A KNOWLEDGE BASE SYSTEM FOR OVERALL SUPPLY CHAIN PERFORMANCE EVALUATION: A MULTI-CRITERIA DECISION-MAKING APPROACH

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SYSTÈME DE BASE DE CONNAISSANCE POUR L'ÉVALUATION GLOBALE DE LA PERFORMANCE DE LA CHAÎNE D'ALIMENTATION: UNE APPROCHE DE DÉCISION MULTI-CRITÈRES

Sharfuddin Ahmed KHAN

RESUME

En raison de l'avancement de la technologie qui permet aux organisations de collecter, stocker, organiser les données et utiliser un système d'information pour une prise de décision efficace, un nouvel horizon d'évaluation de la performance de la chaîne d'approvisionnement commence. Aujourd'hui, la prise de décision passe de «axée sur l'information» en «axée sur les données» pour plus de précision dans l'évaluation globale de la performance de la chaîne d'approvisionnement. Sur la base d'informations en temps réel, des décisions rapides sont importantes afin de fournir des produits plus rapidement. L'évaluation de la performance est essentielle au succès de la chaîne d'approvisionnement (CA). Dans la gestion de CA, de nombreuses décisions doivent être prises à chaque niveau de prise de décision (à court terme ou à long terme) en raison de nombreuses décisions et critères de décision (attributs) qui ont un impact sur la performance globale de la chaîne d'approvisionnement. Par conséquent, il est essentiel pour les décideurs de connaître la relation entre les décisions et les critères de décision sur la performance globale de la CA. Cependant, les modèles existants d'évaluation de la performance de la chaîne d'approvisionnement ne sont pas adéquats pour établir un lien entre les décisions et les critères de décision et la performance globale. La plupart des décisions et des attributs de décision dans la CA sont de nature contradictoire et la mesure de performance de différents critères (attributs) au niveau de décision (à long terme et à court terme) est différente et la rend plus complexe pour l'évaluation de performance de la CA.

La performance de la CA dépend fortement de la façon dont on conçoit. En d'autres termes, il est assez difficile d'améliorer la performance globale de la CA si les critères de décision (attributs) ne sont pas intégrés ou considérés à la phase de conception. La connexion entre la conception de la chaîne d'approvisionnement et la gestion de la chaîne d'approvisionnement est essentielle pour une chaîne d'approvisionnement efficace. De nombreuses entreprises telles que Wal-Mart, Dell Computers, etc. sont des entreprises prospères et elles réussissent en raison de leur conception efficace de la chaîne d'approvisionnement et de la gestion des activités de la chaîne d'approvisionnement. Cette thèse apporte des contributions au niveau de deux volets. Premièrement, un système de base de connaissances intégré basé sur Fuzzy-AHP qui établisse une relation entre les décisions et les critères de décision (attributs) et évalue la performance globale de la CA est développé. Le système de base de connaissances proposé aide les organisations et les décideurs à évaluer leur performance globale et contribue à identifier la fonction de la chaîne d'approvisionnement sous-performée ainsi que les critères associés. À la fin, le système proposé a été mis en place dans un cas d'étude tout en développant un tableau de bord pour le suivi de performance de la CA pour les principaux responsables et gestionnaires. Deuxièmement, un modèle de décision pour la planification à long terme

de la CA et connecté au système proposé est proposé pour aider dans l'amélioration de la performance globale de la CA.

Mots-clés: Gestion de la chaîne d'approvisionnement, système de base de connaissances, évaluation du rendement, performance de la chaîne d'approvisionnement intégrée, Fuzzy-AHP, prise de décision.

A KNOWLEDGE BASE SYSTEM FOR OVERALL SC PERFORMANCE EVALUATION: A MULTI-CRITERIA DECISION-MAKING APPROACH

Sharfuddin Ahmed KHAN

ABSTRACT

Due to the advancement of technology that allows organizations to collect, store, organize and use data information system for efficient decision making (DM), a new horizon of supply chain performance evaluation starts. Today, DM is shifting from "information-driven" to "data-driven" for more precision in overall supply chain performance evaluation. Based on the real-time information, fast decisions are important in order to deliver product more rapidly. Performance evaluation is critical to the success of the supply chain (SC). In managing SC, there are many decisions to be taken at each level of multi-criteria decision making (MCDM) (short-term or long-term) because of many decisions and decision criteria (attributes) that have an impact on overall supply chain performance. Therefore it is essential for decision makers to know the relationship between decisions and decision criteria on overall SC performance. However, existing supply chain performance models (SCPM) are not adequate in establishing a link between decisions and decisions criteria on overall SC performance. Most of the decisions and decision attributes in SC are conflicting in nature and performance measure of different criteria (attributes) at different levels of decisions (long-term and short-term) is different and makes it more intricate for SC performance evaluation.

SC performance heavily depends on how well you design your SC. In other words, it is quite difficult to improve overall SC performance if decisions criteria (attributes) are not embedded or considered at the phase of SC design. The connection between the SC design and supply chain management (SCM) is essential for effective SC. Many companies such as Wal-Mart, Dell, etc. are successful companies and they achieve their success because of their effective SC design and management of SC activities. The purpose of this thesis is in two folds: First is to develop an integrated knowledge base system (KBS) based on Fuzzy-AHP that establish a relationship between decisions and decisions criteria (attributes) and evaluate overall SC performance. The proposed KBS assists organizations and decision-makers in evaluating their overall SC performance and helps in identifying under-performed SC function and its associated criteria. In the end, the proposed system has been implemented in a case company, and we developed a SC performance monitoring dashboard of a case company for top managers and operational managers. Second to develop decisions models that will help us in calibrating decisions and improving overall SC performance.

Keywords: Supply chain management, knowledge base system, performance evaluation, integrated supply chain performance, Fuzzy-AHP, decision-making.

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LIST OF ABBREVIATIONS

AHP	Analytical Hierarchal Process
DM	Decision-Making
FGP	Fuzzy Goal Programming
FMOLP	Fuzzy Multi-Objective Linear Programming
FMILP	Fuzzy Mixed Integer Linear Programming
FMP	Fuzzy Mathematical Programming
KBS	Knowledge Base System
MADM	Multi-Attribute Decision-Making
MCDM	Multi-Criteria Decision-Making
SC	Supply Chain
SCD	Supply Chain Design
SCM	Supply Chain Management
SCPM	Supply Chain Performance Models
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution

INTRODUCTION

Due to globalization and digitalization, SCM is playing a central role in the fulfillment of customer demand. SC integrates all activities from suppliers to customers. Based on the real-time information, fast decisions are essential to deliver product more rapidly. Thus, performance evaluation is critical to the success of the SC. Performance measures are important to evaluate the impact of different decisions and the effectiveness of the SC. The objective of SC is to deliver the right product to the right customer at the right time in good quality while minimizing the overall system cost. Charkha and Jaju (2014) defined SC as follows:

"A SC can be described as a chain that links various entities, from the customer to the supplier, through manufacturing and services so that the flow of materials, money, and information can be effectively managed to meet the requirements."

