clearly;
   - Possibility of data acquirement should be carefully considered;
   - Detailed method to evaluate should be developed, and just presenting a model is not enough.

4.2.3 Overall Value of First Round of In-depth Interviews

The first in-depth interviews provided justification and direction for this research. Supply chain thought and practice leaders pointed out that there was a need for this exploratory research. They emphasized the need for a paradigm shift from single-firm measurement to measurement of supply chain processes linking multiple firms. They indicated that supply chain thinking and supply chain management were in the development stage and were critical to future success of business. They pointed out that the general lack of knowledge of how to implement supply chain measurement was hindering progress. They identified the barriers that companies might face in conducting supply chain performance measurement. They suggested some attributes of SCM in textile and apparel industries and detailed metrics used to measure the performance, to improve the two-level hierarchical structure of SCPM in textile and apparel industries. The first round of in-depth interviews gave the author a strong indication that SCMP system is critical for the industries, which need a more practical SCPM system in reality. Attribute-based hierarchical SCPMS is reasonable, and would be the way for further exploration.

4.2.4 Objective of Second Round of Delphi Survey

In the second round of survey, the textile-apparel supply chain performance measurement model from the findings of the first round of in-depth interviews was presented to the experts. The model is shown in Figure 4.2. The model is similar to that presented in Figure 4.1. However, based on the first round interviews, the yellow parts in Figure 4.2 are added to Figure 4.1. Respondents were asked to evaluate the importance of the measures with a 7-point scale from “extremely unimportant” to “extremely important”. The objective is to verify the consensus of the experts and the reliability of the items for each attribute.

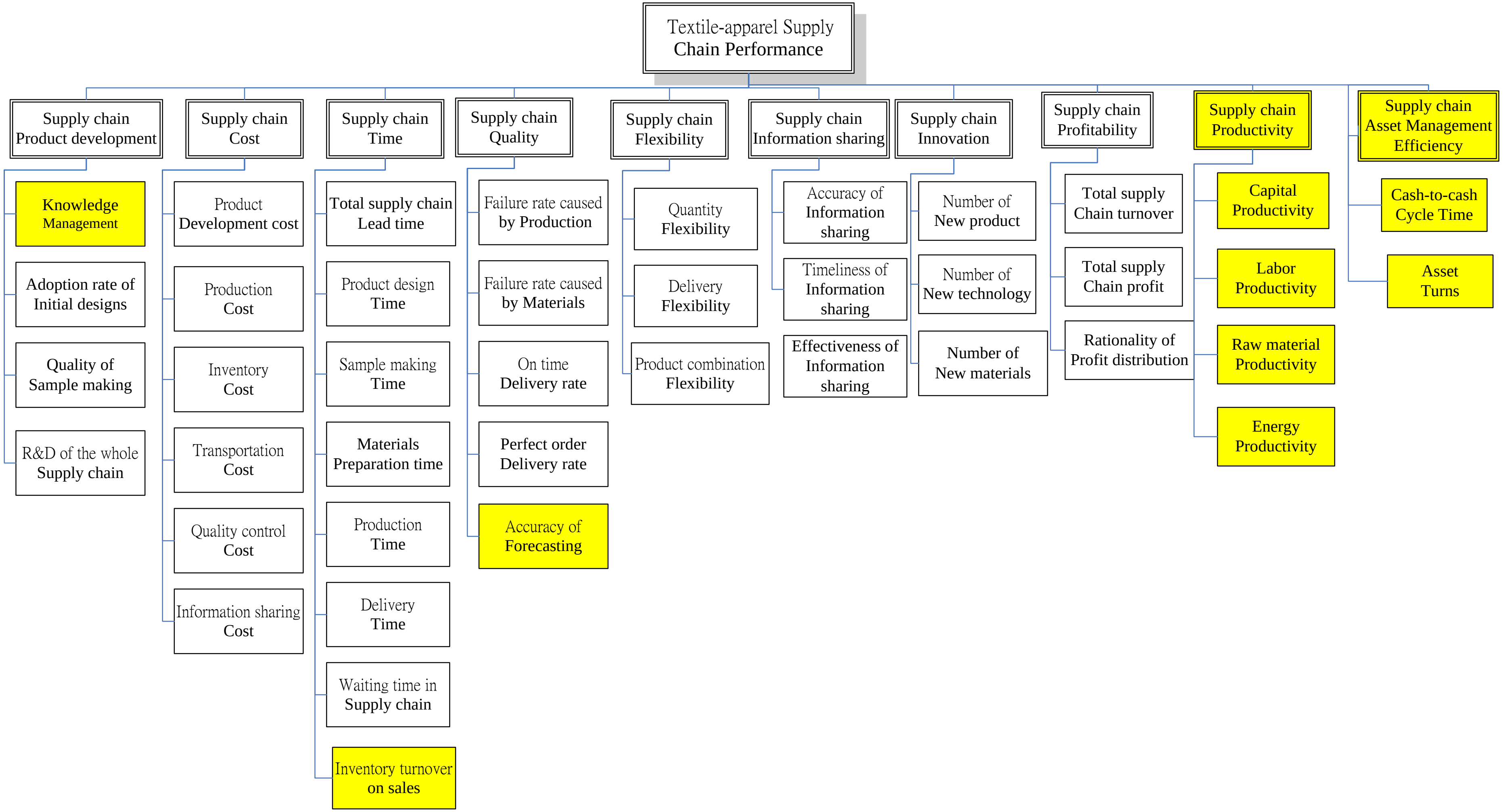


Figure 4.2 Textile-apparel SCPM model for second round Delphi survey

4.2.5 Results of Second Round of Delphi Survey

Based on the second round of Delphi investigation, relative scores and ranking results are shown in Table 4.2 and Table 4.3. In Table 4.2, the first level measures were examined by the experts' consensus. With regard to the experts' consensus, the coefficient of variation was employed to judge whether they have consensus to certain extent. In common, the experts are thought with consensus when their coefficients of variation (CV=standard deviation/average value= $s/\bar{x}$) are smaller than 0.15 (Lin, 2003). In Table 4.3, the Cronbach's alpha was performed to each construct to test the reliability. Reliability estimates for all constructs were greater than 0.7, providing evidence that internal consistency exists within the items (Hair *et al.*, 1995).

Table 4.2 Result for second round Delphi survey—first level of measures

Evaluation criteria	Mean Value	Coefficient of variance
Supply chain information sharing	6.2	0.1278
Supply chain time	6.0	0.1098
Supply chain quality	5.6	0.0836
Supply chain flexibility	5.6	0.0967
Supply chain cost	5.5	0.0887
Supply chain innovation	5.3	0.0965
Supply chain profitability	5.3	0.1167
Supply chain product development	5.1	0.0665
Supply chain asset management efficiency	4.5	0.1876
Supply chain productivity	4.0	0.1654

As shown in Table 4.2, the coefficient of variance of supply chain productivity and supply chain asset management efficiency is more than 0.15, which means that the experts did not have the consensus for these two attributes. This is no surprise, since these two were seldom mentioned in the literature, and are the additions of the project.

Table 4.3 Cronbach's alpha for second round Delphi survey—second level of measures

Evaluation criteria		**Cronbach's α**
Supply chain product development	Knowledge management	0.7474
	Adoption rate of initial designs	
	Level of sample making	
	R&D of the whole supply chain	
Supply chain cost	Product development cost	0.8868
	Product manufacturing cost	
	Inventory cost	
	Transportation cost	
	Quality control cost	
	Information sharing cost	
Supply chain time	Total supply chain lead time	0.7698
	Product design time	
	Sample making time	
	Materials preparation time	
	Manufacturing time	
	Delivery time	
	Waiting time in supply chain	
	Inventory turnover on sales	
Supply chain quality	Fail rate caused by production	0.8654
	Fail rate caused by materials	
	On time delivery rate	
	Perfect order delivery rate	
	Accuracy of forecasting	
Supply chain flexibility	Quantity flexibility	0.7212
	Delivery flexibility	
	Product combination flexibility	
Supply chain information sharing	Accuracy of information sharing	0.9023
	Timeliness of information sharing	
	Effectiveness of information sharing	
Supply chain innovation	Number of new products	0.7698

Supply chain profitability	Adoption rate of new technology Adoption rate of new materials Total supply chain turnover Total supply chain profit Rationality of profit distribution	0.8845

The values of Cronbach's alpha were all above 0.7, and were satisfactory, indicating that the items measure the characteristic of the level-one measures quite well.

4.2.6 Results of Third Round of Delphi Survey

After the second round of Delphi survey, the ten experts were emailed again and were asked about their attitude towards the two unconcensus attributes. Eight of them agreed to delete them. The reason was that they were the two least important attributes and not quite typical in textile and apparel industries.

After the third round of Delphi survey, the final SCPMS in textile and apparel industries employed in this study is shown in Figure 4.3. As stated before, Figure 4.1 is the original SCPMS in textile and apparel industries, mainly from literature review and the author's understand. Eight attributes and related metrics were presented. After the first round in-depth interviews with ten experts, the original SCPMS was revised and was shown in Figure 4.2. Two new attributes and some new metrics were added according to some of the experts' opinion. After the second and third round discussion, the final SCPMS in textile and apparel industries was achieved and shown in Figure 4.3. The original eight attributes were retained and some new metrics were added.

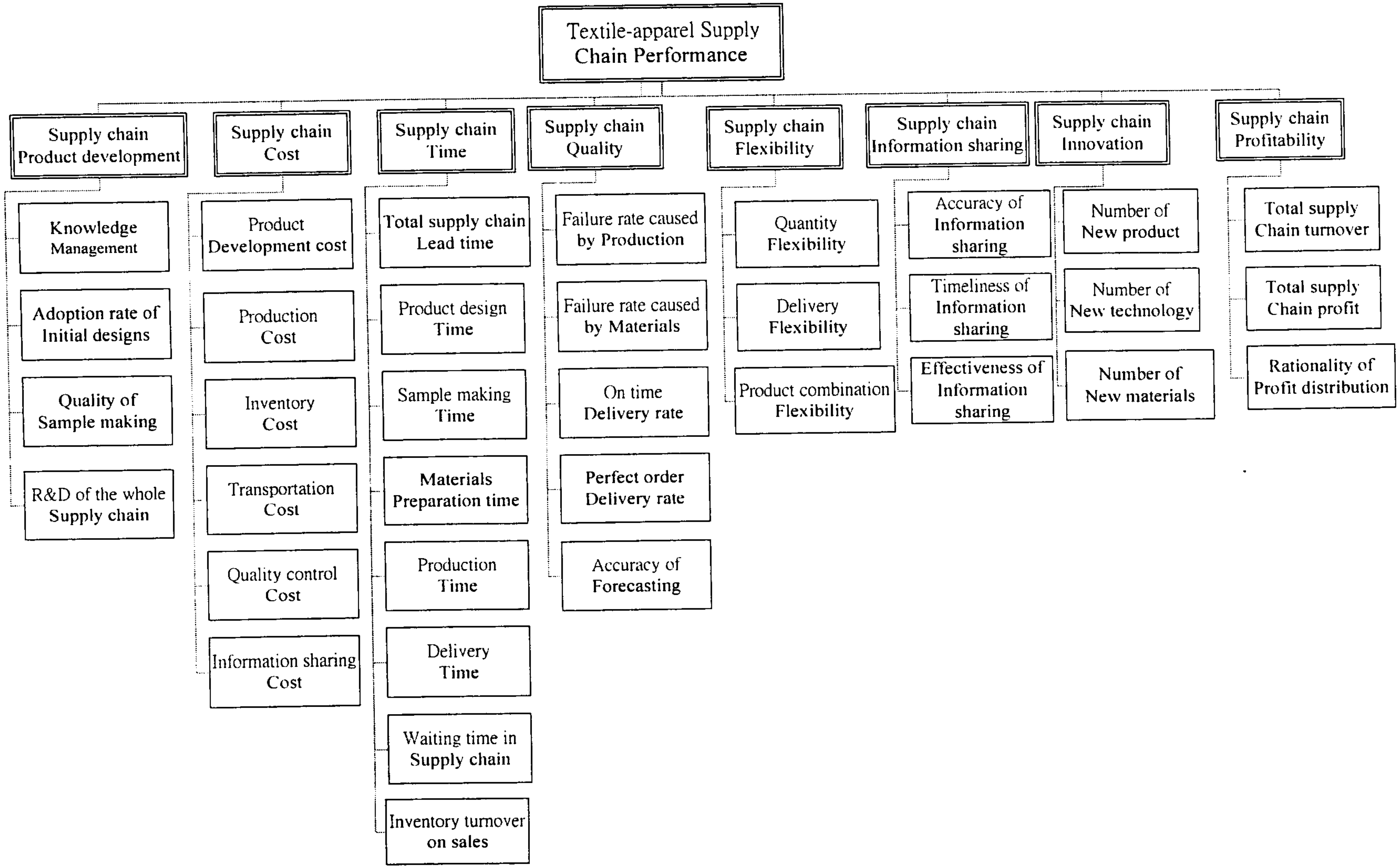


Figure 4.3 Final Version of Textile-apparel SCPM model

4.3 Results in Stage Two—Evaluation Process of SCPMS in Textile and Apparel Industries

4.3.1 Sample Characteristics

Data were collected with 77 companies. Characteristics of these companies are as follows.

Location: The headquarters of 30 (38.9%) companies are located in Hong Kong, while the rest 47 (61.1%) companies are from mainland China.

Number of Employee: Most of the companies are relatively large. Over half of the organizations (51.9%) have between 1000 and 5000 employees, and another 9.0% of the organizations have over 5000 employees. Organizations with between 500-1000 employees account for 13.0% of the sample and the rest (26.1%) have less than 500 employees.

Annual Sales: Almost half of the organizations (49.4%) have sales volumes exceeding 50 million (RMB or HK$) and 9.1% of the organizations have the sales volume below 10 million. 11.7% and 18.2% of the respondents have sales volumes between 10-20 million and between 20-50 million, respectively. Another 11.7% of the respondents did not disclose this data.

Business types: An independent organization may take part in several different business processes in the operation of textile and apparel supply chain. In this survey, 55.8% of the respondents have the business of garment manufacturing, which occupies the largest portion of the respondents. Following business is fashion distribution and retailing, which is 32.5%. 24.7% of the respondents have the business of fabric manufacturing, and 11.7% of the organizations have the business of yarn manufacturing. 16.9% of the respondents major in garment trading. 6.5% of the organizations take part in the auxiliary processes such as finishing, printing or dying, and 2.5% of the respondents are manufacturing auxiliary materials such as zipper and clasp. Nearly all kinds of members of textile and apparel supply chain are involved in this survey.

4.3.2 Results of First Stage of CFMAE Method—Fuzzy Measure and Fuzzy Integral

Using the four metrics of the first attribute "Supply chain product development", which are *Knowledge management*, *Adoption rate of initial designs*, *Level of sample making* and *R&D of the whole supply chain*, as an example, the results of the four steps for fuzzy measure and fuzzy integral are illustrated.

In step 1, each respondent were asked to assess the importance of these four metrics with 7-point scale, from EUI (Extremely Unimportant) to EI (Extremely Important). For example, the answers of one respondent are (VI, N, LI, LI). The respective fuzzy values are (0.7, 0.75, 0.85, 0.9), (0.4, 0.45, 0.55, 0.6), (0.55, 0.6, 0.7, 0.75) and (0.55, 0.6, 0.7, 0.75).

In step 2, according to equation 3.4, averaging the 77 evaluation values, we can get the fuzzy linguistic values as shown in Table 4.4.

Table 4.4 Fuzzy values of the weights of metrics for first attribute

Metrics	Fuzzy Linguistic Values
Knowledge Management	(0.630, 0.678, 0.778, 0.815)
Adoption rate of initial designs	(0.592, 0.641, 0.741, 0.781)
Level of sample making	(0.622, 0.672, 0.772, 0.809)
R&D of the whole supply chain	(0.624, 0.674, 0.774, 0.813)

In step 3, using Equation 3.5-3.8 to defuzzy the fuzzy linguistic values, the corresponding defuzzification values equal to 0.724, 0.688, 0.717 and 0.720, respectively.

In step 4, the value of λ should be first obtained using equation 3.9, which is

$$\lambda + 1 = (1 + 0.724\lambda)(1 + 0.688\lambda)(1 + 0.717\lambda)(1 + 0.720\lambda)$$

We can get that $\lambda = -0.993$

For a given supply chain, suppose the evaluation values of the four metrics $h(X_{11}) > h(X_{12}) > h(X_{12}) > h(X_{14})$, according to Equation 3.10, we can get the fuzzy measures for the attribute "Supply Chain Product Development".

$$g_\lambda(x_1) = 0.724$$

$$g_\lambda(x_1, x_2) = 0.724 + 0.688 + (-0.993) * 0.724 * 0.688 = 0.917$$

$$g_\lambda(x_1, x_2, x_3) = 0.917 + 0.717 + (-0.993) * 0.917 * 0.717 = 0.981$$

$$g_\lambda(x_1, x_2, x_3, x_4) = 1$$

Using Equation 3.11, we can get the evaluation value for the attribute "Supply Chain Product Development".

$$h(X_1) = h(X_{14})*1 + (h(X_{13}) - h(X_{14}))*0.981$$
$$+ (h(X_{12}) - h(X_{13}))*0.917 + (h(X_{11}) - h(X_{12}))*0.724$$
$$= h(X_{14})*1 + h(X_{13})*(1 - 0.981)$$
$$+ h(X_{12})*(0.981 - 0.917) + h(X_{11})*(0.917 - 0.724)$$

The other data can be obtained from MATLAB program. Three files named “xxx.m” are written. The first one is data_origin.m, in which the original data was saved in two matrixs. One is named WtMx, which stands for the weights of the second-level metrics. The other is named EvMx, which stands for the evaluation values of the second-level metrics. The size of WtMx is 77×35. And the size of EvMx is variable according to the evaluation quantities for a certain supply chain.

The second .m file is calculate_fuzzyW.m, in which the eight λs are reached. It includes the calculation of Step 1 to the part of Step 4 described in 3.3.5. With the original data from the questionnaire survey, the eight λs are listed in Table 4.5.

Table 4.5 λs in fuzzy measure process

First-level Attribute	**λs in fuzzy measure process**
Supply Chain Product Development	-0.9926
Supply Chain Cost	-0.9997
Supply Chain Time	-0.9999
Supply Chain Quality	-0.9993
Supply Chain Flexibility	-0.9721
Supply Chain Information Sharing	-0.9803
Supply Chain Innovation	-0.9689
Supply Chain Profitability	-0.9879

The third .m file is calculate_result.m, which is for the second half of Step 4 described in 3.3.5. After the operation of this file, the final result for fuzzy integral can be reached. Once a given supply chain is evaluated and the original data of evaluation values for the second-level metrics are saved in Matrix EvMx, it will calculate the evaluation value of the first-level attributes. The codes of calculate_fuzzyW.m and calculate_result.m are listed in Appendix E.

4.3.3 Results in Second Stage of CFMAE Method—FAHP

As stated in the previous part, five steps are employed to calculate the weights of the first-level attributes. In Step 1, fuzzy pairwise comparison matrix was created. As stated before, 77 valid questionnaires are available for this process. Here, an example is given to illustrate the process. The result of the questionnaire is shown in Table 4.6, where a " √ " represents the choice of the respondent.

Table 4.6 The result of one questionnaire

For the eight attibutes in the first level of supply chain performance measurement system in textile and apparel industries, please indicate the relative importance between them as illustrated in the above example.

F1: supply chain product development
F2: supply chain cost
F3: supply chain time
F4: supply chain quality
F5: supply chain flexibility
F6: supply chain information sharing
F7: supply chain innovation
F8: supply chain profitability

1. For "supply chain product development" and the others

	AI 9		DI 7		SI 5		WI 3		EI 1		WI 3		SI 5		DI 7		AI 9	
F1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	√	☐	☐	☐	☐	☐	☐	F2
	☐	☐	☐	☐	☐	☐	√	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F3
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	√	☐	☐	F4
	☐	☐	☐	☐	☐	√	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F5
	☐	☐	√	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F6
	☐	☐	☐	☐	☐	☐	☐	☐	√	☐	☐	☐	☐	☐	☐	☐	☐	F7
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	√	☐	☐	F8

2. For "supply chain cost" and the others

	AI 9		DI 7		SI 5		WI 3		EI 1		WI 3		SI 5		DI 7		AI 9	
F2	☐	☐	√	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F3
	☐	☐	☐	☐	☐	☐	☐	☐	√	☐	☐	☐	☐	☐	☐	☐	☐	F4
	☐	☐	☐	☐	☐	☐	√	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F5
	☐	☐	☐	☐	√	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F6
	☐	☐	☐	√	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F7
	☐	☐	☐	☐	☐	☐	☐	☐	√	☐	☐	☐	☐	☐	☐	☐	☐	F8

3. For "supply chain time" and the others

	AI 9		DI 7		SI 5		WI 3		EI 1		WI 3		SI 5		DI 7		AI 9	
F3	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	√	☐	☐	☐	☐	☐	☐	F4
	☐	☐	☐	☐	☐	☐	√	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F5

	☐	☐	☐	☐	☐	√	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F6
	☐	☐	☐	☐	☐	☐	√	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F7
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	√	☐	☐	☐	☐	F8

4. For “supply chain quality” and the others

	AI		DI		SI		WI		EI		WI		SI		DI		AI	
	9		7		5		3		1		3		5		7		9	
F4	☐	☐	√	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F5
	☐	☐	☐	☐	√	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F6
	☐	☐	√	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F7
	☐	☐	☐	☐	☐	☐	√	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F8

5. For “supply chain flexibility” and the others

	AI		DI		SI		WI		EI		WI		SI		DI		AI	
	9		7		5		3		1		3		5		7		9	
F5	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	√	☐	☐	☐	☐	☐	☐	F6
	☐	☐	☐	☐	☐	☐	☐	☐	√	☐	☐	☐	☐	☐	☐	☐	☐	F7
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	√	☐	☐	☐	☐	F8

6. For “supply chain information sharing” and the others

	AI		DI		SI		WI		EI		WI		SI		DI		AI	
	9		7		5		3		1		3		5		7		9	
F6	☐	☐	☐	☐	☐	☐	√	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F7
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	√	☐	☐	☐	☐	☐	☐	F8

7. For “supply chain innovation” and “supply chain profitability”

	AI		DI		SI		WI		EI		WI		SI		DI		AI	
	9		7		5		3		1		3		5		7		9	
F7	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	√	☐	☐	F8

AI (9): absolute importance

WI (3): weak importance

DI (7): demonstrated importance

EI (1): equal importance

SI (5): strong importance

The pairwise comparison matrix of Table 4.6 is shown in Table 4. 7.

Table 4.7 Pairwise comparison matrix

	F1	F2	F3	F4	F5	F6	F7	F8
F1	1	1/3	3	1/7	4	7	1	1/7
F2	3	1	7	1	3	5	6	1
F3	1/3	1/7	1	1/3	3	4	3	1/5
F4	7	1	3	1	7	5	7	3
F5	1/4	1/3	1/3	1/7	1	1/3	1	1/5
F6	1/7	1/5	1/4	1/5	3	1	3	1/3
F7	1	1/6	1/3	1/7	1	1/3	1	1/7
F8	7	1	5	1/3	5	3	7	1

According to Table 3.6, the fuzzy pairwise comparison matrix is shown in Table 4.8.

Table 4.8 Fuzzy pairwise comparison matrix

	F1	F2	F3	F4	F5	F6	F7	F8
F1	(1,1,1)	(1/4,1/3,1/2)	(2,3,4)	(1/8,1/7,1/6)	(3,4,5)	(6,7,8)	(1,1,1)	(1/8,1/7,1/6)
F2	(2,3,4)	(1,1,1)	(6,7,8)	(1,1,1)	(2,3,4)	(4,5,6)	(5,6,7)	(1,1,1)
F3	(1/4,1/3,1)	(1/8,1/7,1/6)	(1,1,1)	(1/4,1/3,1/2)	(2,3,4)	(3,4,5)	(2,3,4)	(1/6,1/5,1/4)
F4	(6,7,8)	(1,1,1)	(2,3,4)	(1,1,1)	(6,7,8)	(4,5,6)	(6,7,8)	(2,3,4)
F5	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/8,1/7,1/6)	(1,1,1)	(1/4,1/3,1/2)	(1,1,1)	(1/6,1/5,1/4)
F6	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(1/6,1/5,1/4)	(2,3,4)	(1,1,1)	(2,3,4)	(1/4,1/3,1/2)
F7	(1,1,1)	(1/7,1/6,1/5)	(1/4,1/3,1/2)	(1/8,1/7,1/6)	(1,1,1)	(1/4,1/3,1/2)	(1,1,1)	(1/8,1/7,1.6)
F8	(6,7,8)	(1,1,1)	(4,5,6)	(1/4,1/3,1/2)	(4,5,6)	(2,3,4)	(6,7,8)	(1,1,1)

According to step 3 to step 5, the weight vector W' for the eight attributes is

$$W' = (M'(\tilde{w}_1), M'(\tilde{w}_2), \cdots, M'(\tilde{w}_8))^T$$
$$= (0.2808, 0.3960, 0.3326, 0.2506, 0.1330, 0.2097, 0.0793, 0.4434)$$

Via normalization, we get the normalized weight vectors which are shown in Table 4.9.

$$W = (M(\tilde{w}_1), M(\tilde{w}_2), \cdots, M(\tilde{w}_8))^T$$
$$= (0.1321, 0.1863, 0.1565, 0.1179, 0.0626, 0.0987, 0.0373, 0.2087)$$

Table 4.9 Normalized weights of the eight attributes

Attributes	Normalized Weights
Supply Chain Profitability	0.2087
Supply Chain Cost	0.1863
Supply Chain Time	0.1565
Supply Chain Product Development	0.1321
Supply Chain Quality	0.1179
Supply Chain Information Sharing	0.0987
Supply Chain Flexibility	0.0626
Supply Chain Innovation	0.0373

The most important attribute to measure the performance of a textile-apparel supply chain is supply chain profitability. Following are supply chain cost, supply chain time, supply chain product development, supply chain quality, supply chain information sharing, supply chain flexibility and supply chain innovation.

4.3.4 Results in Third Stage of CFMAE Method—SAW

The final index of the performance can be reached by Equation 3.12.

$$\begin{aligned} SC_P &= h_1 \cdot W_1 + h_2 \cdot W_2 + \cdots + h_m W_m \\ &= h_1 * 0.1321 + h_2 * 0.1863 + h_3 * 0.1565 + h_4 * 0.1179 \\ &+ h_5 * 0.0626 + h_6 * 0.0987 + h_7 * 0.0373 + h_8 * 0.2087 \end{aligned}$$

4.4 A supposed Case

Suppose for a given textile-apparel supply chain, the evaluation value for the 35 metrics of an expert is {N, LG, LP, VG; VP, N, LG, EG, VG, VG; LP, N, N, LG, N, VG, EG, N; LP, VP, N, LG, LP; N, LG, VG; N, VG, EG; VG, VP, N; LG, VG, EG}. In the first stage of the CFMAE process, we can get the fuzzy integral values of the eight attributes using the MATLAB program. The eight evaluation values listed in Table 4.10.

Table 4.10 Evaluation values of eight attributes

Attributes	**Evaluation Values**
Supply Chain Profitability	0.7397
Supply Chain Cost	0.8848
Supply Chain Time	0.8846
Supply Chain Product Development	0.6017
Supply Chain Quality	0.7458
Supply Chain Information Sharing	0.8803
Supply Chain Flexibility	0.6920
Supply Chain Innovation	0.8964

According to Equation 3.12 and the weights of first-level attributes, the index of the supply chain performance is:

$$SC_P = 0.7379 * 0.1321 + 0.8848 * 0.1863 + 0.8846 * 0.1565 + 0.6017 * 0.1179$$
$$+ 0.7458 * 0.0626 + 0.8803 * 0.0987 + 0.6920 * 0.0373 + 0.8964 * 0.2087$$
$$= 0.8184$$

According to Equation 3.13, the fuzzy linguistic value for the evaluation result is (0.7, 0.75, 0.85, 0.9), which stands for VG=Very Good.

The fuzzy linguistic values for the eight attributes can also transformed using Equation 3.13, which are shown in Table 4.11.

Table 4.11 Fuzzy linguistic value for the eight attributes

Attributes	Performance	Linguistic Value
Supply Chain Product Development	0.7397	VG
Supply Chain Cost	0.8848	EG
Supply Chain Time	0.8846	EG
Supply Chain Quality	0.6017	LG
Supply Chain Flexibility	0.7458	VG
Supply Chain Information Sharing	0.8803	EG
Supply Chain Innovation	0.6920	LG
Supply Chain Profitability	0.8964	EG

The results show that the total performance for the supply chain is very good. In the aspects of supply chain cost, supply chain time, supply chain information sharing, and supply chain profitability, the performances are extremely good. In the aspects of supply chain product development, and supply chain flexibility, the performances are very good. While for supply chain quality, and supply chain innovation, the performances are only little good. The supply chain members should pay more attention to supply chain quality and the supply chain innovation.

4.5 Implications of Final Result

The index of the supply chain performance can be compared in three ways. First, it can be used to c. For example, Bossini (a Hong Kong listed company with the stock code 592) can compare its performance of its knitwear supply chain with Giordano (also a Hong Kong listed company with the stock code 709) to find its advantages and disadvantages, thus to improve the operations of their supply chain. Second, it can be employed to compare the performance of a certain supply chain in different time. For example, Bossini can compare its performance of its knitwear supply chain every half year to check the effectiveness and efficiency of its operations. Third, it can also be used to compare different supply chains when a company chooses the new supply chain partners. For example, Bossini can compare its future performance of its knitwear supply chain with two different knitwear manufacturers to make a judgment of which one to choose.

Chapter 5 Online SCPM System in Textile and Apparel Industries

5.1 Introduction

The final objective of this study is to develop a tool to assist the decision maker in actual evaluation. The online SCPMS in textile and apparel industries to be described in this chapter is developed to achieve the goal. In the online system, the weights of first-level attributes are calculated from the questionnaire data, while the importance and performance value of the according second-level metrics are required to evaluate by the decision makers for the consistency.

To evaluate the performance of a given supply chain, there must be an organizer (administrator) who organizes the evaluation processes and valuators who take part in the evaluation. The valuators directly evaluate the importance and performance value for each metric and the data are saved in a database. Synthesizing the valuators' data, the organizer (administrator) then arranges the final evaluation with the methods in this study.

5.2 System Platform and System Components

5.2.1 System Platform

The online system adopts PHP + MySQL structure to implement all the functions and runs on an X86 + Redhat platform. This is a classic configuration which has been widely used in many Web-based applications.

5.2.1.1 PHP

PHP is a recursive acronym that stands for *PHP: Hypertext Preprocessor*; this is in the naming style of *GNU*, which stands for *GNU's Not Unix* and which began this odd trend. The name isn't a particularly good description of what PHP is and what it's commonly used for. PHP is a scripting language that's usually embedded or combined with the HTML of a web page. When the page is requested, the web server executes the PHP script and substitutes the result back into the page. PHP has many excellent libraries that provide fast, customized access to database management systems (DBMSs) and is an ideal tool for developing application logic in the middle tier of a three-tier application (Lane and William, 2004).

5.2.1.2 MySQL

MySQL, the most popular Open Source Standard Query Language (SQL) database management system, is developed, distributed, and supported by MySQL AB. MySQL AB is a commercial company, founded by the MySQL developers. It is a second generation Open Source company that unites Open Source values and methodology with a successful business model. MySQL has the following characteristics:

- MySQL is a database management system.

A database is a structured collection of data. It may be anything from a simple shopping list to a picture gallery or the vast amounts of information in a corporate network. To add, access, and process data stored in a computer database, one needs a database management system such as MySQL Server. Since computers are very good at handling large amounts of data, database management systems play a central role in computing, either as standalone utilities or as parts of other applications.

- MySQL is a relational database management system.

A relational database stores data in separate tables rather than putting all the data in one big storeroom. This adds speed and flexibility. The SQL part of “MySQL” stands for “Structured Query Language.” SQL is the most common standardized language used to access databases and is defined by the ANSI/ISO SQL Standard.

- MySQL software is Open Source.

Open Source means that it is possible for anyone to use and modify the software. Anybody can download the MySQL software from the Internet and use it without pay. If one wishes, one may study the source code and change it to suit one’s needs.

- The MySQL Database Server is very fast, reliable, and easy to use.

MySQL Server was originally developed to handle large databases much faster than existing solutions and has been successfully used in highly demanding production environments for several years. Although under constant development, MySQL Server today offers a rich and useful set of functions. Its connectivity, speed, and security make MySQL Server highly suited for accessing databases on the Internet.

- MySQL Server works in client/server or embedded systems.

The MySQL Database Software is a client/server system that consists of a multi-threaded SQL server that supports different backends, several different client programs and libraries, administrative tools, and a wide range of application programming interfaces (APIs).

- A large amount of contributed MySQL software is available.

It is very likely that one's favorite application or language supports the MySQL Database Server.

Based on the characteristics of MySQL, MySQL is selected as the database management system in this study. It is very powerful especially integrated with PHP. PHPMyAdmin, which is also open source software and a very convenient tool to manage MySQL visually, is employed in the program. Figure 5.1 illustrated the database setup for the weights of the second-level metrics, using PHPMyAdmin.

Figure 5.1 Database setup for the weights using PHPMyAdmin

5.2.1.3 Operating System

The operating system is Linux Redhat 9.0. Redhat 9.0 can integrate MySQL and PHP very well and the server performance is also very good.

5.2.1.4 Hardware Platform

The hardware platform is X86 architecture server with 1G RAM, 100G hard-disk and 2.4G CPU.

5.2.1.5 Structure of System Platform

The whole structure of system platform is depicted in Figure 5.2.

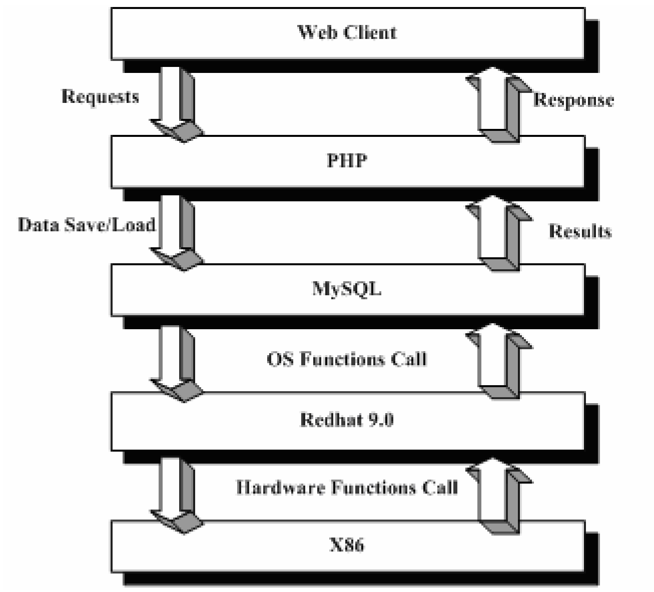


Figure 5.2 Structure of system platform

As shown in Figure 5.2, the whole system is Web-based, which means that clients can use this system via a browser. Requests will be sent to the PHP Web page, after necessary processing, some important data will be saved into MySQL. Both PHP and MySQL will run based on local APIs provided by Redhat 9.0. On the other hand, Redhat 9.0 implements all functions by hiding the hardware level call. When responses are returned, the process is reverse.

5.2.2 System Components

The whole system is comprised of three sub systems: evaluation sub system, administration (organizing) sub system and login sub system. As mentioned before, there are two kinds of participants in the evaluation process. One is the organizer, the other is the valuator. The general function of the three sub systems are described in the following.