A typical SC can be represented as in figure 0.1:

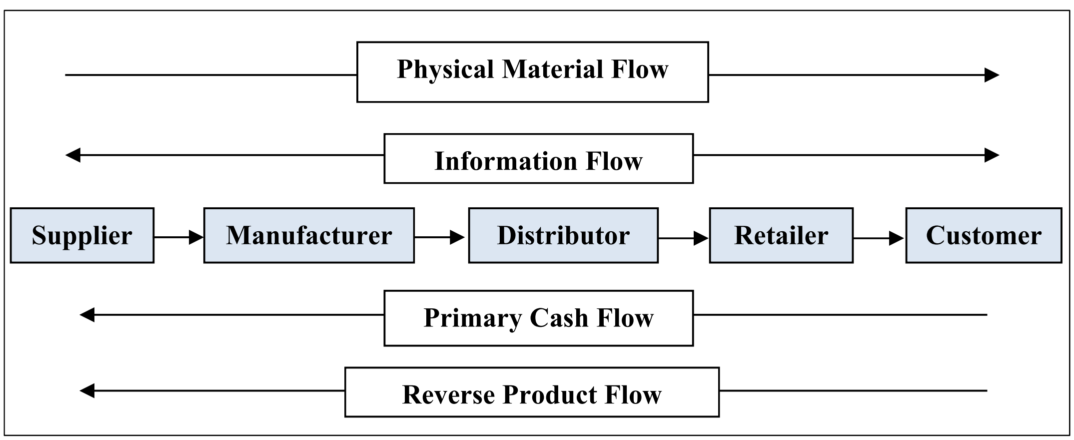

Figure 0.1 Typical SC

In order to improve a system, we need to measure its current performance. The performance measure is a process or set of metrics used to quantify the efficiency or effectiveness of decisions and actions. This will also help in identifying which decisions have an impact on performance and which criteria is linked to that particular decision. For example, if logistics performance is not up to the mark, this might lead to inadequate overall SC performance and needs improvement. So, the decision is clear; we have to improve logistics performance. However, we also need to know which decisions criteria require improvement. For example, flexibility in delivery or production schedule (long-term criteria) or on-time delivery (short-term criteria) improvements will enhance logistic performance and thus improve the overall SC performance. This shows that identifying under-performed functions alone is not sufficient enough, and we need to identify the relation between decision criteria along with decisions that will help in improving overall performance.

Many factors have an impact on overall SC performance. In managing SC, there are many decisions that have to be taken at each level of DM (short-term or long-term). However, it is quite difficult to see the effect of decisions on overall SC performance. For example, if a SC manager wants to increase 10% productivity of any product, is it good or bad? The answer depends on how much service level and cost has improved. This information is without value and we cannot see the impact of the decision that we take at short-term or long-term MCDM level on overall SC performance (McNann & Nanni, 1994). Fragmented SC in which decision makers and managers considered the particular function of SC and focused on that function separately is not able to answer these questions. Existing performance measurement systems with limited integration and little information sharing cannot answer precisely how the SC is performing. How to improve our SC performance? Why is the performance not good?

Organizations cannot prevent what will happen in future, but they can plan ahead in order to minimize the negative impact on overall SC performance. There must be a link between the different level of planning and decisions makers should be able to evaluate what decisions at which level will improve overall SC performance.

Usually, a SC performance model (SCPM) is based on information and data collection provided to top management. Data is analyzed, and different decisions are made for SC improvement. At this level, it is important to identify the link between performance indicators and MCDM level. Sillanpää (2015) mentioned that decision-makers need to know how efficient and effective their SC is. Criteria are also important to define at the design phase in order to predict SC performance before implementation. Moreover, SCPM helps management in monitoring, improving and helps organizations in gaining a competitive edge. According to Taghipour et al.(2015), evaluation of several performance measure frameworks already recommends that SCPM can be perceived under different categories such as "strategic and operational level; cost and non-cost; customer, financial and business process perspective; financial, internal operation, learning, and growth perspective." As stated by Ambe (2014), measuring SC performance can facilitate a greater understanding of the SC, positively influence actors' behaviors, and improve its overall performance. So the process of supply chain performance evaluation should be linked to SC functions (activities), decisions maker's preferences, and lead to the overall SC performance evaluation.

Wong & Wong (2008) pointed out that literature on performance evaluation had not seen SC as a separate entity, therefore making it difficult to evaluate performance with several inputs and outputs to the system. Lambert & Pohlen (2001) affirmed that SC metrics are in reality about internal logistics performance measures that have an inner focus and do not show how the firms make value or profitability in the SC. It has been suggested that SC performance indicators should be measured in the form of input-output ratios, despite their qualitative or quantitative characteristic (Asadi, 2012). Evaluating overall SC performance is a challenging task because of the following reasons:

- Availability of data from SC execution due to the digital transformation to take the right decisions is a challenge, and we need to establish the relation with data, performance metrics (criteria), and decisions (short-term and long-term).

- Whole SC is dynamic, and many criteria in entire SC are dependent on each other, such as delivery time from supplier and order fill rate. This makes SC performance evaluation a complex task.

- In entire SC cycle, we have a combination of linguistic (green supplier, goodwill of suppliers) and non-linguistic criteria (cost, defects, delivery lead time). It is difficult to quantify linguistic criteria of SC performance evaluation.

- There is a difficulty in balancing among financial and non-financial performance measures.

- It is quite difficult to integrate entire SC performance evaluation criteria to measure overall SC performance.

0.1 Problem statement and research questions

0.1.1 Context of the problem

Technology advancement that allows organizations to collect, store, organize and use data for efficient MCDM initiate a new horizon and dimensions of SCPM. Today, MCDM is shifting from “information-driven” to “data-driven.” In managing supply chain (SC), there are many decisions that have to be taken at each level (short-term or long-term) because of many factors that have an impact on overall supply chain performance.

Consider the case of Amazon: “After sellers send products to Amazon’s fulfillment centres, Amazon’s business partners upload listings into Amazon’s online system. The online system provides PDF labels (shipping labels) and shipping statuses, receives, and scans inventory, and records item storage dimensions. It also locates the products using methods such as advanced web-to-warehouse, high-speed picking and sorting and fulfills orders placed directly or by sellers. In this case, both partners and customers can track their inventory and shipments. Technology has helped Amazon to achieve a high performance and profitability standards” (www.amazon.com). This particular example shows that integration, visibility, information sharing, decisions (short-term and long-term), and underperformed decisions criteria identification are so important in measuring and improving overall SC performance.

Rapid advancement in technology, high internet penetration, and information availability affected customer buying behaviors and demand patterns significantly. This advancement in technologies is affecting all parts of our way of doing business including ways of managing SC. But will this technology adoption by customers have any major impact on traditional SC? Will existing SC performance models help organizations to improve their SC performance effectively and efficiently? Will application of emerging technologies help organizations to fulfill the need of customers efficiently?

Therefore it is essential for organizations to utilize the advancement in technology and develop a performance system based on the knowledge base that evaluates overall supply chain performance and integrates major functions of SC.