5.2.2.1 Valuator Sub System

Valuator sub system is relatively simple. Its main function is to enable experts identified by the administrator to evaluate the supply chain, including the value and the weight of the metrics. Data will be saved into database system after completing all necessary evaluations.

5.2.2.2 Administrator Sub System

Administrator sub system is more complex than the valuator sub system. It provides many functions, such as experts setting and weights setting. All necessary parameters can be set by administrator, and all the evaluation results are managed by administrator.

5.2.2.3 Login Sub System

Login Sub System is to identify the status of the users, providing the relative functions to them.

5.3 System Design

5.3.1 Design Method

This system is designed and developed according to the waterfall process, the most common software development process. Figure 5.3 shows a simplified representation of the waterfall process.

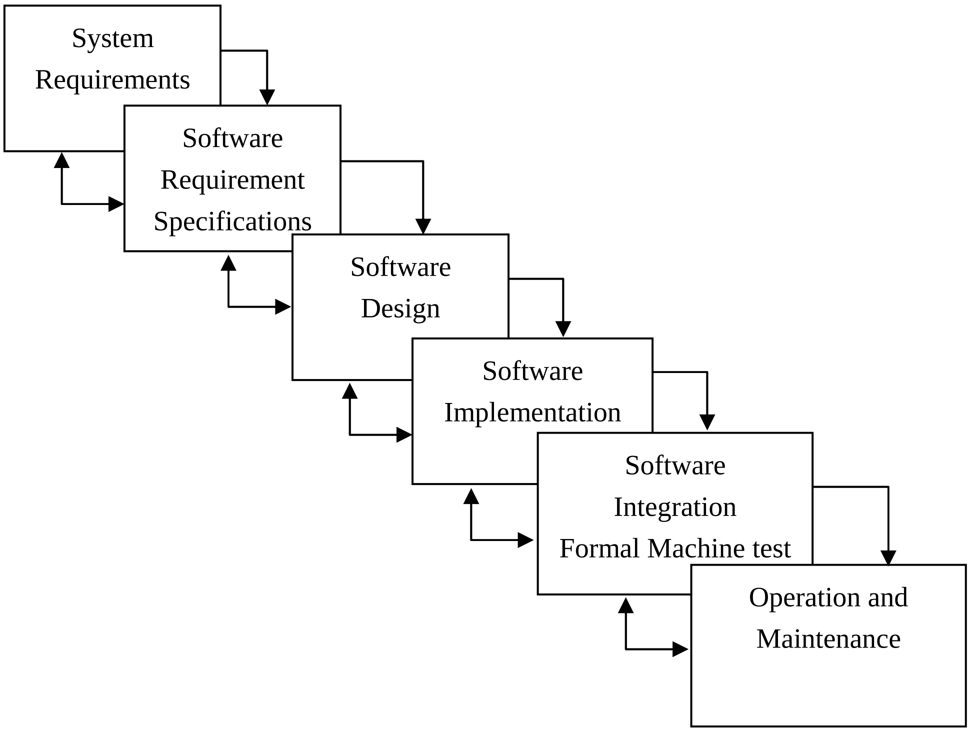


Figure 5.3 Simplified representation of the waterfall development process

As shown in Figure 5.3, the waterfall process model encourages the developers to specify first what the software is supposed to do (gather and define system requirements) before developing the system. It then breaks the complex mission of development into several logical steps (design, code, test, and so forth) and intermediate deliverables that lead to the final completion of the product. The divided and conquered approach of the waterfall process has several advantages. It enables tracking of the project progress more accurately and uncovering of possible slippages early. It forces the organization that develops the software system to be more structured and manageable (Kan, 1995). The waterfall process can organize the development process in a logical process, thus it is employed in this study.

The concrete development process for the system is depicted in Figure 5.4.

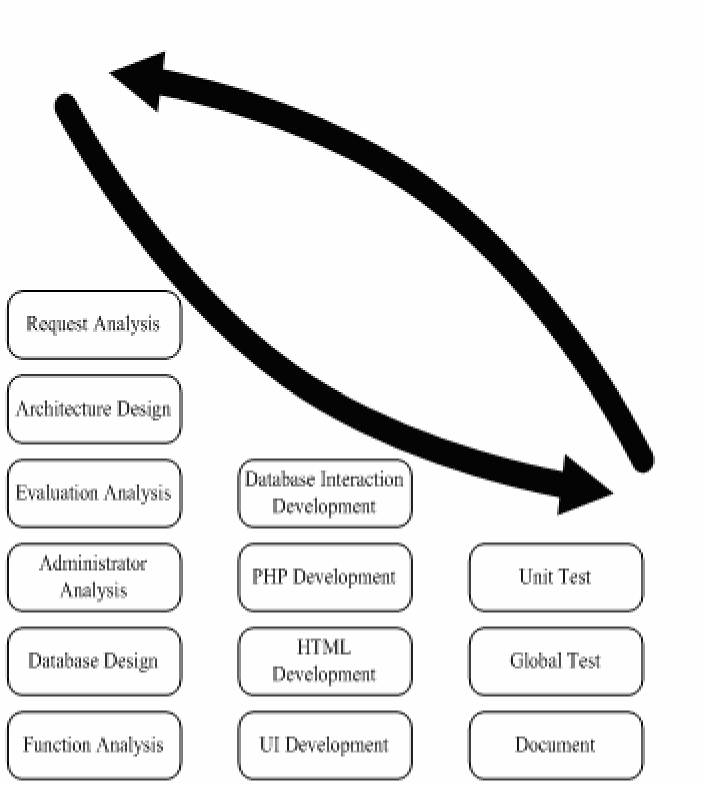


Figure 5.4 The waterfall process for the system development

5.3.2 Database Design

Six tables are designed in MySQL database for the program. The details are descried as follows.

5.3.2.1 TabEval

TabEval is used to save the evaluations results of all valuators, and has 74 fields, saving the evaluation ratings (both the weights and the values) and the other related information.

ID – the primary key of this table

userNick – the nickname of the valuator

evalTime – the exact time of the corresponding evaluation time xmn and wmn – the evaluation ratings (35*2)

flag – the supply chain or company ID it should bound

5.3.2.2 TabActiveCom

TabActiveCom is used to save information of the current evaluated supply chain or company. Two fields are in this table.

ID – the primary key of this table

comID – the supply chain or company ID

5.3.2.3 TabEvalCom

TabEvalCom is used to save all the supply chains or companies information. The table contains 2 fileds.

ID – the primary key of this table

com – the description of all supply chains or companies

5.3.2.4 TabEvalResult

TabEvalResult is used to save all the final results confirmed by administrator. Four fields are in this table.

ID – the primary key of this table

evaltime – the exact time when administrator decide to import

result – the exact final result of the evaluation

comID – the company ID

5.3.2.5 TabEvalUser

TabEvalUser is used to save all user information. There are 6 fields in the table.

ID – the primary key of this table

userNick – the nickname of the user

password – the password of the user to login

flag – to tell if the user is an administrator

org – the organization which the user belongs

pos – the position of the user

5.2.6 TabEvalWeight

TabEvalWeight is used to save the weight of all the metrics. This table contains 2 fields.

ID – the primary key of this table

wm – the weight of the m^{th} evaluation

5.4 Functions of the System

As mentioned before, three sub systems comprised of the whole system, which are evaluation sub system, administration sub system and login sub system. Figure 5.5 shows the detailed functions of each sub system.

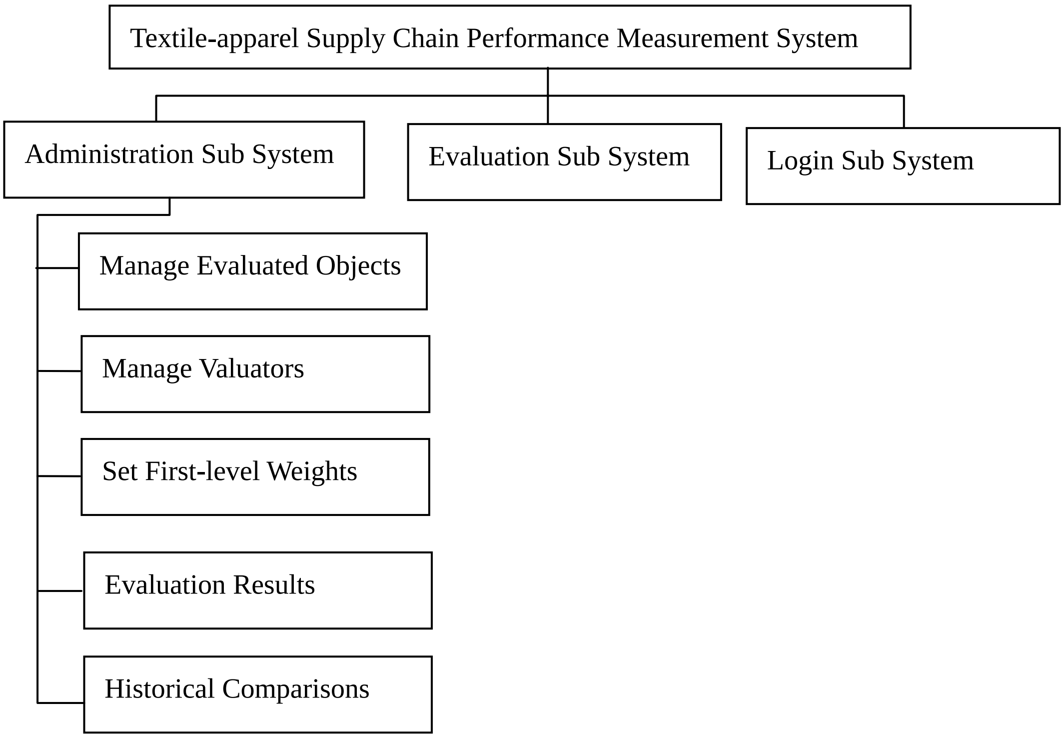


Figure 5.5 Functions of the system

5.4.1 Login Sub System

Figure 5.6 shows the login sub system. User ID and password are required for the users. Identity is to distinguish the administrator and the valuator. User ID and password are preset for the administrator.

Figure 5.6 Interface of Login Sub System

5.4.2 Valuator Sub System

After login using the user ID and password defined by administrator in Administrator sub system, the valuator can evaluate the objective supply chain or company. Figure 5.7 to Figure 5.9 illustrated the processes of the evaluation sub system.

Figure 5.7 shows the explanation page for the valuator after they login in. The information of structure of the evaluation system, the illustration of the symbol, and the objective supply chain or company to be evaluated is provided in this page.

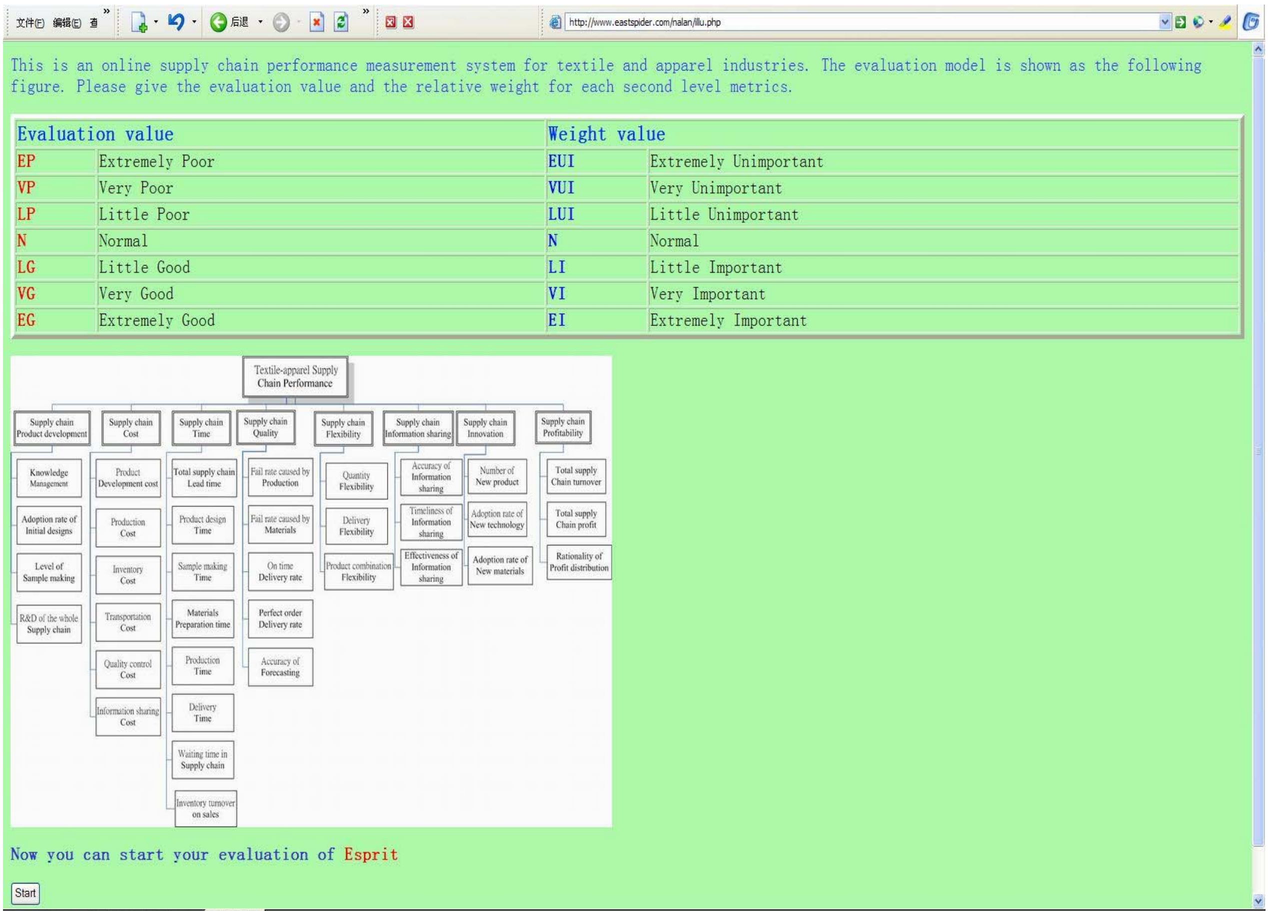


Figure 5.7 The explanation page for the valuator

After click start, the valuator will enter into the evaluation process with the attribute one by one. The default value for the evaluation value is Extremely Poor and that for the weight value is Extremely Unimportant. Figure 5.8 shows the evaluation page for the first attribute, supply chain product development.

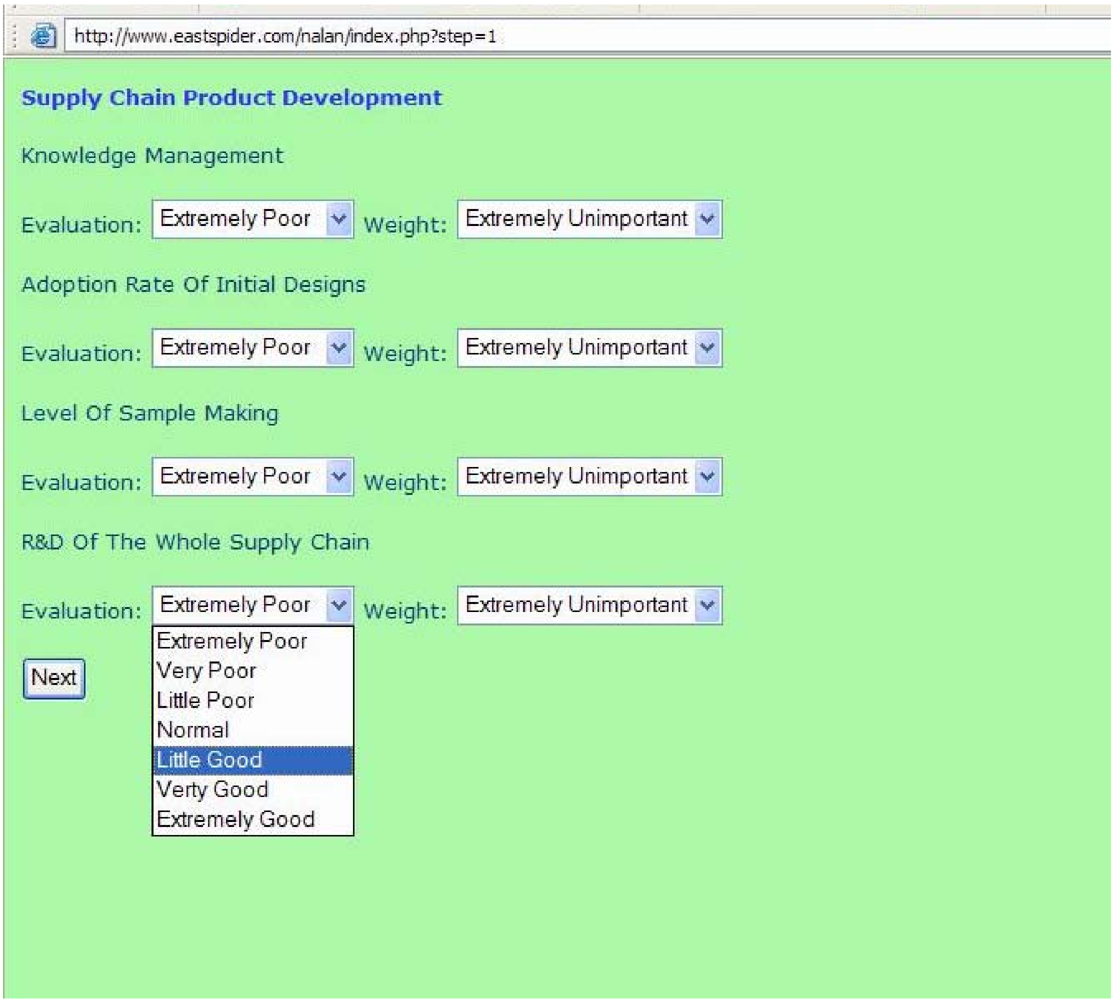


Figure 5.8 The evaluation page for the first attribute

After they have evaluated all the eight attributes, the system will provide them the final result of their evaluation. Figure 5.9 shows the submission page for the evaluation. After clicking submit button, the data they evaluated will be saved in the database for further calculation.