0.1.2 Problem Statement

Existing SC performance evaluation systems are not integrated with the DM process. Moreover, the criteria (attributes) used in the evaluation are not directly linked to decisions. Finally, the overall SC performance is not sensitive to the industrial context or to DM preferences. Moreover, they are not adequate to identify underperformed criteria at a particular MCDM level (long-term and short-term) and integrate all functions of SC and their associated decision criteria. These issues lead to further sub-problems which are as follows.

- Dealing with all key players of SC network is a complex task, and many authors considered SC as a MCDM problem. Existing literature does not provide a systematic approach to select most widely used MCDM methods at each level of MCDM (strategic, tactical and operational) of entire SC network.

- Due to advancement in technology storing and collections of data is not a problem. Decision makers should utilize collected data efficiently in the DM process. Existing SC performance evaluation systems are not taking the wholly benefiting from those collected data to provide a link between decisions and decision criteria (attributes) in evaluating overall SC performance.

- Decisions makers' knowledge and experience in making any decisions are essential for effective MCDM. Therefore in group MCDM process, it is necessary to utilize this knowledge and experience and develop a KBS. However, existing SC performance evaluation systems are not using this knowledge base in evaluating overall SC performance.

- Decision makers' need to calibrate their decisions based on experience and current performance. Existing decision models are not considering knowledge and expertise of decision makers and current performance as a basis to calibrate their decisions and improve overall SC performance.

0.2 Research Questions

SCM is considered as MCDM problem because in managing SC, managers have to take many decisions. Often SC decisions are conflicting in nature. SC managers are keen to know the entire SC performance, the relationship between long-term and short-term decision criteria (attributes) and SC functions, and to identify areas which require extra attention. Moreover, they need to find out how to calibrate decisions to improve overall SC performance to meet customer demands on time. Linking the SCPM system for a SC with the MCDM process is a real challenge and need to answer the following questions that are common to most of the organizations:

RQ 1: *Which MCDM method will facilitate in developing integrated SC performance evaluation system??*

RQ 2: *How to evaluate overall SC Performance?*

RQ 3: *Which decision criteria at which level requires improvement?*

RQ 4: *How to develop decision models to calibrate decisions and improve overall SC performance?*

In this thesis, we will conduct a systematic literature review in the application of MCDM in SC. This will identify which MCDM method will facilitate in developing integrated SC performance evaluation system. This will answer research question 1. We will propose KBS that integrates different SC functions and evaluates overall SC performance. Proposed KBS will identify under-performed criteria of a considered SC function and provide direction of improvement. This will help in answering research question 2 and research question 3. At last, we will develop decision models that will help in incorporating decisions at the design phase of SC and help decision makers to find the expected (optimum) SC performance and improve overall SC performance. This will help in answering research question 4.

0.2.1 Significance and Objectives of the Thesis

Every system needs evaluation after a certain period of implementation, and such evaluations are essential for corrective measures and continuous improvements. Once we implement the system (quality management systems, SCM systems, inventory management system, etc.), managers are eager to evaluate the performance of the systems they implemented. Most of the evaluation systems mostly depend on subjective opinions which are usually tendentious. A similar type of situation is faced by SC managers due to lack of performance measurement framework to evaluate overall SC performance.

This research is more important from an industrial perspective as compared to academic. Moreover, the developed framework will be equally useful in all sectors (manufacturing or service) and could be efficiently utilized to measure or improve overall SC performance. Most of the companies will use the developed framework to benchmark with their competitors' or for monitoring their performance over a period of time.

Despite the increasing attention to the supply chain performance evaluation over the last decade from both academic and practitioners, there has been little research to date in this area, and not many authors have proposed or developed any framework or model that measures the entire SCM performance of given organization. SC performance is vital for companys' overall performance and the key to fulfill customer demands in a cost-effective manner. Due to globalization and ever-increasing competition, it is mandatory for organizations to measure and standardize their SCM systems. This task is difficult due to the lack of performance measurement framework that includes the relevant criteria for any business nature such as manufacturing or service.

Literature review shows lacking in a similar kind of framework that evaluates overall supply chain performance of an organization. This research has a significant impact in SCM field in general and performance evaluation field in specific as to date many authors proposed or developed model to evaluate supply chain performance that is specific but none of the previously developed models or proposed frameworks considered the entire network of SC and different level of MCDM. Moreover, this research will help SC managers to identify the problem area specifically, and they will be able to pay more attention to mitigate such problem. The developed framework will be applicable in most of the sectors (after minor modifications) and can be used for benchmarking and continuous improvement. Our proposed KBS will help in developing SC performance monitoring dashboard. This dashboard will provide managers and decision makers with a snapshot of their overall SC performance and show the functions' long-term and short-term decisions criteria performance. This will also help them in monitoring their performance over a selected period.

0.2.2 Thesis Objectives

The overall objective of this thesis is to address the challenging problem in evaluating overall SC performance due to the complexity and uncertainty persistent in a SC network and develop a KBS to evaluate overall SC performance.

The specific objectives that this thesis will achieve are:

- *Identifying most appropriate MCDM methods that facilitate the development of integrated SCP evaluation system through literature.*
  To achieve this objective, this thesis conducted a systematic literature review in the application of MCDM methods in SCM .

- *Review existing supply chain performance measurment systems (SCPMS) in order to categorize and highlight their focus area.*
  To address this objective, we will review all existing SCPMS, categorized them into different dimensions (MCDM levels, functions/perspective considered, financial / non-financial). This will help us in identifying the attributes that are important in the decision-making process. It is a mapping between what MCDM propose and what SCPM considers. This allows the establishment of a link between DM and SC performance evaluation.

- *Develop KBS that integrates SC functions, establish a relationship between SC decision criteria, and evaluate overall SC performance.*
  To address this objective, this thesis will develop an integrated KBS based on Fuzzy-AHP that establishes a relationship between decisions and decisions criteria (attributes) and evaluate overall SC performance.

- *Develop decision model to calibrate decisions and improve overall SC performance.*
  To achieve this objective, this thesis will develop decision model of considered SC functions and decisions criteria (attributes). Developed model will provide expected (optimum) value for the considered long-term decision criteria (attribute) and help decision makers to compare and improve overall SC performance with the expected (optimum) SC performance.

0.2.3 Challenges and Contribution

The main challenge in this thesis is how to utilize decision makers' knowledge and experience in group MCDM and integrate SC functions to evaluate overall SC performance. Once we assess the overall SC performance, it is essential for decision-makers to know what the expected (optimum) SC performance is and how far their SC performance is. Another challenge is in identifying long-term and short-term decision criteria (attribute) of each considered SC function. In literature, there is no clear guideline available that helps in finding long-term and short-term decision criteria (attribute) for each function of the SC.

Our contribution in SCM literature in general and in MCDM and SC performance evaluation literature, in particular, is as follows:

- This thesis provides guidelines to SC managers and decision makers in selecting appropriate MCDM methods in considered SC functions through systematic literature review paper.

- This thesis reviewed existing SCPM frameworks, highlights their limitations, and categorizes them in terms of MCDM level, functions/perspective considered, financial and non-financial performance measure and the relationship between SC functions and decision criteria.

- This thesis identified long-term and short-term decision criteria (attributes) of considered SC function from literature.

- This thesis identified the need for integrated KBS to measure overall SC performance considering the limitations of existing performance measures and digitalization.

- The thesis integrates and establishes a relationship between decisions and decision criteria (attributes) as mentioned in figure 0.3 and proposed a KBS to evaluate overall SC performance. Moreover, the proposed KBS will help in developing SC performance monitoring dashboard for a period of time.

- This thesis developed a decision model that helps managers and decision makers to calculate expected (optimum) overall SC performance and allow them to compare their overall SC performance with the expected (optimum) SC performance.

0.2.4 Organization of the Thesis

In order to address objectives sets in section 0.2.2 and answer research questions sets in section 0.2, this thesis is structured in four major parts which are i) Introductory part, ii) Theoretical part, iii) KBS development part and iv) Conclusion part. All these parts are distributed in total six (6) chapters. Description of these parts is defined as follows:

Introductory Part will provide an overview and introduction of SCM, the background of the problem statement, set objectives and develop research questions. This is considered chapter (0) in the thesis.

Theoretical Part presents the current state of theoretical knowledge by reviewing the literature relevant to research objectives set out in section 0.2.2. This part will conduct an extensive literature review in the field of MCDM methods application, existing supply chain performance evaluation systems, literature review to identify long-term and short-term decisions and decision criteria, and on models to design/redesign SC. This part will answer RQ1 and consists of two chapters (chapter 1 and chapter 2) in this thesis.

Knowledge Base System (KBS) Development Part consists of three chapters (chapter 3, 4, and 5). In chapter 3, we develop KBS to evaluate overall SC performance and establish the relationship between decisions and decision criteria (attributes). Chapter 4 shows a numerical example to validate and implement proposed KBS in a case company. Chapter 5 develop a decision model to calibrate decisions by considering underperformed long-term decision criteria. This part will answer RQ2, RQ3, and RQ4.

Conclusion Part will draw a summary of this thesis and discusses future research directions.

The overview of this thesis is also shown in figure 0.2.

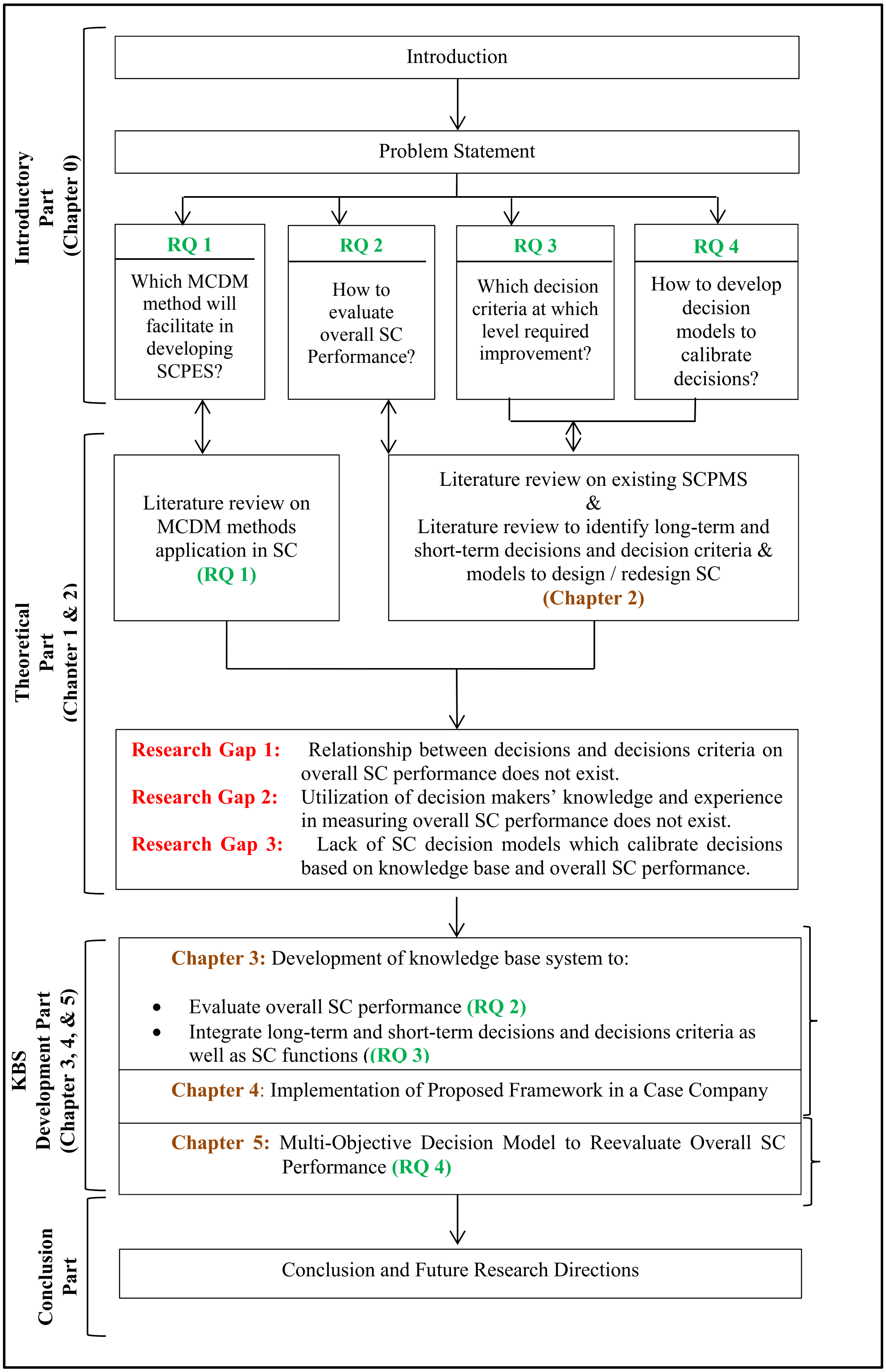

Figure 0.2 Overview of Thesis

Figure 0.2 shows the structure of the thesis, and from next chapter onwards, we will follow the same structure and chapter numbers (from 1 to 5) and conclusion.

CHAPTER 1

THEORETICAL BACKGROUND

This theoretical part of the thesis aims to establish an academic foundation for studying supply chain performance and their impact on organization performance. This section will review literature that is relevant to our work and will be helpful to the reader to bear in mind throughout the thesis. Since our thesis work combines supply chain performance measurement and MCDM methods, it is meaningful to review the literature of both areas. In addition to that, we need to identify long-term and short-term decision criteria of considered SC functions and models to design SC. So, to answer research questions and find the solution to the problem that was mentioned in the previous chapter, our literature review is divided into two (2) chapters. Chapter one (1) will provide a systematic literature review of the application of MCDM methods application in a considered SC functions. Chapters (2) will overview most of existing SCPMS and identify criteria and sub-criteria (attributes) for long-term and short-term decisions. At the end of this chapter, we will summarize learning from literature, research gaps based on this literature review and draw a conclusion. Figure 1.1 shows a schematic view of literature.