Figure 5.9 The submission page of the evaluation

5.4.3 Administrator Sub System

There are five functions in administration sub system, which are managing evaluated objects, setting evaluators, setting first-level weights, evaluation results and historical comparisons. Figure 5.10 shows the main page after login as the administration.

Figure 5.10 Main page of administration sub system

5.4.3.1 Managing Objects Evaluated

The first step is to ascertain the evaluated object. The function "Managing Objects Evaluated" is provided to realize it. The supply chain or company evaluated is selected in the process. New objects can also be added to the database. Figure 5.11 shows the function.

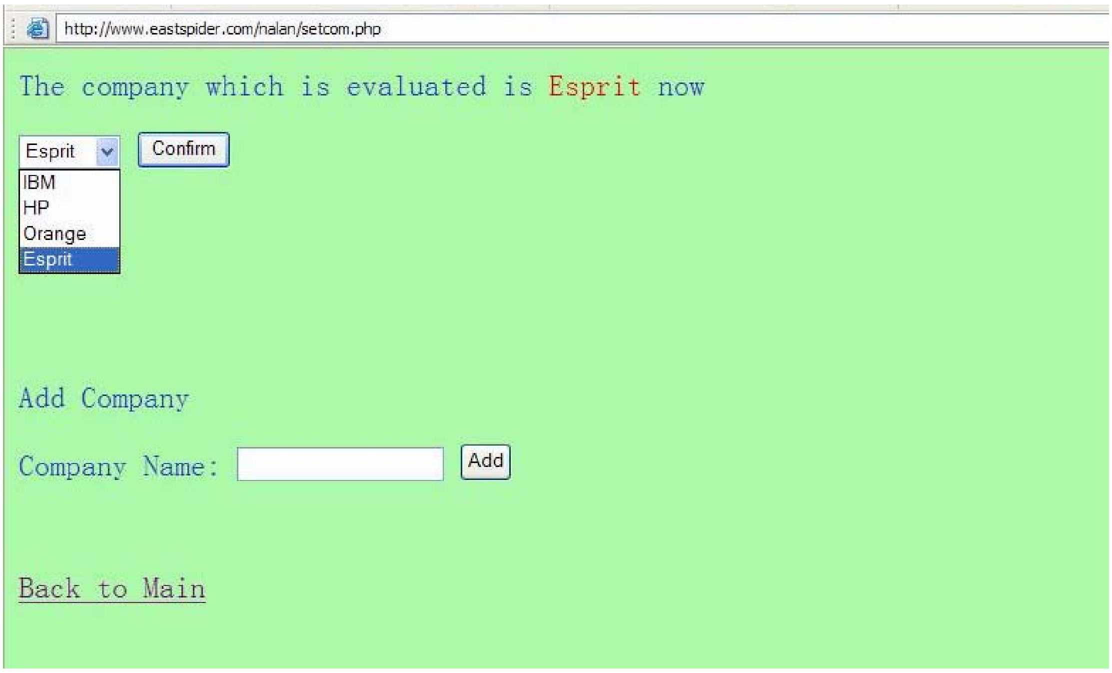


Figure 5.11 Managing evaluated objects

5.4.3.2 Managing Valuators

After selecting which supply chain or company to be evaluated, the following task for the administrator is to manage valuators. Managing valuators provides the functions of add valuators, delete valuators, and set up the authority of the valuators. Figure 5.12 to Figure 5.14 show these functions respectively.

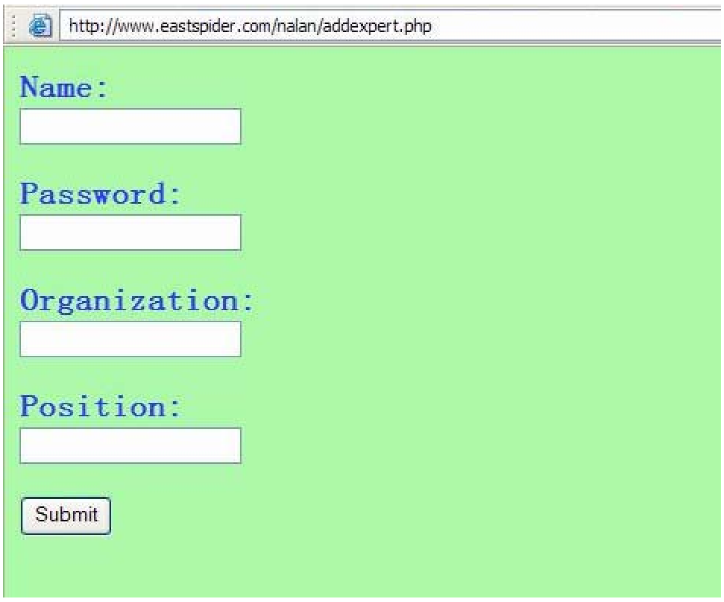


Figure 5.12 Adding valuators

Figure 5.13 Deleting valuators

Figure 5.14 Setting up authority of valuators

5.4.3.3 Setting up First-level Weights

The first-level weights in this study were calculated by the questionnaire survey described in Chapter 4. To increase the flexibility of the program, the system also has the setting up first-level weights module which is shown in Figure 5.15.

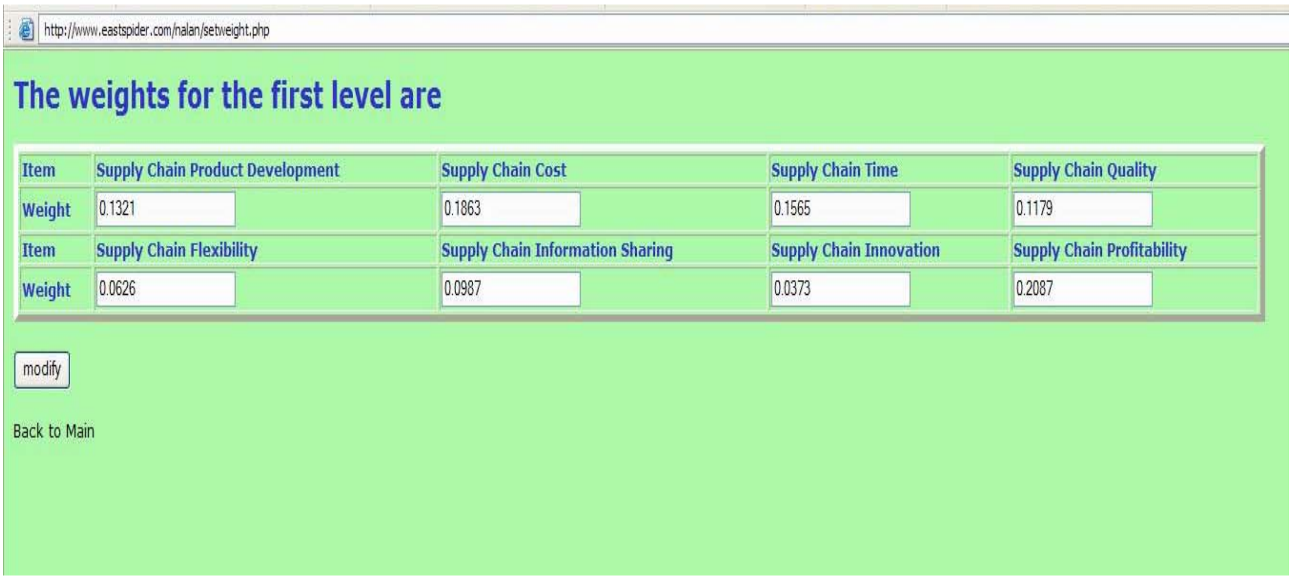
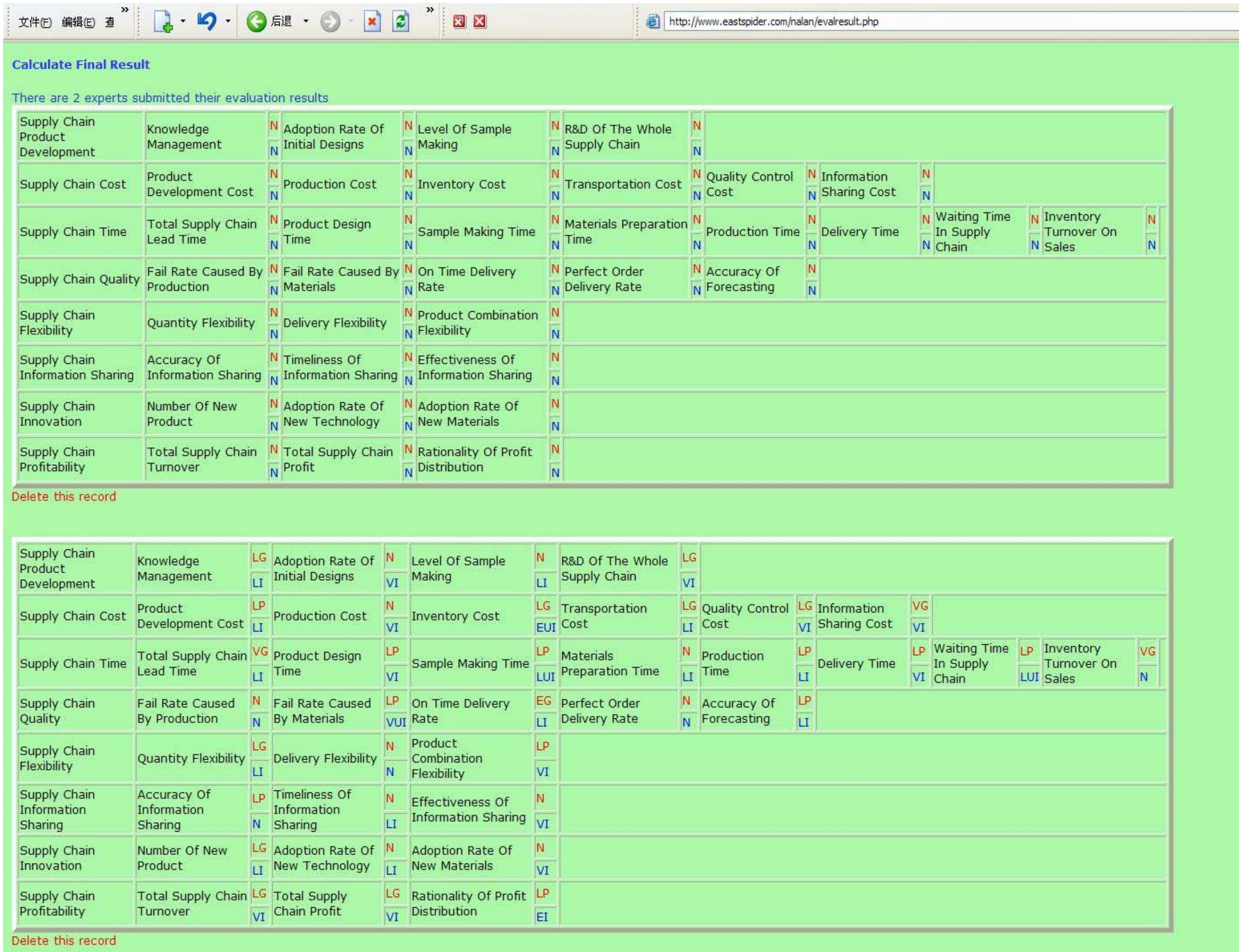


Figure 5.15 Setting up first-level weights

5.4.3.4 Evaluation Results

In this module, the evaluation processes described in Chapter 4 are conducted in background. The evaluation data saved in the database were first presented. The administrator can delete the record if it is not appropriate. If all the data is suitable for the evaluation, just press "Calculate Final Results". Figure 5.16 to Figure 5.17 illustrated the processes.



Supply Chain Product Development	Knowledge Management	N / N	Adoption Rate Of Initial Designs	N / N	Level Of Sample Making	N / N	R&D Of The Whole Supply Chain	N / N										
Supply Chain Cost	Product Development Cost	N / N	Production Cost	N / N	Inventory Cost	N / N	Transportation Cost	N / N	Quality Control Cost	N / N	Information Sharing Cost	N / N						
Supply Chain Time	Total Supply Chain Lead Time	N / N	Product Design Time	N / N	Sample Making Time	N / N	Materials Preparation Time	N / N	Production Time	N / N	Delivery Time	N / N	Waiting Time In Supply Chain	N / N	Inventory Turnover On Sales	N / N		
Supply Chain Quality	Fail Rate Caused By Production	N / N	Fail Rate Caused By Materials	N / N	On Time Delivery Rate	N / N	Perfect Order Delivery Rate	N / N	Accuracy Of Forecasting	N / N								
Supply Chain Flexibility	Quantity Flexibility	N / N	Delivery Flexibility	N / N	Product Combination Flexibility	N / N												
Supply Chain Information Sharing	Accuracy Of Information Sharing	N / N	Timeliness Of Information Sharing	N / N	Effectiveness Of Information Sharing	N / N												
Supply Chain Innovation	Number Of New Product	N / N	Adoption Rate Of New Technology	N / N	Adoption Rate Of New Materials	N / N												
Supply Chain Profitability	Total Supply Chain Turnover	N / N	Total Supply Chain Profit	N / N	Rationality Of Profit Distribution	N / N												

Delete this record

Supply Chain Product Development	Knowledge Management	LG / LI	Adoption Rate Of Initial Designs	N / VI	Level Of Sample Making	N / LI	R&D Of The Whole Supply Chain	LG / VI										
Supply Chain Cost	Product Development Cost	LP / LI	Production Cost	N / VI	Inventory Cost	LG / EUI	Transportation Cost	LG / LI	Quality Control Cost	LG / VI	Information Sharing Cost	VG / VI						
Supply Chain Time	Total Supply Chain Lead Time	VG / LI	Product Design Time	LP / VI	Sample Making Time	LP / LUI	Materials Preparation Time	N / LI	Production Time	LP / LI	Delivery Time	LP / VI	Waiting Time In Supply Chain	LP / LUI	Inventory Turnover On Sales	VG / N		
Supply Chain Quality	Fail Rate Caused By Production	N / N	Fail Rate Caused By Materials	LP / VUI	On Time Delivery Rate	EG / LI	Perfect Order Delivery Rate	N / N	Accuracy Of Forecasting	LP / LI								
Supply Chain Flexibility	Quantity Flexibility	LG / LI	Delivery Flexibility	N / N	Product Combination Flexibility	LP / VI												
Supply Chain Information Sharing	Accuracy Of Information Sharing	LP / N	Timeliness Of Information Sharing	N / LI	Effectiveness Of Information Sharing	N / VI												
Supply Chain Innovation	Number Of New Product	LG / LI	Adoption Rate Of New Technology	N / LI	Adoption Rate Of New Materials	N / VI												
Supply Chain Profitability	Total Supply Chain Turnover	LG / VI	Total Supply Chain Profit	LG / VI	Rationality Of Profit Distribution	LP / EI												

Delete this record

Figure 5.16 Data prepared for the evaluation

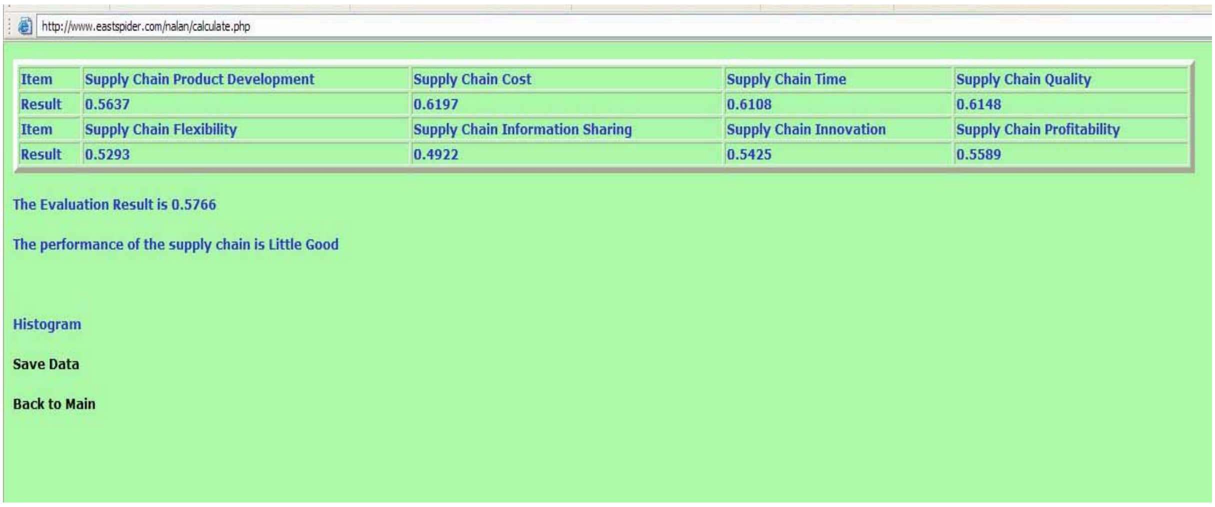


Figure 5.17 Final result page

As shown in Figure 5.17, the administrator can directly get the final result of the evaluation. The fuzzy integral values of the eight attributes are presented, and the SAW process of the final supply chain performance is also calculated. The linguistic value of the final result is also calculated. There are also two extra functions in this module. One is showing the histogram of the fuzzy integral values of the eight attributes to give the graphical result. The other is saving data for historical comparison. Figure 5.18 shows the histogram of the fuzzy integral values.