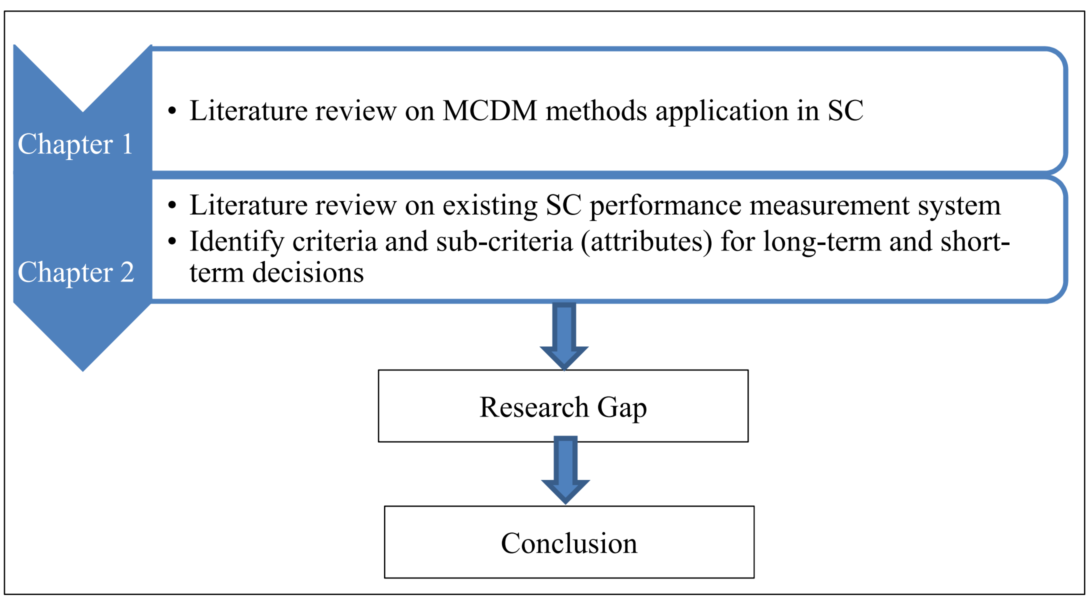

Figure 1.1 Schematic View

1.1 Literature review on MCDM methods application in SC

Over the last decade, a large number of research papers, certified courses, professional development programs and scientific conferences have addressed SCM, thereby attesting to its significance and importance. SCM is a multi-criteria decision making (MCDM) problem because, throughout its process, different criteria related to each SC activity and their associated sub-criteria must be considered. Often, these criteria are conflicting in nature. For their part, MCDM methods have also attracted significant attention among researchers and practitioners in the field of SCM. The aim of this chapter is to conduct a systematic literature review of published journal articles in the application of MCDM methods in SCM decisions at the strategic, tactical and operational levels. This review considers major SC activities, such as supplier selection, manufacturing, warehousing, logistics, and integrated SC. A total of 111 published articles (from 2005 to 2015) were studied and categorized, and gaps in the literature were identified. This review is useful for academic researchers, decision makers, and experts to whom it will provide a better understanding of the application of MCDM methods in SCM, at various levels of the decision-making process, and establish guidelines for selecting an appropriate MCDM method for managing SC activities at different levels of decision-making and under uncertainty.

1.1.1 Introduction

SCM is crucial in today's competitive environment and is steadily gaining serious research attention. Companies are facing challenges in discovering ways to fulfill ever-rising customer expectations and remain competitive in the market while keeping costs manageable. To that end, they must carry out investigations to isolate inefficiencies in their SC processes.

From a practitioner perspective, an Accenture report (Accenture, 2010), realized in collaboration with Stanford and INSEAD, and covering a survey of executives, indicated that 89% of them found SCM to be critically important or very important. Moreover, SCM is gaining steadily in importance, with 51% of the executives stating that their investments in the area had increased significantly over the past three years. Over the last two decades, SCM has received a substantial amount of attention from academics and practitioners (Tyagi et al., 2015). To cope with new elements of the business environment, SC managers must develop new perspectives with respect to the management of SC functions (Ralston, Blackhurst, Cantor, & Crum, 2015).

1.1.2 SCM: definitions and evolution

The SC structure and SCM have attracted a great deal of attention from many researchers over the last few years, and impact corporate efficiency. According to James (2011), a literature review plays an important role in SC theory and practice research. The literature indicates that the term *SCM* was initially coined in the late 1980s, and gained currency in the 1990s. Previous to that, organizations used terms such as *logistics* and *operations management* to convey the phenomenon. An alternative more general approach includes the raw materials producer and closes the chain with feedback from customers. (Min & Mentzer, 2004) considered information systems management, make-or-buy decisions, inventory management, order processing, production scheduling, warehousing, and customer service level in their definition. Bechtel & Jayaram (1997) mentioned that the concept of SC includes the flow of information and materials, which starts with suppliers and ends with customers. Based on the preceding, it is clear that supplies chains are complex, and as a result, managing them effectively therefore necessarily requires having a full handle on that complexity.

Another approach defines SCM in terms of different DM levels, namely, strategic, tactical and operational, and indicates that this DM of all scales optimizes SC performance. On the other hand, traditional SC can be defined as a network which consists of suppliers, manufacturing facilities, distribution centers from which we procure raw materials, converted into finished good and deliver it to end user (Fox et al., 2000). Certain differences exist between SCM and traditional logistics. Traditional logistics consists of actions that usually occur inside single organization boundaries, while SCM essentially defines a network of different companies working in coordination, with their main goal being to deliver finished products to customers. In addition, traditional logistics emphasizes SC functions, including purchasing, distribution and inventory management.

SCM includes all the components of traditional logistics, but also tags on actions such as new product development, finance, marketing, and customer service (Glykas, 2011).

In the early 1970s, the major concerns for decision makers and managers were increasing the work in process inventory, challenges associated with new product development, maintaining a high quality of products, and pressure to meet delivery deadlines. Several authors have highlighted many factors as being at the root of these concerns, but the literature shows that the main reason was the introduction of Manufacturing Resource Planning (MRP II). According to Daugherty (2011), in the 1980s, organizations dealt with increased demand for "better, faster, cheaper logistical service." As a result, many manufacturers outsourced their logistics activities in order to be able to focus more on their core business and activities. This increased the level of uncertainty as compared to what obtained in the previous years. SCM got a boost after the introduction of Enterprise Resource Planning (ERP) in the 1990s, due mainly to the buyer-supplier relationship. However, the literature contains many entries (e.g., https://www.ukessays.com/contact/press.php) indicating that the Information Technology (IT) planning systems that had previously been used had only focused on internal organizations, while ERP systems focused mainly on intra-organizational integration. Due to advances in IT, the development of more refined systems (Internet-based solution systems) ideal for inter-organizational and intra-organizational integration minimized communication gaps and improved visibility. Today, the relationship between buyers and suppliers has moved one step ahead, and the focus of organizations has now evolved from regular partnerships to long-term relationships and strategic alliances: they now share both technology and risk in product development, which minimizes fluctuations in demand and promotes the partnership.