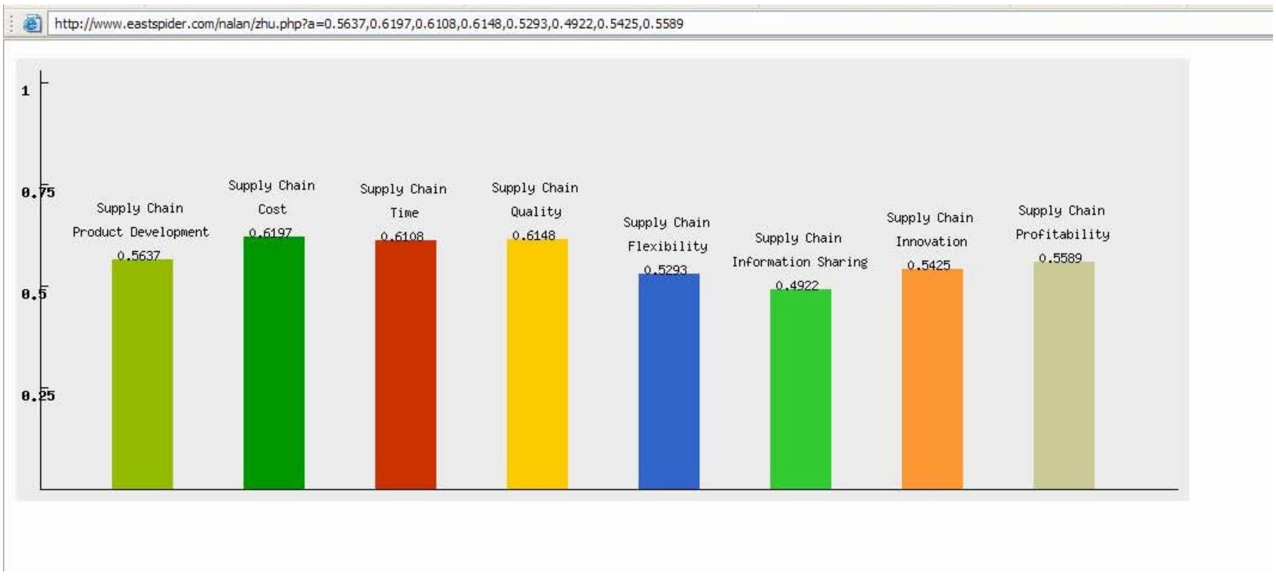
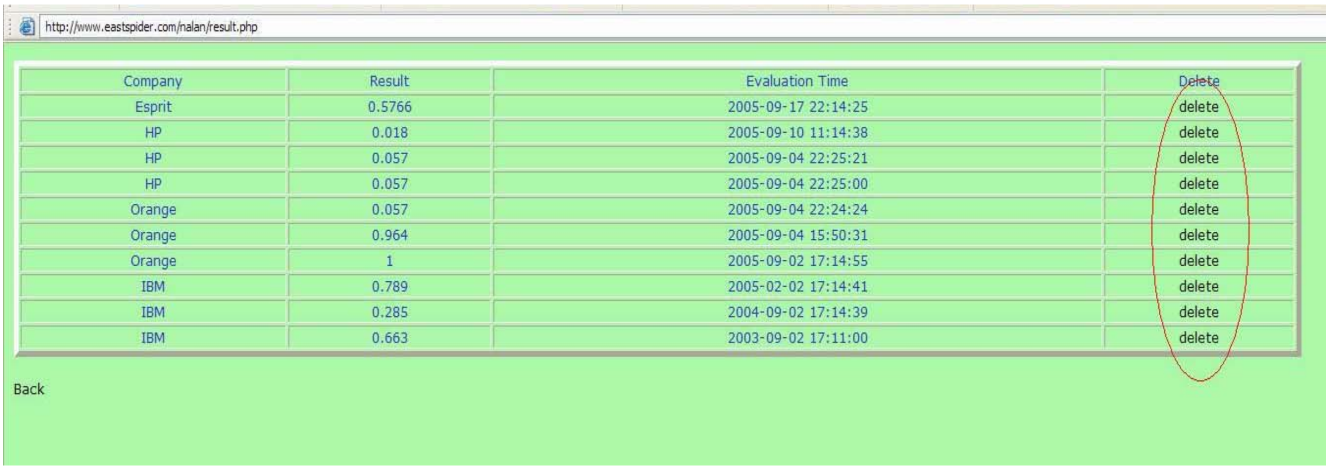


Figure 5.18 Histogram of the fuzzy integral values

5.4.3.5 Historical Comparison

In this module, to a given supply chain or company, results from evaluation of different time can be compared in a broken line graph. All results that have been evaluated can be managed in this module. Figure 5.19 shows the results management function. Figure 5.20 shows the comparison selecting page. Figure 5.21 shows the broken line graph of comparison.



Company	Result	Evaluation Time	Delete
Esprit	0.5766	2005-09-17 22:14:25	delete
HP	0.018	2005-09-10 11:14:38	delete
HP	0.057	2005-09-04 22:25:21	delete
HP	0.057	2005-09-04 22:25:00	delete
Orange	0.057	2005-09-04 22:24:24	delete
Orange	0.964	2005-09-04 15:50:31	delete
Orange	1	2005-09-02 17:14:55	delete
IBM	0.789	2005-02-02 17:14:41	delete
IBM	0.285	2004-09-02 17:14:39	delete
IBM	0.663	2003-09-02 17:11:00	delete

Figure 5.19 Results management

Figure 5.20 Comparison selecting

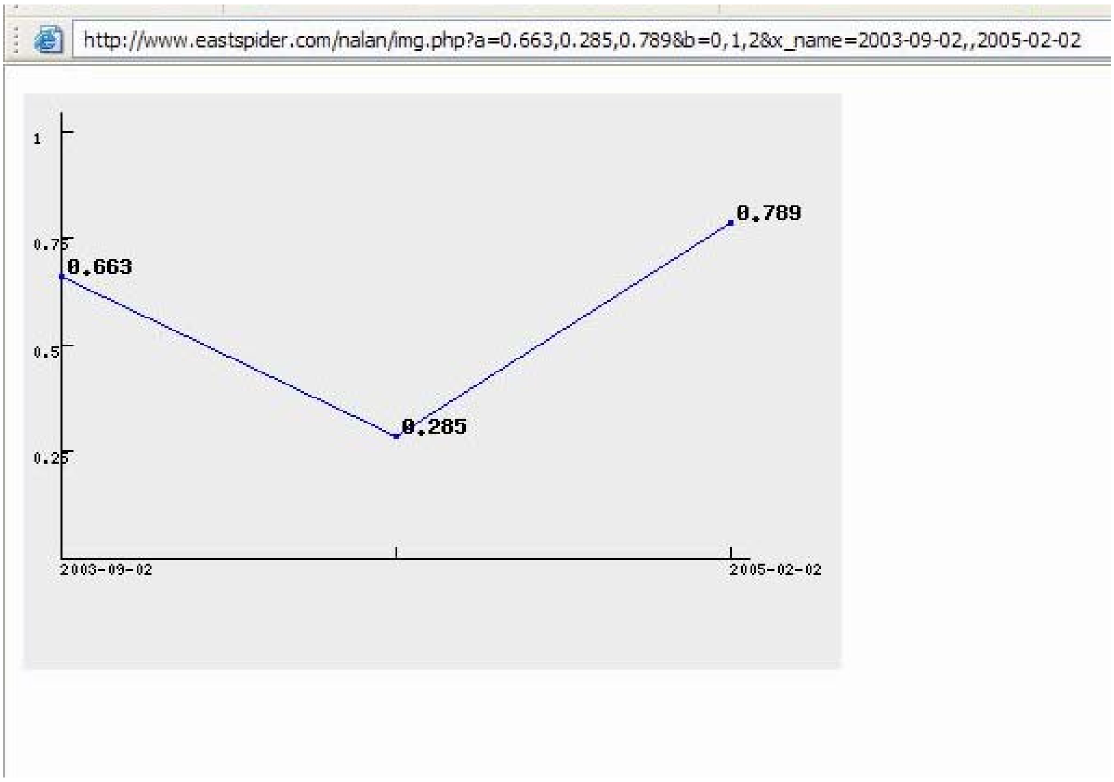


Figure 5.21 Broken line graph of comparison

Chapter 6 Conclusions

6.1 Summary

In this thesis, one important issue of SCM, that is SCPM in textile and apparel industries had been addressed. The final objective of the study was to provide a practical tool for SCPM in textile and apparel industries. To achieve this objective, a hierarchical system for SCPM was firstly set up. A CFMAE method was then developed to obtain the index value of supply chain performance.

The author first surveyed literatures on textile and apparel supply chain management, and explored the unique attributes of SCM in textile and apparel industries. Issues related to SCPM, including SCPM design, supply chain performance measures were followed. The evaluation methods in multiple attribute decision making (MADM), were then explored. Through literature review, the extant research progress and the research gaps were identified.

Multiple methodologies were utilized in this study. Based on literature review, the modified Delphi technique was employed to solicit best thinking from supply chain related managers and experts in textile or apparel companies or related organizations. The result was used to construct the SCPMS in textile and apparel industries. A CFMAE method was then developed. A comprehensive questionnaire for a mail survey was conducted to assist in the evaluation model. The questionnaire survey was completed by 77 senior managers related to SCM, who were from Hong Kong and mainland China. Based on above two stages, a SCPM online system was developed for application in reality. PHP and MySQL were employed for the online system development.

After the first round in-depth interview and the second round questionnaire survey, a two-level hierarchical structure of SCPM system in textile and apparel industries was proposed. The first level included eight attributes, which were supply chain product development, supply chain cost, supply chain time, supply chain quality, supply chain flexibility, supply chain information sharing, supply chain innovation and supply chain profitability. The eight attributes for the first level were composed of 4, 6, 8, 5, 3, 3, 3, 3 concrete metrics in the second level, respectively.

Three stages were included in the CFMAE processes. Fuzzy measure and fuzzy integral, as the first stage, was employed for the evaluation value of eight first-level attributes through the evaluation of the weight and value of each second-level metric. FAHP, as the second stage, was employed to calculate the weight of first-level attribute. The third stage was to obtain the index of the overall performance, which was an operation of Simple Additive Weight (SAW) that integrated the score of each attribute. The weight of supply chain profitability was the highest of the 8 attributes with the number of 0.2087. Followings were supply chain cost, 0.1863; supply chain time, 0.1565; supply chain product development, 0.1321; supply chain quality, 0.1179;

supply chain information sharing, 0.0987; supply chain flexibility, 0.0626; and supply chain innovation, 0.0373. A MATLAB program was developed for the process of fuzzy measure and fuzzy integral with proper input.

A more practical online SCPM system in textile and apparel industries was developed after the following two processes. The aim of the online system was to provide the direct use of the SCPM system to the industries, instead of the complicated calculation. To evaluate the performance of a given supply chain, organizer and valuator were needed. The valuator could directly evaluate the weight and value of each metric, saving in a database. Synthesizing the valuators' data, the organizer could get the evaluation result of the supply chain. The online system also supported for comparisons of different evaluations.

6.2 Contributions

6.2.1 Theoretical Originalities

From theoretical perspective, it is the first study on SCPM in textile and apparel industries. The inductive study set up a comprehensive map of SCPM in textile and apparel industries, including both the construction of SCPMS in textile and apparel industries and concrete evaluation method. The whole processes of SCPM in textile and apparel industries were provided. No such kind of work was conducted before. It filled in the theoretical gaps in the extant research.

The second originality of this research is the construction of supply chain performance measurement system in textile and apparel industries, which was attribute-based, and from holistic and balanced perspectives. The core value of SCM is that SCM is a system approach to viewing the channel as a whole, as a single entity, rather than a set of fragmented parts. Seldom research on SCPM was from holistic and balanced perspective before.

Thirdly, fuzzy logic was introduced into the evaluation process. A CFMAE method was developed, which further extended the methods of MADM.

6.2.2 Practical Impacts

The most important practical contribution in this study is the SCPM online system. To some extent, it is a commercial product. Industries can directly use the online system to evaluate their supply chain performance. Using this online system, organizations can easily measure their supply chain performance and improve it.

Another important aspect is the weights of first-level attributes in SCPM in textile and apparel industries. In this study, instead of surveying limited quantity of experts, a questionnaire survey to industries was conducted. The respondents include companies in each stage of textile-apparel supply chain, for example fashion retailers, fashion distributors, garment manufacturers, fabric manufacturers, and even yarn manufacturers. The result is the synthesis of their opinion. It is definitely a more practical result.

It is also a practical tool to improve the operations of supply chain through comparing the evaluation results. The index of the supply chain performance can be used to compare the performance of supply chains between competitors. It can be employed to compare the performance of a certain supply chain in different time. It can also be used to compare different supply chains when a company chooses the new supply chain partners.

6.3 Limitations

While the current research made significant contributions from both a theoretical and practical point of view, it also has some limitations, which are acknowledged below.

Firstly, in the construction process of SCPM in textile and apparel industries, the detailed definitions of the first-level attributes and second-level metrics are not quite clear. It may cause slightly different understanding to the same measure by the experts.

Secondly, although 77 companies from almost each stage of textile-apparel supply chain completed and returned the questionnaire, the proportion of each kind of company is random. In a textile-apparel supply chain, different companies play different roles and their attentions are also different. A fashion retailer may pay more attention on supply chain time and flexibility, while a garment manufacturer may think supply chain quality and supply chain innovation more important. Thus, the weights of their opinions should be differently treated, while they are equal in this study.

Thirdly, in the SCPM online system, all the metrics are treated qualitatively, although many of them can be evaluated quantitatively.

Fourthly, all the results of the performance measurement in this study are digits and graphics. The management implications behind the digits should be further explored.

And, no validation was conducted in the project. That means, we need to evaluate the performance of a real supply chain in textile and apparel industries. It is quite difficult because not a single company, but companies in a supply chain should be integrated to get information for the evaluation. Most of them are reluctant to public their information to others.

6.4 Future Research

The limitations discussed above and careful considerations of the research potentials lead to some interesting directions for future research.

Firstly, it is quite necessary to further explore who should be the implementation organization of SCPM in textile and apparel industries. Without a powerful coordinator in SCPM, even the best SCPM system can not work. In practice, textile-apparel supply chain is relatively complex because it encompasses several chucks of manufacturing processes such as fibre and yarn processing, fabric manufacturing/finishing, garment manufacturing and retailing. There are also many intermediate processing steps, and auxiliary materials production and service sectors involved. To different supply chain, different kind of company may play the role of coordinator, and should also be in charge of organizing supply chain performance measurement. Thus, the match of chain type and the implementation organization deserves to be further studied.

Secondly, as mentioned in the limitation part, the further study of concrete definition of each metric in SCPM in textile and apparel industries is of value. Quantitative ones are preferable for accurate comparison.

Thirdly, the standards of the metrics should also be researched in future. With these standards, the quantitative evaluation result can be transferred to the fuzzy numbers for the further calculation.

Finally, future research should pay more attention to the related implications of the results of performance measurement. The digits and graphics should tell the decision makers what is the story about and how to improve in future.

Appendix A – General Knowledge of Supply Chain and SCM

AA.1 Concepts of Supply Chain and SCM

With ever shortening product life cycles, complex corporate joint ventures, and stiffening requirements for customer service, it is necessary to consider the complete scope of supply chain, from supplier of raw material to in-store demand for product (Davis, 1993). There are many definitions of supply chain and SCM provided by both academicians and practitioners. Some typical ones are listed in Table AA.1.

Table AA.1 Definitions of supply chain and supply chain management

Stevens, 1989

Supply chain is a system whose parts include material suppliers, production facilities, distribution services and customers linked together through the feed-forward flow of materials and the feedback flow of information.

Berry et al., 1994

Supply chain management aims at building trust, exchanging information on market needs, developing new products, and reducing the supplier base to a particular OEM (original equipment manufacturer) so as to release management resources for developing meaningful, long term relationship.

APICS Dictionary, 1995

Supply chain has two parts: 1) the process from the initial raw materials to the ultimate consumption of the finished product linking across supplier-user companies; and 2) the functions within and outside a company that enable the value chain to make products and provide services to the customer (as cited in Cooper, *et. al*, 1997).

Global Supply Chain Forum, 1997

Supply chain management is the integration of key business processes from end user through original suppliers that provides products, services, and information that add value for customers (as cited in Cooper, *et. al*, 1997).

Lummus and Vokurka, 1999

Supply chain can be stated as: all the activities involved in delivering a product from raw material through to the customer including sourcing raw materials and parts, manufacturing and assembly, warehousing and inventory tracking, order entry and order management, distribution across all channels, delivery to the customer, and the information systems necessary to monitor all of these activities. Supply chain management coordinates and integrates all of these activities into a seamless process. It links all of the partners in the chain including departments within an organization and the external partners including suppliers, carriers, third-party companies, and information systems providers.

Handfield and Nichols, 1999

The supply chain encompasses all activities associated with the flow and transformation of goods from raw materials stage (extraction), through to the end user, as well as the associated information flows. Material and information flow both up and down the supply chain. Supply chain management is the integration of these activities through improved supply chain relationships, to achieve as sustainable competitive advantages.

Mentzer, 2001

A supply chain is a set of three or more organizations directly linked by one or more of the upstream and downstream flows of products, services, finances, and information from a source to a customer. Supply chain management is the systemic, strategic coordination of the traditional business functions and the tactics across businesses within the supply chain, for the purpose of improving the long-term performance of the individual companies and the supply chain as a whole.

Chopra and Meindl, 2003

A supply chain consists of all parties involved, directly or indirectly, in fulfilling a customer request. The supply chain not only includes the manufactures and suppliers, but also transporters, warehouses, retailers, and customers themselves. Within each organization, such as a manufacture, the supply chain includes all functions involved in receiving and filling a customer request. These functions include, but are not limited to, new product development, marketing, operations, distribution, finance, and customer service. Supply chain management involves the management of information, product, and funds flows between and among stages in a supply chain in maximize total supply chain profitability.

Supply Chain Council, 2004

The supply chain — a term now commonly used internationally — encompasses every effort involved in producing and delivering a final product or service, from the supplier's supplier to the customer's customer. Supply Chain Management includes managing supply and demand, sourcing raw materials and parts, manufacturing and assembly, warehousing and inventory tracking, order entry and order management, distribution across all channels, and delivery to the customer.