The latest trend in SC evolution is globalization with highly connected international SC networks. These phenomena lead to the creation of Global SCs subject to different disruptions events. Disruptions are defined as unplanned events that hamper the SC system (Yang et al., 2017). Today, the supplier-buyer and supplier-distributor relations are not limited by national boundaries, and the global SCM concept has now been introduced into the SC literature. Being competitive in the market now requires an integrated SC. In many developed economies, competition has switched from "firm to firm" to "chain to chain" (Koh, Demirbag, Bayraktar, Tatoglu, & Zaim, 2007), and that, in a nutshell, attests to how the SCM has evolved over the past decades.

UK Essays (2013) (https://www.ukessays.com/contact/press.php) segmented SCM evolution into three stages, namely, (a) the Creation era, which is during the 1980s, (b) the Integration era, which began in the 1990s and continued into the 21st century, and last, (c) the Globalization era, which is where we are today. Table 1.2 summarizes the evolution of SCM.

Table 1.1 Evolutionary Stages of SCM

S. No.	Time Frame	Evolution Name	Description
1	Early 1960s	Physical Distribution Management	During this SC period, manufacturers only focused on the manufacturing process, and consequently, faced high inventory cost, transportation cost, etc.
2	Late 1970s	Logistics and Total Logistics	This period of SCM was characterized by cost reduction and Japanese manufacturing techniques.
3	1990s	Logistics and Business Process Re-engineering	During this period of SCM, industries began to focus on "Core Competencies, " and they extended their SC operations beyond their companies' walls. SC partnerships and the outsourcing concept were surfacing.
4	Last 20 Years	SCM Integration and its Optimization	Integration of new techniques such as ZI (Zero Inventory), JIT (Just-in-time), ECR (Efficient Customer Response), TQM (Total Quality Management), CD (Cross docking), and VMI (Vendor Managed Inventory) into the SC process.

It is essential for organizations to integrate different SC functions (supplier selection, manufacturing, warehousing, logistics, etc.) in order to minimize inherent "waste" and non-value added activities such as data entry repeating and duplication of activities in different SC functions. In the digital SC model, Web 2.0 technologies help organizations trace every transaction. Tagging technologies such as Radio Frequency Identification (RFID) and barcode provide real-time data feed for physical movement at any stage of operation. As compared to reporting techniques, which are often used today, it is important to combine operational data (financial and non-financial) that help decision makers improve the overall SC performance. Integrated SC performance models should support flexibility in SC decisions (short-term or long-term) since information, and the relationship between SC functions are no longer independent (interconnected logistics). This integration allows decision makers to take a closer look at the performance of SC functions and to increase the visibility of the impact of their decisions on overall SC performance.

1.1.3 MCDM in SCM

An organization's strategic, tactical and operational decision-making plays a vital role in ensuring that its SC is operating efficiently, allowing it to achieve the highest levels of customer satisfaction at an optimum cost. Decision-making at each level should focus on gaining a competitive edge and increasing market share. At each level, the nature of decision-making as well as and the related activities are different, as explained below.

Strategic SC decisions are taken by the company's upper management and apply to the whole organization. SC decisions at this level should reflect the overall corporate strategy set by upper management, and form the long-term foundation for the organization's whole SC. In order to develop an efficient process, strategic-level decision-making respecting the SC is the first step in the right direction. At this level, decisions relating to the following are usually addressed (www.procurementbulletin.com).

At the tactical level, organizations make short-term decisions related to the SC. Generally, standard planning begins at the strategic level, but actual processes are defined at the tactical level. Decisions made at the tactical level are vital for controlling costs and minimizing overall risk. The main focus at this decision-making level is on fulfilling customer demand in a cost-effective manner.

The most obvious decisions related to day-to-day processes and planning are taken at the operational level. Effective and efficient operational level processes are usually the result of strong strategic and tactical planning. With an increase in the volume of data (Big Data) from multiple sources within the SC, real-time DM is becoming more important in

SCM. In real-time decision-making, deciders must act immediately for events that require on-the-spot decisions for solutions.

In summary, Table 1.2 shows the levels of decision-making, as well as a description of decisions (defined by (David Simchi-Levi, Kaminsky, & Simchi-Levi, 2008)), and indicates the timeline and the type of decisions made.

Table 1.2 Level of DM and Timeline (David Simchi-Levi et al., 2008)

Level of DM	**Description of Decisions**	**Timeline**	**Type of Decision Made**
Strategic	The strategic level includes decisions that have a long-lasting effect on the firm	Long-term effect on the organization's performance Usually 3 to 10 years	This includes decisions related to warehouse location, capacity of warehouse and distribution centers, manufacturing decisions such as automated or manual, SC network design
Tactical	The tactical level includes decisions for the coming year	Medium effect on the organization's performance Usually 3 months to 2 years	This includes decisions related to production, inventory level, absorption of uncertainty in production plan, and transportation
Operational	The operational level includes decisions which are usually day-to-day, such as loading/unloading, daily production plan, etc.	Usually day-to-day	These include decisions related to satisfying daily and weekly forecasting, settling damages or losses with suppliers, vendors, and clients, and monitoring logistics activities for contract and order fulfillment
Real-Time	The real-time DM level comprises decisions made instantly according to the current situation	On the spot	These include decisions that are required on an as-needed basis and in the event of any unplanned activity which occurs, such as a sudden increase in customer demand, delivered products not meeting quality standards, etc.

1.1.4 SCM and MCDM

Decision makers need to make decisions every day, and these decisions are either simple or complex and involve multiple criteria. Usually, decisions depend mainly on several factors and conflicting criteria. MCDM, in a broader sense, is a method or approach for solving problems which involve many factors, criteria, or objectives. MCDM can be classified, based on different problem settings, into two types, namely, Multi-Objective Decision-making (MODM) and Multi-Attribute decision-making (MADM). In MODM, we usually have problems with a very large (infinite) number of feasible alternatives. First, we set objectives, and then we go on to design alternatives, which are not predetermined. In MADM, we have problems that have a relatively small (finite) number of alternatives, and here, alternatives are predetermined and considered in terms of attributes. The best alternative is commonly selected based on comparisons between the alternatives, with respect to each attribute.

MCDM is a technique that combines alternative's performance across numerous, contradicting, qualitative and/or quantitative criteria, and results in a solution requiring a consensus (Kolios, Mytilinou, Lozano-Minguez, & Salonitis, 2016; Dadda & Ouhbi, 2014). Knowledge garnered from many fields, including behavioral decision theory, computer technology, economics, information systems and mathematics is used. Since the 1960s, many MCDM techniques and approaches have been developed, proposed, and implemented successfully in many application areas (Mardani et al., 2015). The objective of MCDM is not to suggest the best decision, but to aid decision makers in selecting short-listed alternatives or a single alternative that fulfills their requirements and is in line with their preferences (Brito, Silva, Pereira, & Medina, 2010). Belton & Stewart (2002), Seydel (2006) and Dooley, Smeaton, Sheath, & Ledgard (2009) mentioned that at early stages, knowledge of MCDM methods and an appropriate understanding of the perspectives of DM themselves (players who are involved in decision process) are essential for efficient and effective DM.