From these definitions, we can get the following points:

- Supply chains are autogenetic in nature, whereas managed supply chains are artificially organized with collective efforts of supply chain members;
- A supply chain should consist of multiple firms, at least three, in both upstream (i.e., supply) and downstream (i.e., distribution) operation;
- Supply chain management is a system approach to viewing the channel as a whole, as a single entity, rather than a set of fragmented parts;
- The implementation of SCM needs the integration of processes from sourcing, to manufacturing, and to distribution across supply chain;
- A minority of the entities in the supply chain controls the power in the supply chain; and
- To provide the timely release of product，information and product flows must be accounted for at all levels of the supply chain.

AA.2 Evolution of SCM

Several hundred years ago, Napoleon made the remark, “An army marches on its stomach”. Napoleon was a master strategist and a skillful general and this remark shows that he clearly understood the importance of what we would now call an efficient supply chain (Hugos, 2003). It seemed that the concept of supply chain management (SCM) emerged several centuries ago.

In order to understand the significance of changes taking place in supply chain initiatives, it would be prudent to review historical aspects of production and operations management activities (Bruce, 1997; Poirier and Reiter, 1996).

During the period from 1960 to 1975, corporations had vertical integration structures and optimization of activities was focused on functions. Relationships with vendors were win-lose interactions, and many times adversarial. Manufacturing systems were focused on materials requirement planning (MRP).

In the timeframe from 1975 to 1990, corporations were still vertically aligned but several were involved in process mapping and analysis to evaluate their operations. There was realization by organizations of the benefit of integration of functions such as product design and manufacturing. Various quality initiatives, such as the total quality management (TQM) philosophies of Deming, Juran, and Crosby, and ISO Standards for quality measurement were initiated by many organizations. The Malcolm Baldrige award and Shingo Prize for recognizing excellence in these and other quality initiatives were initiated. Manufacturing systems were focused on manufacturing resource planning (MRPII).

Starting in 1990, corporations all over the world have been experiencing increasing national and international competition. Strategic alliances among organizations have been growing. Organization structures are starting to align with processes. Manufacturing systems in organizations have been enhanced with information technology tools such as enterprise resource planning (ERP), electronic commerce, product data management, collaborative engineering, etc. (Aberdeen, 1996). Design for disassembly, synchronous manufacturing, and agile manufacturing are some of the new paradigms in manufacturing. There has been a growing appreciation in many firms of total cost focus for a product from its source to consumption, as opposed to extraction lowest price from immediate vendor(s) (Turbide, 1997). There has also been an increased reliance on purchased materials and outside processing with a simultaneous reduction in the number of suppliers and greater sharing of information between vendors and customers. A noticeable shift has taken place in the marketplace from mass production to customized products. This has resulted in the emphasis on greater organizational and process flexibility and coordination of processes across many sites. More and more organizations are promoting employee empowerment and the need for rule-based, real-time decision support systems to attain organizational and process flexibility, as well as to respond to competitive pressure to introduce new products more quickly, cheaply and of improved quality.

The well known SCM practice started with Ford's highly integrated River Rouge plant in the early twentieth century, in which raw materials would enter one side of the plant, and a finished Model T would exit the other end. Following World War II, Toyota redefined supply chain standards by strengthening its relationship with suppliers. The next evolutionary step was Wal-Mart's development of cross-docking and vendor-managed inventory to improve the supply chain linkages between manufacturers and retailers. Finally, Dell has been the exemplar of a manufacturer linking directly to consumers (Boyer *et al.*, 2004).

In academia, the first theory related with SCM was Forrester's (1958) system dynamics. More than 40 years ago, Forrester (1958) introduced a theory of management that recognized the integrated nature of organizational relationships in distribution channels. Because organizations are so interwinded, he argued that system dynamics could influence the performance of functions such as research, engineering, sales and promotion. He illustrated this using a computer simulation of order information flow and its influence on production and distribution performance for each channel member, as well as the entire channel system. More recent replications of this phenomenon include the "Beer Game" simulation and research covering the "Bullwhip Effect" (Lee *et al.*, 1997).

Discussing the shape of the future, Forrest (1958) proposed that after a period of research and development involving basic analytic techniques "there will come general recognition of the advantage enjoyed by the pioneering management who have been the first to improve their understanding of the interrelationships between separate company functions and between the company and its markets, its industry, and the national economy" (p.52). Forrest identified key management issues and illustrated the dynamics of factors associated with what we call today SCM.

The term "supply chain management" was originally introduced by consultants in the early 1980s, and then analyzed by the academic community in the 1990s (Oliver and Webber, 1992). Nowadays, the literature is replete with buzzwords such as: integrated purchasing strategy, integrated logistics, supplier integration, buyer-supplier partnerships, supply base management, strategic supplier alliance, supply chain synchronization and supply chain management, to address elements of stages of this new management philosophy of SCM (Tan, 1998). While each term addresses elements of phenomenon, typically focusing on immediate suppliers of an organization, SCM is the most widely used (but abused) term to describe this philosophy.

AA.3 Current Research in SCM

Based on examining and consolidating over 400 articles, Chen and Paulraj (2004) developed a SCM research framework shown in Figure AA.1.

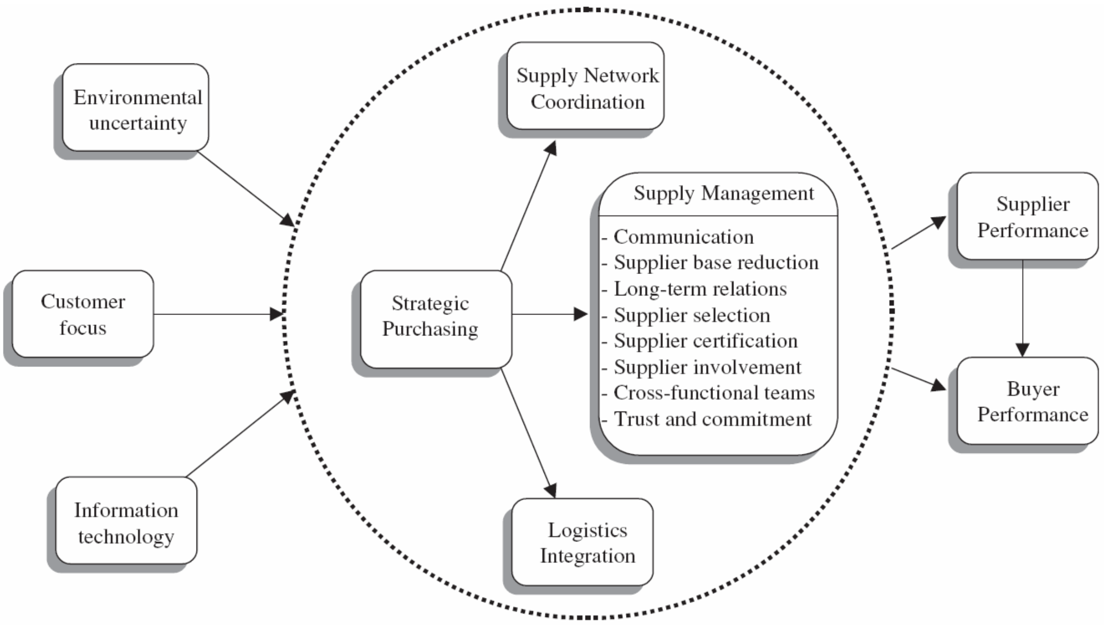


Figure AA.1 Theoretical framework for supply chain management research

As shown in Figure AA.1, environmental uncertainty, customer focus and information technology are the three key external driving forces instrumental to the development of the notion of SCM. Mentzer (2001) also presented the three driving forces for the popularity of the concept, which included trends in global sourcing, an emphasis on time- and quality-based competition, and their respective contributions to greater environmental uncertainty. SCM initiatives and activities are classified into four streams of research efforts: strategic purchasing, supply management, logistics integration, and supply network coordination. Strategic purchasing serves as an internal driving force for supply management. Also, the strategic nature of purchasing reflects its integrative role. The conceptual re-description of purchasing as integration of internal and external exchange functions, therefore, illustrates that it is conductive and instrumental to supply network coordination and enterprise-wide logistics integration. It is evident that superior buyer-supplier relationships lead to improved performance of both supplier and buyer. In addition, supplier performance is one of the key determinant factors for the company's operational performance. Thus, supplier performance is a mediating role in facilitating the link between strategic purchasing guided supply management and buy performance.

Ganeshan *et al.* (1999) classified the SCM research into three broad perspectives: competitive strategy, firm focused tactics, and operational efficiencies. The details are shown in Table AA.2. They also divided the solution methodologies into four areas: concepts and non-quantitative models, case oriented and empirical study, frameworks, taxonomies, and literature reviews, and quantitative models. The details are shown in Table AA.3.

Table AA.2 Classifying Research on Supply Chain Management

Category	**Focus**	**Subcategory**	**Definition**
Competitive Strategy	1. should develop objectives and policies for the entire supply chain AND clearly analyze how these support the needs of the firm;	Objectives	Understanding the dynamics of the supply chain and the development of objectives for the entire supply chain that includes analysis of how such goals support the needs of the firm. Includes contextual evaluation of supply chain alternatives.
	2. should determine the shape of the supply chain in terms of design;	Design	Should determine the shape of the supply chain. Includes the design of supply chains or location decisions. Needs to focus on the objectives of the design and not just the development of a tool used in decision making.
	3. should discuss how supply chain management can enhance the competitiveness of the firm	Competitive Advantage	How supply chain management can enhance the competitiveness of the firm. Includes strategic planning tools.
		Historical Perspectives	Evolutionary or historical perspectives which give us insight to the strategic nature of supply chain management.
Firm Focus Tactics	1. should focus on the implementation of strategic decisions;	Relationship Development	Developing upstream and downstream relations, third-party issues.
	2. are functional in nature, and may deal with only a few player in	Integrated Operations	Managing firm operations as an integrated unit while achieving efficiencies in operations management, including engineering, manufacturing, purchasing & may include immediate up &

	the overall chain; 3. may involve systems (MRP, DRP, JIT, etc.) necessary to manage the supply chain.		downstream links.
		Transportation and Distribution	Achieving efficiencies in managing transportation and physical distribution as an integrated system.
		Systems	Development of operation and information systems or the use of information to aid the achievement of strategic objectives.
Operational Efficiency	1. is concerned with the efficient operation of the company within the supply chain; 2. focuses on controls and performance measures (inventory investment, service level, throughput efficiency, supplier performance and cost)	Inventory Management and Control	In terms of the operating efficiency of the supply chain, determining & measuring the performance of inventory. Also includes inventory investment, service level, allocation schemes & multi-echelon inventory theory.
		Production, Planning and Scheduling	Determining & measuring the performance of production, planning and scheduling to aid the efficient operation of the supply chain.
		Information Sharing, Coordination and Monitoring	Specifies schemes for coordination and control in the sharing of information needed in the efficient operation of the supply chain.
		Operational Tools	Development of tools which aid in the efficient operation of the supply chain.

Table AA.3 Solution Methodology

Solution Methodology	**Definition**
Concepts and Non-Quantitative Models	Research that analyzes the supply chain in an attempt to define, describe, and develop methods for the management of the supply chain without using quantitative models.
Case Oriented and Empirical Study	Research that works with specific firms or industries and uses data collected by researcher or another qualified source to aid in the management of the supply chain.
Frameworks, Taxonomies, and Literature Reviews	Research that categorizes or explains concepts in SCM as an effort in the understanding of the breadth and depth of the concept.
Quantitative Models	Research that attempts to develop methods for the management of the supply chain using quantitative models.

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Appendix B – General Knowledge of Fuzzy Sets

AB.1 Introduction to Fuzzy Sets

Most real world decision making takes place in an environment in which the states of nature, feasible actions and outcomes, and available information are only imprecisely known. Imprecision has been quantified primarily by means of probability theory, a practice which implies that imprecision of any sort can be equated to randomness. Several researchers (Bellman and Zadeh, 1970; Dutta, 1985) have emphasized the need for differentiating among the sources of imprecision underlying particular assumptions or items of evidence.

In 1965, L. A. Zadeh introduced the theory of fuzzy sets. Fuzzy sets are based on the concept that the boundaries of sets involving approximate data are not precisely defined and that membership within the set is not a matter of absolute truth, but rather, a matter of degree. Zadeh (1965) defined a fuzzy set as “a class of objects with a continuum of grades of membership.” A fuzzy set can be defined mathematically by assigning each element in the set a value which represents the grade of membership in the set. The membership grades are represented by real number values in the closed interval from zero to one. In essence, a fuzzy number can be regarded as a special fuzzy subset of a real number. Classical sets, usually distinguished as “crisp sets”, can be viewed as special cases of fuzzy sets in which the associated function maps each element of the set to the binary set {0,1}. Crisp sets only allow full membership or no membership at all, while fuzzy sets allow partial membership (Yager and ZadehB, 1992).

The application of fuzzy set theory has several advantages in comparison with the crisp sets (Klir, 1995). First, fuzzy set theory is capable of handling a higher degree of uncertainty than regular crisp set method. Second, it requires fewer assessments than other methods such as Bayes' theorem or evidential theory. Third, it requires that very few assumptions be satisfied. Fourth, fuzzy set theory has realistic means of including degrees of importance for decision makers. Most important of all is that it can combine evidence in a simple way. Fuzzy logic, therefore, with its simplicity, wide range of application, and reduction of problem solving sensitivity is chosen in this study.

AB.2 Fundamental Concepts of Fuzzy Sets Theory

The following concepts are defined in a vast amount of literature on the subject of fuzzy sets theory including Gupta *et al.* (1979); Karwowski and Mital (1986); Klir (1995); Klir and Folger (1988); Klir and Yuan (1995); Yager and Zadeh (1992); and Zadeh (1965).

Definition: A fuzzy set A in X is characterized by a membership function $\mu_A(x)$ which associates with each point of X a real number in the interval [0,1], with the value of $\mu_A(x)$ at x representing the "grade of membership" of x in A (Zadeh, 1965).

A fuzzy number can simply be described as a fuzzy set that is a subset of the real line (Bonissone, 1982). However, according to the definition of fuzzy numbers given by Dubois and Prade (1978), the membership function of the fuzzy number A on the real line R has to satisfy the following requirements:

(i) Continuous mapping from R to the closed interval [0,1]

(ii) Constant on $(-\infty, a]$: $\mu_A(x) = 0 \quad \forall x \in (-\infty, a]$

(iii) Strictly increasing on [a,b]

(iv) Constant on [b,c]: $\mu_A(x) = 1 \quad \forall x \in [b, c] \rightarrow$ Normality Constraint

(v) Strictly decreasing on [c,d]

(vi) Constant on $[d, \infty)$: $\mu_A(x) = 0 \quad \forall x \in [d, \infty)$

where $a \le b \le c \le d \in R$

A fuzzy number can also be denoted by the quadruple [a, b, c, d; 1] and the membership function can be defined as

$$f_A(x) = \begin{cases} f_A{}^L(x) & a \le x \le b \\ 1 & b \le x \le c \\ f_A{}^R(x) & c \le x \le d \\ 0 & otherwise \end{cases}$$

It is possible to have a and $b \rightarrow -\infty$, or $a=b$, or $b=c$, or $c=d$, or c and $d \rightarrow \infty$, and if $a=b=c=d$, then A is an ordinary real number. Constraints (ii), (iii), (v), (vi) can be summarized into one convexity constraint (Dubois and Prade, 1980):

$$\mu_A(\lambda x_1 + (1-\lambda)x_2) \geq \min(\mu_A(x_1), \mu_A(x_2)) \quad \text{where} \quad \lambda \in [0,1] \quad \text{and} \quad x_1, x_2 \in A$$

Any set that meets the above requirements can be used in modeling the decision problems. However, due to their good representation of uncertain events, trapezoidal and triangular fuzzy members with linear edges are used more often than others, with triangular fuzzy numbs ($b=c$) being the preferred one as computations are much easier on them.

It is also possible to come across discrete fuzzy numbers in the literature (Kacprzyk, 1983). An example is the fuzzy set of “integers much higher than 7”.

AB.3 Fuzzy Sets Properties and Operations

Some of the properties of fuzzy numbers are (assuming A and B are two fuzzy numbers on the real line):

1) Equality: $A, B \subset R$

$$A = B \quad \Leftrightarrow \quad \mu_A(x) = \mu_B(x) \quad \forall x \in R$$

2) Containment: $A, B \subset R$

$$A \subset B \quad \Leftrightarrow \quad \mu_A(x) \leq \mu_B(x) \quad \forall x \in R$$

3) Support of a fuzzy set: Supp $A = \{x \in R : \mu_A(x) \geq 0\}$

4) α -cut (α -level set): $A_\alpha = \{x \in R : \mu_A(x) \geq \alpha\}$

5) Identity Elements:

a. Additive:

$$I=(0, 0, 0) \qquad A+I=A \qquad \forall A$$

b. Multiplicative:

$$I=(1, 1, 1) \qquad A\cdot I=A \qquad \forall A$$

6) Opposite (Negative) of a Fuzzy Number:

$$\mu_{-A}(x)=\mu_A(-x)$$

7) Multiplicative Inverse of a Fuzzy Number:

$$\mu_{A^{-1}}(x)=\mu_A(1/x)$$

The definitions of mathematical operations on fuzzy numbers are given next. Note that $\wedge$ is the min operator for fuzzy sets.

1) Addition:

Definition: $$\mu_{A+B}(z)=\max_{x+y=z}(\mu_A(x)\wedge\mu_B(y))$$

2) Subtraction:

Definition: $$\mu_{A-B}(z)=\max_{x-y=z}(\mu_A(x)\wedge\mu_B(y))$$

3) Multiplication:

Definition: $$\mu_{A\cdot B}(z)=\max_{x\cdot y=z}(\mu_A(x)\wedge\mu_B(y))$$

4) Division:

Definition: $$\mu_{A/B}(z)=\max_{x/y=z}(\mu_A(x)\wedge\mu_B(y))$$

In defining operations on fuzzy numbers Dubois and Prade (1978) have used the extension principle introduced by Zadeh (1965) to extend nonfuzzy mathematical concepts in order to deal with fuzzy quantities. However, these (exact) computations become increasingly cumbersome in the case of continuous fuzzy numbers. Since triangular fuzzy numbers are the most frequently used, they also developed approximations for the extended operations. The underlying idea is approximating the result of the multiplication or division of two fuzzy numbers with linear edges with a fuzzy number of the same type. Multiplying (dividing) two fuzzy numbers involves the multiplication (division) of two linear equations (edges). The result becomes a nonlinear equation, but as long as the deviation is small, a linear approximation can be justified.