There are several MCDM methods available, such as the Analytical Hierarchal Process (AHP), the Analytical Network Process (ANP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Data Envelopment Analysis (DEA), and Fuzzy decision-making. MCDM has been one of the fastest growing problem areas in many disciplines (Triantaphyllou, 2013). Over the past decade, many researchers have applied these methods in the field of industrial engineering, particularly in SCM, in making decisions. All the methods are equally capable of making decisions under uncertainty, and each one has its own advantages. One of the most prevalent and popular MCDM methods, which is used extensively in the field of SCM, is the Analytical Hierarchal Process (AHP). Ariff et al. (2008) and Hajeeh & Al-Othman (2005) posit that AHP is an instinctive technique for analyzing and formulating decisions. However, according to Cheng & Li (2001), the AHP method is subjective. AHP contains three main philosophies, namely priority analysis, consistency verification, and hierarchy framework (Ariff et al. (2008), Adhikaril, Kim, & Lee (2006), and Cheng, Chen, Chang, & Chou (2007)). Over many years, different authors successfully applied MCDM methods in the field of business ethics (Perez-Gladish & M'Zali, 2010). Furthermore, sensitivity analysis in AHP is useful when checking the robustness of a decision. Finally, AHP has been proven useful in many industrial and practical applications (Dweiri, Khan, & Jain (2015).

The Analytical Network Process (ANP) is just as useful as AHP. Köne & Büke (2007) used ANP in their study attempting to determine the best fuel mixture for electricity production to ensure sustainable development for Turkey. Similarly, Önüt, Tuzkaya, & Saadet (2008) examined the existing energy sources in the Turkish manufacturing sector by using the ANP multi-criteria evaluation method. As well, Guneri, Cengiz, & Seker (2009) used the ANP approach for shipyard location selection. The TOPSIS method is another technique which is currently one of the most popular methods for Multiple Criteria Decision-Making that establishes order preference by similarity to the ideal solution and was primarily developed for dealing with real value data (Dymova, Sevastjanov, & Tikhonenko, 2013). The method has been successfully used by Abo-Sinna & Amer (2005), Cheng & Lin (2002), Jee & Kang (2000), Liao & Rittscher (2007), Olson (1998), Opricovic & Tzeng (2004), who incorporated it into MCDM in many different fields. Moreover, the classical TOPSIS method has been successfully used in SCM by Chen (2011).

Many authors, such as French (1995) and Zimmermann (2000) have made an effort to categorize kinds or causes of uncertainty into two broad categories, namely, internal uncertainty and external uncertainty (Stewart & Durbach, 2016). Internal uncertainties are associated with the structure of the model implemented and judgmental inputs required by the models, while external uncertainties are due to a lack of knowledge about the outcome of a particular choice (Stewart & Durbach, 2016). All decisions in the application of MCDM methods are subject to different (internal and external) uncertainties. Uncertainty is usually related to many factors such as the complexity of the system, the inherent randomness, the lack of data, and also to the different interpretations of information in some cases (Refsgaard, van der Sluijs, Højberg, & Vanrolleghem, 2007; Ascough, Maier, Ravalico, & Strudley, 2008; Zhang & Achari, 2010). MCDM methods have structured mechanisms to identify the most suitable solution, and these techniques fundamentally try to minimize uncertainties in the decision-making process; moreover, the methods can identify uncertainties associated with decision makers' preferences and knowledge (Mosadeghi, Warnken, Tomlinson, & Mirfenderesk, 2012).

Finally, because of the uncertain and imprecise data available in any MCDM problem, Fuzzy MCDM is adequate for dealing with them. Since its introduction in 1965, Fuzzy sets theory has been innovative in a variety of ways and been protracted to many disciplines. Many authors have applied this theory to areas such as decision theory, expert systems, artificial intelligence, medicine, computer science, control engineering, logic, management science, pattern recognition, robotics, and operations research (Zimmermann, 2010).

SCM is an MCDM problem because, in the entire SC cycle, we must consider different criteria related to each sub-criterion of the SC cycle. In order to manage the entire SC, we have to identify the relationship of each criterion, which in turn impacts the performance of the SC. Based on the indicators identified, we then make decisions. This shows that decision-making is critical in managing the SC cycle and that SCM is an MCDM problem. SCM decisions are made under the conflicting criteria of maximizing profit and customer responsiveness while minimizing SC risk. MCDM in SCM provides a comprehensive overview of multi-criteria optimization models and methods that can be used in SC MCDM (Snyder et al., 2016). The literature shows that MCDM applications in the field of SCM have been growing steadily over the past decade. According to Triantaphyllou (2001), SCM reflects the central problem regarding how to evaluate and judge groups of choices and decisions with respect to some specific criteria, and according to the preference of the decision maker (Stewart & Hanne, 1999; Jones, Mirrazavi, & Tamiz, 2002). Moreover, the involvement of internal and external stakeholders at the strategic, tactical and operational levels, decision-making provides alternatives which are usually conflicting in nature. This situation increases the complexity of decision process.

In the past decade, many researchers have highlighted the importance of MCDM in the context of SCM. A large amount of literature review papers have focused mainly on the applications and methodologies of MCDM, such as supplier selection and partner evaluation, green SC, forest management and planning, supplier selection in agile manufacturing (Mardani et al., 2015; Velasquez & Hester, 2013; Ho, 2008; Govindan, Diabat, & Madan Shankar, 2015; Ananda & Herath, 2009; Chai, Liu, & Ngai, 2013; Wu & Barnes, 2011; Ho, Xu, & Dey, 2010; Agarwal, Sahai, Mishra, Bag, & Singh, 2011; Beck & Hofmann, 2014). Although the DM is closely related to the decision phase and the SC function, it is not clear which method is used for which function, and at which DM level. Moreover, categorization of MCDM methods and its application at the different level of SC decisions (strategic, tactical, and operational) is very limited and not highlighted clearly in the literature. Thus, this chapter attempts to close this gap through a systematic literature review and by answering the following research questions:

a) Which MCDM method will facilitate in developing integrated SCP evaluation system, and why?

b) What is the distribution of MCDM methods applications in terms of different SC decision levels (strategic, tactical, and operational) in the SC functions considered, and why?

c) What is the distribution of MCDM methods applications in terms of uncertainty (internal, external)?

1.1.5 Objectives of this literature review

The objective of this study is to provide a systematic literature review on the application of MCDM methods in the decision process related to the considered SC functions (supplier selection, manufacturing, warehousing, logistics, and integrated SC). The literature will be also categorized in terms of MCDM level (strategic, tactical, and operational) and uncertainty considered (internal, external, and both) during the decision process. First, this work looks at various MCDM methods applied to decision-making in SCM at the strategic, tactical and operational levels, and analyzes the reasons behind their adoption. Second, this work will assist SCM researchers and practitioners engaged in SCM decision-making in selecting an appropriate MCDM approach at different specific levels (strategic, tactical and operational). Finally, this paper provides SC managers with a guideline on the decisions to be taken at the strategic, tactical and operational levels when engaged in SCM.