Let $A = (A^{L(\alpha)}, A^{R(\alpha)}) = (a,b,c)$ $B = (B^{L(\alpha)}, B^{R(\alpha)}) = (d,e,f)$

where $A = (A^{L(\alpha)}, A^{R(\alpha)})$ is the left-right representation of the triangular fuzzy number, $A^{L(\alpha)}$ and $A^{R(\alpha)}$ being the equations of edges of the fuzzy number to the left and to the right of the most likely value, respectively, and $A = (a,b,c)$ is the three point representation, where *a, b, c* are the smallest, most likely, and highest possible values, respectively. Then,

1) Addition:

$$A + B = (A^{L(\alpha)} + B^{L(\alpha)}, A^{R(\alpha)} + B^{R(\alpha)}) = (a+d, b+e, c+f)$$

2) Subtraction:

$$A - B = (A^{L(\alpha)} - B^{L(\alpha)}, A^{R(\alpha)} - B^{R(\alpha)}) = (a-d, b-e, c-f)$$

3) Multiplication:

$$A > 0, B > 0 \rightarrow A \cdot B = (A^{L(\alpha)} \cdot B^{L(\alpha)}, A^{R(\alpha)} \cdot B^{R(\alpha)}) \qquad \text{exact}$$

$$= (a \cdot d, b \cdot e, c \cdot f) \qquad \text{approx.}$$

$$A<0, B<0 \rightarrow A\cdot B=(A^{R(\alpha)}\cdot B^{R(\alpha)}, A^{L(\alpha)}\cdot B^{L(\alpha)}) \qquad \text{exact}$$

$$=(c\cdot f, b\cdot e, a\cdot d) \qquad \text{approx.}$$

$$A>0, B<0 \rightarrow A\cdot B=(A^{R(\alpha)}\cdot B^{L(\alpha)}, A^{L(\alpha)}\cdot B^{R(\alpha)}) \qquad \text{exact}$$

$$=(c\cdot d, b\cdot e, a\cdot f) \qquad \text{approx.}$$

$$A<0, B>0 \rightarrow A\cdot B=(A^{L(\alpha)}\cdot B^{R(\alpha)}, A^{R(\alpha)}\cdot B^{L(\alpha)}) \qquad \text{exact}$$

$$=(a\cdot f, b\cdot e, c\cdot d) \qquad \text{approx.}$$

4) Division:

$$A>0, B>0 \rightarrow A/B=(A^{L(\alpha)}/B^{R(\alpha)}, A^{R(\alpha)}/B^{L(\alpha)}) \qquad \text{exact}$$

$$=(a/f, b/e, c/d) \qquad \text{approx.}$$

$$A<0, B<0 \rightarrow A/B=(A^{R(\alpha)}/B^{L(\alpha)}, A^{L(\alpha)}/B^{R(\alpha)}) \qquad \text{exact}$$

$$=(c/d, b/e, a/f) \qquad \text{approx.}$$

$$A>0, B<0 \rightarrow A/B=(A^{R(\alpha)}/B^{R(\alpha)}, A^{L(\alpha)}/B^{L(\alpha)}) \qquad \text{exact}$$

$$=(c/f, b/e, a/d) \qquad \text{approx.}$$

$$A<0, B>0 \rightarrow A/B=(A^{L(\alpha)}/B^{L(\alpha)}, A^{R(\alpha)}/B^{R(\alpha)}) \qquad \text{exact}$$

$$=(a/d, b/e, c/f) \qquad \text{approx.}$$

Note that under the approximate approach if $A=(a,b,c)$,then

1) Multiplicative inverse of A $=1/A=(1/c, 1/b, 1/a)$

2) Natural logarithm of A $=\ln(A)=(\ln(a), \ln(b), \ln(c))$

3) Exponential of A $=\exp(A)=(\exp(a), \exp(b), \exp(c))$

AB.4 Typical Shapes of Fuzzy Set Membership Functions

Membership functions of fuzzy sets can assume many forms. Several geometric functions have been developed which are extremely useful in the characterization of the environments of real systems. These geometric functions include the S, π, trapezoidal, and triangular shaped functions (McCauley-Bell and Badiru, 1996). The class of trapezoidal-shaped functions is frequently used to represent linguistics terms. Figure AB.1 graphically depicts the trapezoidal function. The trapezoidal-shaped membership function $f(x;\alpha,\beta,\gamma,\delta,\theta)$ is defined by

$$f(x;\alpha,\beta,\gamma,\delta,\theta)=\begin{cases}\dfrac{(\alpha-x)\theta}{\alpha-\beta} & \alpha\le x\le\beta\\ \theta & \beta\le x\le\gamma\\ \dfrac{(\delta-x)\theta}{\delta-\gamma} & \gamma\le x\le\delta\\ 0 & otherwise\end{cases}$$

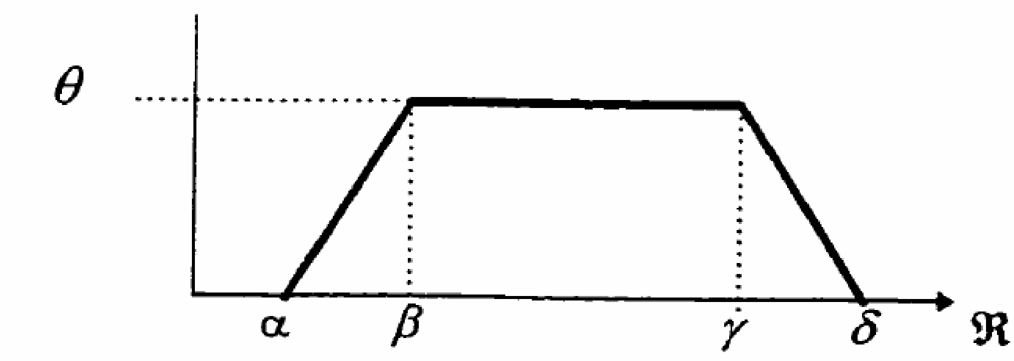

Figure AB.1 Trapezoidal-shaped Membership Function

(Klir and Yuan, 1995)

Triangular-shaped membership functions are special cases of trapezoidal function where $\beta=\gamma$.

AB.5 Linguistic Variables

Linguistic variables are variables whose values are represented by words or sentences in a natural or artificial language, rather than numbers (Zimmerman, 1991). In many scientific applications, data which is imprecise or difficult, if not impossible, to measure directly is more adequately represented in linguistic terms. Klir and Yuan (1995) have defined a characteristic quintuple for linguistic variables (v, T, X, g, m). The name of the variable, *v*, characterizes the meaning of the base variable. *T* is the set of linguistic terms that refer to a base variable whose values range within the universal set *X* (a closed interval of real numbers within a specific range). The syntactic rule for generating the linguistic terms is represented by *g* and *m* is the semantic rule that assigns a meaning to each linguistic term, which is a fuzzy number defined on the range of the base variable. Figure AB.2, adapted from Klir (1995) graphically depicts the quintuple of a linguistic variable frequently used in subjective assessments.

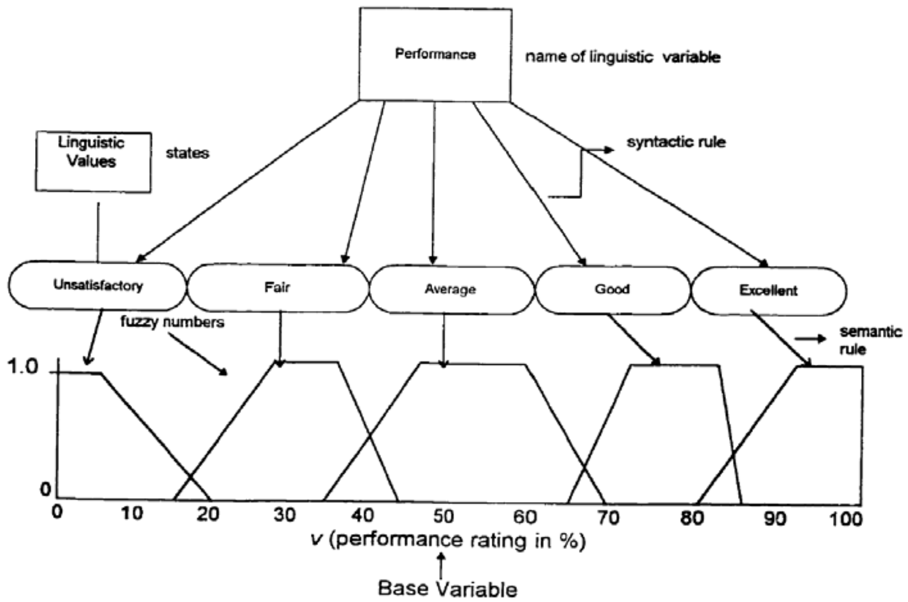

Figure AB.2 Example of a Linguistic Variable

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Appendix C – Delphi Study

C1 List of Experts

C2 Outline of In-depth Interview

C3 Questionnaire of Second Round Delphi Study

Appendix C1 List of Experts

Name	Organization	Position
YANG Jian	China Fashion Association	Deputy General Secretary
LIU Xiansheng	Guangdong Association of Garment and Garment Article Industry	General Secretary
XIA Naijin	Tianjin Association of Garment	General Secretary
YAO Ting	Hangzhou Association of Textile and Garment Industry	General Secretary
Kennedy Chow	Bossini Enterprises Limited	Process Improvement Manager
Jordan Dong	White Collar Fashion Co. Ltd	CEO
LI Xiaoyan	LEBOLE Industry and Commerce Development (BJ) Co. Ltd.	President
WANG Jianming	YOUNGOR GROUP CO.,LTD	Merchandising Manager
ZHU Jiahua	Shanxi Weizhi Shirt Limited	Market Manager
WANG Canping	KAIWANG International Group	CEO

Appendix C2 Outline of In-depth Interview

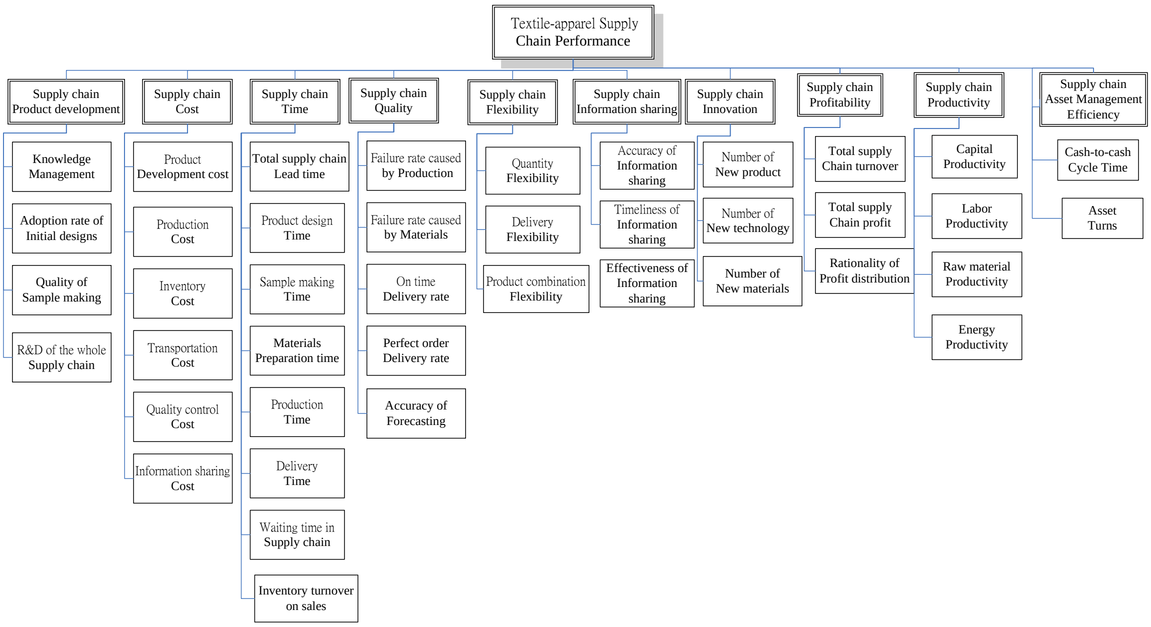
The outline prepared for the in-depth interview is listed below.

1. What do companies think of SCM in textile and apparel industries?
2. Please comment on the evolution of the process of measuring activities across firms. What is the current stage? How fast is it evolving? How much progress will occur in the next five years?
3. What are the barriers that companies face in moving toward a supply chain process orientation?
4. Which attributes do you think are typical and important for SCM in textile and apparel industries?
5. What are the key activity or process measures being used inside companies in textile and apparel industries today?
6. What metrics should be considered to measure the holistic supply chain performance in textiles and clothing industries?
7. What comments or guidance do you have on what should be the focus of research in this area?

Appendix C3 Questionnaire of Second Round of Delphi Study

Dear Expert:

Thank you for your effort in the first round interview. After discussing with all of you experts, we present the following model to evaluate the supply chain performance in textile and apparel industries. In this round, would you please evaluate each first-level attribute and the items for each attribute with a 7-point scale, in which 1 means "very unimportant" and 7 means "very important". Please return the email to us within 4 weeks. Thank you for your contribution.



1. For each of the first-level attribute, what is the importance do you think?

Supply chain product development	□1	□2	□3	□4	□5	□6	□7
Supply chain cost	□1	□2	□3	□4	□5	□6	□7
Supply chain time	□1	□2	□3	□4	□5	□6	□7
Supply chain quality	□1	□2	□3	□4	□5	□6	□7
Supply chain flexibility	□1	□2	□3	□4	□5	□6	□7
Supply chain information sharing	□1	□2	□3	□4	□5	□6	□7
Supply chain innovation	□1	□2	□3	□4	□5	□6	□7

Supply chain profitability	□1	□2	□3	□4	□5	□6	□7
Supply chain productivity	□1	□2	□3	□4	□5	□6	□7
Supply chain asset management efficiency	□1	□2	□3	□4	□5	□6	□7

2. For the second-level metrics, what is the importance do you think to reflect the corresponding first-level attribtue, thus to measure the holistic supply chain performance?

Supply chain product development							
Knowledge management	□1	□2	□3	□4	□5	□6	□7
Adoption rate of initial designs	□1	□2	□3	□4	□5	□6	□7
Quality of sample making	□1	□2	□3	□4	□5	□6	□7
R&D of the whole supply chain	□1	□2	□3	□4	□5	□6	□7
Supply chain cost							
Product development cost	□1	□2	□3	□4	□5	□6	□7
Product manufacturing cost	□1	□2	□3	□4	□5	□6	□7
Inventory cost	□1	□2	□3	□4	□5	□6	□7
Transportation cost	□1	□2	□3	□4	□5	□6	□7
Quality control cost	□1	□2	□3	□4	□5	□6	□7
Information sharing cost	□1	□2	□3	□4	□5	□6	□7
Supply chain time							
Total supply chain lead time	□1	□2	□3	□4	□5	□6	□7
Product design time	□1	□2	□3	□4	□5	□6	□7
Sample making time	□1	□2	□3	□4	□5	□6	□7
Materials preparation time	□1	□2	□3	□4	□5	□6	□7
Manufacturing time	□1	□2	□3	□4	□5	□6	□7
Delivery time	□1	□2	□3	□4	□5	□6	□7
Waiting time in supply chain	□1	□2	□3	□4	□5	□6	□7
Inventory turnover on sales	□1	□2	□3	□4	□5	□6	□7
Supply chain quality							
Failure rate caused by production	□1	□2	□3	□4	□5	□6	□7
Failure rate caused by materials	□1	□2	□3	□4	□5	□6	□7
On time delivery rate	□1	□2	□3	□4	□5	□6	□7
Perfect order delivery rate	□1	□2	□3	□4	□5	□6	□7
Accuracy of forecasting	□1	□2	□3	□4	□5	□6	□7
Supply chain flexibility							
Quantity flexibility	□1	□2	□3	□4	□5	□6	□7
Delivery flexibility	□1	□2	□3	□4	□5	□6	□7

Product combination flexibility	□1	□2	□3	□4	□5	□6	□7
Supply chain information sharing							
Accuracy of information sharing	□1	□2	□3	□4	□5	□6	□7
Timeliness of information sharing	□1	□2	□3	□4	□5	□6	□7
Effectiveness of information sharing	□1	□2	□3	□4	□5	□6	□7
Supply chain innovation							
Number of new products	□1	□2	□3	□4	□5	□6	□7
Number of new technology	□1	□2	□3	□4	□5	□6	□7
Number of new materials	□1	□2	□3	□4	□5	□6	□7
Supply chain profitability							
Total supply chain turnover	□1	□2	□3	□4	□5	□6	□7
Total supply chain profit	□1	□2	□3	□4	□5	□6	□7
Rationality of profit distribution	□1	□2	□3	□4	□5	□6	□7
Supply chain productivity							
Capital productivity	□1	□2	□3	□4	□5	□6	□7
Labor productivity	□1	□2	□3	□4	□5	□6	□7
Raw material productivity	□1	□2	□3	□4	□5	□6	□7
Energy productivity	□1	□2	□3	□4	□5	□6	□7
Supply chain asset management efficiency							
Cash-to-cash cycle time	□1	□2	□3	□4	□5	□6	□7
Asset turns	□1	□2	□3	□4	□5	□6	□7

Appendix D Questionnaire Survey

Cover Letter:

Dear Sir/Madam,

This is a letter asking for your help from Institute of Textiles and Clothing, The Hong Kong Polytechnic University. The research is about performance measurement for textile-apparel supply chain, which is part of supply chain management (SCM) research. Supply chain performance measurement is one of the most important parts of efficient SCM because you can not manage what you can not measure. In reality, most supply chain members are measuring their performance only from internal perspective. Fewer are measuring the whole supply chain's performance.

We have proposed a model of performance measurement after discussing with some experts in industries. We hope to do a more practical work to establish a supply chain performance measurement system. So your opinion is valuable.

We greatly appreciate your participation in this research. This questionnaire is estimated to take no longer than 30 minutes to complete. We are looking forward to your prompt response. Please mail back the questionnaire with the self-addressed envelope in a month.

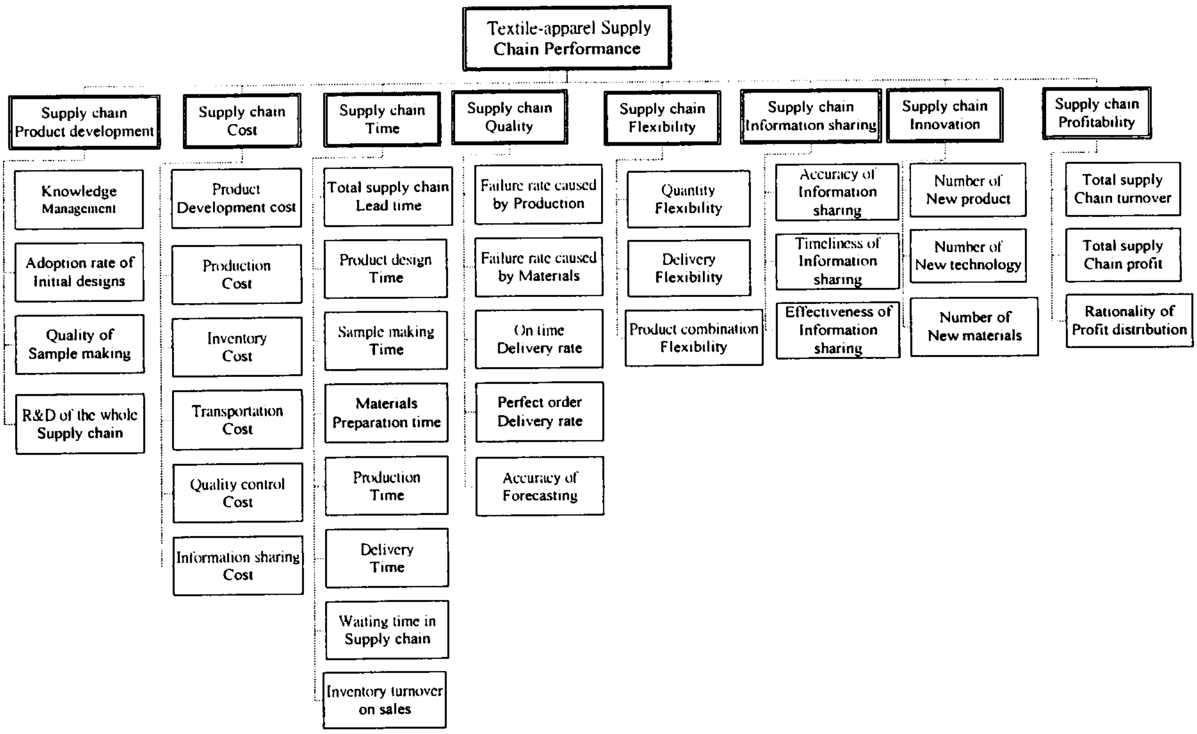
Sincerely,

Ning Cao, Ph.D Candidate

Institute of Textiles and Clothing, The Hong Kong Polytechnic University

Questionnaire:

The following model is to evaluate the supply chain performance in textile and apparel industries. There are two parts of the questionnaire. Part I is about the relative importance for the first-level eight attributes. Part II is about the importance of the second-level metrics. Please choose as you think. Part III is the demographics of your organization.



Part I:

Please assess the relative importance between the eight first-level attributes. You can follow the guide of the example.

Example:

When you buy clothing, there are many factors to be considered such as price and style. If you think that price is absolutely more important than style, please tick “absolutely important” in price side.

	AI		DI		SI		WI		EI		WI		SI		DI		AI	
	9		7		5		3		1		3		5		7		9	
Price	√	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	Style

Or if you think that style is more important than price, and the extent is between weakly more important and strongly more important, please tick between SI and WI in style side.

	AI		DI		SI		WI		EI		WI		SI		DI		AI	
	9		7		5		3		1		3		5		7		9	
Price	□	□	□	□	□	□	□	□	□	□	□	√	□	□	□	□	□	Style

AI (9): absolute importance

DI (7): demonstrated importance

SI (5): strong importance

WI (3): weak importance

EI (1): equal importance

For the eight attributes in the first-level of supply chain performance measurement system in textile and apparel industries, please indicate the relative importance between them as illustrated in the above example.

F1: supply chain product development

F2: supply chain cost

F3: supply chain time

F4: supply chain quality

F5: supply chain flexibility

F6: supply chain information sharing

F7: supply chain innovation

F8: supply chain profitability

1. For “supply chain product development” and the others

	AI		DI		SI		WI		EI		WI		SI		DI		AI	
	9		7		5		3		1		3		5		7		9	
F1	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	F2
	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	F3

	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F4
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F5
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F6
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F7
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F8

2. For “supply chain cost” and the others

	AI		DI		SI		WI		EI		WI		SI		DI		AI	
	9		7		5		3		1		3		5		7		9	
F2	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F3
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F4
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F5
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F6
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F7
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F8

3. For “supply chain time” and the others

	AI		DI		SI		WI		EI		WI		SI		DI		AI	
	9		7		5		3		1		3		5		7		9	
F3	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F4
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F5
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F6
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F7
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F8

4. For “supply chain quality” and the others

	AI		DI		SI		WI		EI		WI		SI		DI		AI	
	9		7		5		3		1		3		5		7		9	
F4	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F5
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F6
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F7
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F8

5. For “supply chain flexibility” and the others

	AI		DI		SI		WI		EI		WI		SI		DI		AI	
	9		7		5		3		1		3		5		7		9	
F5	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F6
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	F7

	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	F8

6. For "supply chain information sharing" and the others

	AI		DI		SI		WI		EI		WI		SI		DI		AI	
	9		7		5		3		1		3		5		7		9	
F6	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	F7
	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	F8

7. For "supply chain innovation" and "supply chain profitability"

	AI		DI		SI		WI		EI		WI		SI		DI		AI	
	9		7		5		3		1		3		5		7		9	
F7	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	F8

AI (9): absolute importance

DI (7): demonstrated importance

SI (5): strong importance

WI (3): weak importance

EI (1): equal importance

Part II:

For the items of each level 1 attribute, what is the importance do you think to reflect the corresponding level 1 indicator, thus to measure the holistic supply chain performance? (1=EUI=Extremely Unimportant, 2=VUI=Very Unimportant, 3=LUI=Little Unimportant, 4=N=Normal, 5=LI=Little Important, 6=VI=Very Important, 7=EI=Extremely Important)

Supply chain product development							
Knowledge management	□1	□2	□3	□4	□5	□6	□7
Adoption rate of initial designs	□1	□2	□3	□4	□5	□6	□7
Quality of sample making	□1	□2	□3	□4	□5	□6	□7
R&D of the whole supply chain	□1	□2	□3	□4	□5	□6	□7
Supply chain cost							
Product development cost	□1	□2	□3	□4	□5	□6	□7
Product manufacturing cost	□1	□2	□3	□4	□5	□6	□7
Inventory cost	□1	□2	□3	□4	□5	□6	□7
Transportation cost	□1	□2	□3	□4	□5	□6	□7
Quality control cost	□1	□2	□3	□4	□5	□6	□7
Information sharing cost	□1	□2	□3	□4	□5	□6	□7
Supply chain time							
Total supply chain lead time	□1	□2	□3	□4	□5	□6	□7
Product design time	□1	□2	□3	□4	□5	□6	□7
Sample making time	□1	□2	□3	□4	□5	□6	□7
Materials preparation time	□1	□2	□3	□4	□5	□6	□7
Manufacturing time	□1	□2	□3	□4	□5	□6	□7
Delivery time	□1	□2	□3	□4	□5	□6	□7
Waiting time in supply chain	□1	□2	□3	□4	□5	□6	□7
Inventory turnover on sales	□1	□2	□3	□4	□5	□6	□7
Supply chain quality							
Failure rate caused by production	□1	□2	□3	□4	□5	□6	□7
Failure rate caused by materials	□1	□2	□3	□4	□5	□6	□7
On time delivery rate	□1	□2	□3	□4	□5	□6	□7
Perfect order delivery rate	□1	□2	□3	□4	□5	□6	□7
Accuracy of forecasting	□1	□2	□3	□4	□5	□6	□7
Supply chain flexibility							
Quantity flexibility	□1	□2	□3	□4	□5	□6	□7
Delivery flexibility	□1	□2	□3	□4	□5	□6	□7

Product combination flexibility	□1	□2	□3	□4	□5	□6	□7
Supply chain information sharing							
Accuracy of information sharing	□1	□2	□3	□4	□5	□6	□7
Timeliness of information sharing	□1	□2	□3	□4	□5	□6	□7
Effectiveness of information sharing	□1	□2	□3	□4	□5	□6	□7
Supply chain innovation							
Number of new products	□1	□2	□3	□4	□5	□6	□7
Number of new technology	□1	□2	□3	□4	□5	□6	□7
Number of new materials	□1	□2	□3	□4	□5	□6	□7
Supply chain profitability							
Total supply chain turnover	□1	□2	□3	□4	□5	□6	□7
Total supply chain profit	□1	□2	□3	□4	□5	□6	□7
Rationality of profit distribution	□1	□2	□3	□4	□5	□6	□7
Supply chain productivity							
Capital productivity	□1	□2	□3	□4	□5	□6	□7
Labor productivity	□1	□2	□3	□4	□5	□6	□7
Raw material productivity	□1	□2	□3	□4	□5	□6	□7
Energy productivity	□1	□2	□3	□4	□5	□6	□7
Supply chain asset management efficiency							
Cash-to-cash cycle time	□1	□2	□3	□4	□5	□6	□7
Asset turns	□1	□2	□3	□4	□5	□6	□7

Part III Demographics

1. Your company name:______________________, the headquarter is in___________

2. What are the main businesses of your company? (Multiple choices)

□1 Yarn manufacturing	□2 Fabric manufacturing	□3 Finishing and printing
□4 Garment manufacturing	□5 Distributing and retailing	□6 Garment trading
□7 Auxiliary materials	□8 Others(specify)______	

3. How many employees does your company currently have?

□1 Less than 100	□2 100 - 500	□3 500 – 1,000
□4 1,000 – 2,000	□5 2,000 -5,000	□6 More than 5,000

4. What is the turnover of your company in last fiscal year (HK$ million)?

□1 Less than 5	□2 5 - 10	□3 10 – 20
□4 20 – 50	□5 50 -100	□6 More than 100

Appendix E Listing of MATLAB M Files

Data_origin.m

```
% original evaluation of the items' weight

WtMx=[77×35];

EvMx= [N×35];
```

Calculate_fuzzW.m

```
% data_origin    to define BMx

data_origin

[yaW,ybW]=size(WtMx);

nnW=yaW;

SXN=[4, 6, 8, 5, 3, 3, 3, 3];

  % to define Linguistic value matrix

LinV=[  0,0,0.1,0.2;  0.1,0.1,0.2,0.3;  0.2,0.3,0.4,0.5;  0.4,0.5,0.5,0.6;  0.5,0.6,0.7,0.8;

0.7,0.8,0.8,0.9; 0.8,0.9,1,1 ];

Rsn=(1+i)*ones(sum(SXN),1);

wtn=zeros(sum(SXN),3);

svn=0;

bkn=zeros(1,7);

bcm=zeros(nnW,1);

Lvi=zeros(1,4);
```

```
% % begin to compute the fuzzy roots
for si=1:8
    Ni=SXN(1,si);
    for iin=1:Ni
    bcm=WtMx(:,svn+iin);
        for kx=1:nnW
            bk=bcm(kx,1);
            bkn(1,bk)=bkn(1,bk)+1;
        end
        Lvi=bkn*LinV/nnW;
        % % calculate weight N_i1
        wd1=sum((ones(1,4)-Lvi).^2)^0.5/2;
        wd2=sum( Lvi.^2)^0.5/2;
        wtn(svn+iin,1)=wd2/(wd2+wd1);
        % % calculate weight N_i2
        wtn(svn+iin,2)=(Lvi(1,2)*2+Lvi(1,3)*2+Lvi(1,4)+Lvi(1,1))/6;
        % % calculate weight N_i3
        if
( Lvi(1,1)-Lvi(1,2))^2+(Lvi(1,3)-Lvi(1,2))^2+(Lvi(1,4)-Lvi(1,3))^2<1e-10
            wtn(svn+iin,3)=Lvi(1,1);
        else
wtn(svn+iin,3)=( Lvi(1,4)^2+Lvi(1,3)^2-Lvi(1,1)^2-Lvi(1,2)^2+Lvi(1,4)*Lvi(1,3)-Lv
```

```
i(1,1)*Lvi(1,2) )/3;
wtn(svn+iin,3)=wtn(svn+iin,3)/(Lvi(1,4)++Lvi(1,3)-Lvi(1,1)-Lvi(1,2));
        end
        wtn(svn+iin,1)=sum(wtn(svn+iin,:))/3;
        bkn=bkn*0;
     end
    polif=[wtn(svn+1), 1];
    for itn=2:Ni;
        tf=[wtn(svn+itn), 1];
        polif=conv(polif, tf);
    end
    polif(1,Ni)=polif(1,Ni)-1;
    polif(1,Ni+1)=polif(1,Ni+1)-1;   % % constant item of the polif is 0
    Rsn(svn+1:svn+Ni,1)=roots(polif);
    svn=svn+Ni;
end
xSn=zeros(1,8); % * valid roots
for xi=1:8
    x0=sum(SXN(1,1:xi));
    xSn(1,xi)=Rsn(x0,1);
end
```

Calculate_result.m

```
% * precompute the weight roots
calculate_fuzyW ;
% SXN=[4, 6, 8, 5, 3, 3, 3, 3];
  % to define Linguistic value matrix
% LinV=[ 0,0,0.1,0.2; 0.1,0.1,0.2,0.3; 0.2,0.3,0.4,0.5; 0.4,0.5,0.5,0.6; 0.5,0.6,0.7,0.8;
0.7,0.8,0.8,0.9; 0.8,0.9,1,1 ];
vutn=zeros(sum(SXN),3);
arrWx=zeros(sum(SXN),1);
Vux=zeros(1,sum(SXN));
Arp=zeros(sum(SXN),1);
% Given times and digit arrays of evaluation
   % EvMx= ...;    is the evalution digit matrix
[yaE,ybE]=size(EvMx);
enn=yaE ;
svn=0;
vbkn=zeros(1,7);
bcm=zeros(enn,1);    % enn to give
Lvi=zeros(1,4);
% * begin to compute the fuzzy roots                   % rpc=0;
for si=1:8
```

```
Ni=SXN(1,si);
for iin=1:Ni
bcm=EvMx(:,svn+iin);
    for kx=1:enn    % enn to give
        bk=bcm(kx,1);
        vbkn(1,bk)=vbkn(1,bk)+1;
    end
    Lvi=vbkn*LinV/enn; % enn to give
    % % calculate weight N_i1
    wd1=sum((ones(1,4)-Lvi).^2)^0.5/2;
    wd2=sum( Lvi.^2)^0.5/2;
    vutn(svn+iin,1)=wd2/(wd2+wd1);
    % % calculate weight N_i2
    vutn(svn+iin,2)=(Lvi(1,2)*2+Lvi(1,3)*2+Lvi(1,4)+Lvi(1,1))/6;
    % % calculate weight N_i3
    if
( Lvi(1,1)-Lvi(1,2))^2+(Lvi(1,3)-Lvi(1,2))^2+(Lvi(1,4)-Lvi(1,3))^2<1e-10
        vutn(svn+iin,3)=Lvi(1,1);
    else
vutn(svn+iin,3)=(  Lvi(1,4)^2+Lvi(1,3)^2-Lvi(1,1)^2-Lvi(1,2)^2+Lvi(1,4)*Lvi(1,3)-L
vi(1,1)*Lvi(1,2) )/3;
vutn(svn+iin,3)=vutn(svn+iin,3)/(Lvi(1,4)++Lvi(1,3)-Lvi(1,1)-Lvi(1,2));
```

```
        end
        vutn(svn+iin,1)=sum(vutn(svn+iin,1:3))/3;
        vbkn=vbkn*0;
     end
     Arp(svn+1:svn+Ni,1)=vutn(svn+1:svn+Ni,1);
     for ain=1:Ni
         bi=1;
         for ci=2:Ni
             if Arp(svn+ci,1)>Arp(svn+bi,1)
                 bi=ci;
             end
         end
             Arp(svn+bi,1)=-100;
             arrWx(svn+ain,1)=bi;    % % arrWx= (sum(SXN),1);
    end
    Vux(1,svn+1:svn+Ni)=vutn(svn+arrWx(svn+1:svn+Ni,1),1)';
    svn=svn+Ni;
end
gWN=zeros(sum(SXN),1);
gww=zeros(sum(SXN),1);
svn=0;
SxgN=zeros(1,8);
```

```
for rsi=1:8
    Ni=SXN(1,rsi);
    gWN(svn+1,1)=wtn(svn+arrWx(svn+1,1),1);
    for sni=2:Ni
        gWN(svn+sni,1)=gWN(svn+sni-1,1)+wtn(svn+arrWx(svn+sni,1),1)+
gWN(svn+sni-1,1)*wtn(svn+arrWx(svn+sni,1),1)*xSn(1,rsi);
    end
   gww(svn+2:svn+Ni,1)=gWN(svn+1:svn+Ni-1,1);
SxgN(1,rsi)=Vux(1,svn+1:svn+Ni)*(gWN(svn+1:svn+Ni,1)-gww(svn+1:svn+Ni,1));
% wanted result !
   svn=svn+Ni;
end
  SxgN     % Show
```

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