1.2 Basic terminology and delimitations

Before continuing into the main sections of the chapter, basic terminology and terms need to be defined. Therefore, the different SC functions are defined as follows:

1.2.1 Supplier selection

Supplier selection is the process by which the buyer identifies, evaluates, and contracts with suppliers based on predefined criteria (Beil, 2009). To select potential suppliers, the firm evaluates each supplier's ability to meet reliably and cost-effectively its needs using selection criteria, namely, are mainly financial, managerial, technical, support resource and quality systems and process (Kahraman, Ruan, & Doğan, 2003). To gain a competitive edge over competitors, it is beneficial to include potential suppliers in the product development and design phase.

1.2.2 Manufacturing

A manufacturing system is a subset of the production or enterprise system (Black, 1991). More specifically, manufacturing is the organization of man, machine, material, tools, and information in order to produce physical goods or service products in a cost-effective manner (Chryssolouris, 1992; Wu, 1992).

1.2.3 Warehousing

Warehousing or warehouse management is the combination of decision-making and inbound and outbound flow of materials for internal or external customers (Faber, de Koster, & Smidts, 2013). According to Tompkins & Smith (1998), the primary functions of a warehouse are receiving goods from a source, storing them until they are required, picking them when they are required, and shipping them to the appropriate user.

1.2.4 Logistics

Logistics is defined as the flow of materials from suppliers to manufacturing and from manufacturing to the end customer in order to meet customer requirements in a cost-effective manner (Shahzadi, Amin, & Chaudhary, 2013).

1.2.5 Integrated SC

A SC is an integrated system of suppliers, manufacturers, warehouses, and logistics so that the products are manufactured and delivered to the right customer at the right time in the right quantity while minimizing system-wide cost and meet desired service levels (Simchi-Levi, Kaminsky, & Simchi-Levi, 2003).

1.2.6 Internal uncertainty

Internal uncertainty refers to both the structure of the model which we are developing and experts' judgments in assigning weights to the criteria and sub-criteria (Stewart & Durbach, 2016).

1.2.7 External uncertainty

External uncertainty refers to a lack of knowledge about the consequences of a particular choice. It is the anxiety about the problems which are not under the control of the decision maker. These uncertainties could result from the DM not having complete knowledge about the system, and variability, which is natural in the process and outside the control. Such uncertainties include the probability of machine failure, market share or the stock market (Stewart & Durbach, 2016).

1.2.8 No uncertainty

External uncertainty means that in applying MCDM methods, the decision maker did not include or consider any uncertainty. The criteria and sub-criteria considered in the application of MCDM methods are known without any uncertainty.

1.3 Research methodology

A literature review is a suitable approach for reviewing the literature body of work produced by researchers, scholars and in detail. It is essential for all research types and constitutes an important step in structuring a research field. It also forms an integral part of any research conducted (Seuring, Müller, Westhaus, & Morana, 2005); Mentzer & Kahn, 1995; Easterby-Smith, Thorpe, & Lowe, 2002). Meredith (1993) stated that the literature review helps in identifying the conceptual content of the research area, and will lead to the development of theory. Content analysis is an effective tool for conducting literature reviews in a systematic and transparent fashion. Moreover, it is helpful in conducting quantitative and qualitative literature reviews in a mannered that are both structured and reproducible (Seuring & Gold, 2012; Seuring, Müller, Westhaus, & Morana, 2005). According to Seuring, Müller, Westhaus, & Morana (2005) quantitative and qualitative content analysis are not contradictory, but can appropriately support one another. We, therefore, use both qualitative and quantitative content analysis in our literature review.

In order to systematically carry out our literature review and use content analysis in the process, we adopt a methodology composed of four (4) steps, based on the practical guidelines provided by Seuring & Gold (2012) and Seuring, Müller, Westhaus, & Morana (2005). The process model consists of following steps: i) Material Collection, ii) Descriptive Analysis, iii) Category Selection, and iv) Material Evaluation.

1.3.1 Material collection

The scope of the literature review in this chapter is limited to academic reviewed journals, conference papers, and graduate dissertations because of their academic relevance, accessibility, and ease of search. We did not include unpublished works, non-reviewed papers, working papers and book chapters. The inclusion of such papers is suggested as a future extension of our work. Papers using only MCDM methods and its integration with MODM methods were also included. However, papers focused solely on applied MODM methods were not included because it is beyond the scope and objective of this study. Indeed, many SC decisions are not subject to optimization, as they involve multiple imprecise, uncertain and qualitative criteria (Beck & Hofmann, 2014). In addition, this review considers only papers published during the last ten years (2005 to 2015) due to the fact that applications of MCDM methods are relatively new in SCM, and many researchers have conducted literature reviews by considering different SC functions and their collected papers time span was between 5-12 years (see: Beck & Hofmann, 2014; Ho, 2008; Chai et al., 2013; Ho et al., 2010; Agarwal et al., 2011; Wu & Barnes, 2011). Moreover, the concept of integrated SC and its importance only started being discussed during the last ten years. Therefore, we believe that this period is sufficient to answer the research questions mentioned above.

According to Seuring & Gold (2012), the most common literature search method is the keyword search in database and library services and is recommended, and so in this study, the keyword search technique is used. We searched within titles and abstracts in the Emerald, Elsevier, Taylor & Francis, Springer, and Inderscience databases. Table 1.3 lists the keywords we considered. We used non-method-specific as well as method-specific MCDM keywords, DM keywords, and SCM keywords.

Table 1.3 Search Terms of the Systematic Literature Review

MCDM Methods Search Terms (Non-method-specific)		**MCDM Methods Search Terms (Method-Specific)**		**DM Level**		**SCM Search Terms**
“multicriteria” “multi-criteria” “multi-criteria” “multiattribute” “multi-attribute” “multi-attribute” “multi attributive.” “multi-attributive” “multi attributive.”	OR	“analytic hierarchy process” “AHP” “analytical hierarchy process” “Fuzzy” “TOPSIS” “Data envelop analysis” “DEA” “analytic network process” “ANP” “analytical network process” “PROMETHEE” “Fuzzy systems” “Fuzzy inference systems”	AND	“strategic” “tactical” “operational” “long-term DM” “short-term DM”	AND	“supplier selection” “manufacturing” “warehousing” “logistics” “integrated SC” “facility location” “outsourcing” “logistics network” “network design” “SC design”

Below is the brief description of how different combinations of keywords were generated:

- The keywords within the columns were connected to each other with the operator "OR".
- For explicit and imprecise keywords for methods, columns one and two were linked with each other with the operator "OR".
- The keywords of SCM (column 4) are connected with operator "AND".
- Columns one and two are linked with operator "AND" and method specific which is DM level keyword (column 3).

Thus, a piece of a hit at least counted an explicit and imprecise word and "SC" or "SCM" and DM level. The methodological approach used in our literature survey is similar to that of Glock & Hochrein (2011) and Beck & Hofmann (2014) and followed the guidelines provided by Seuring & Gold (2012) and Seuring, Müller, Westhaus, & Morana (2005). The material selection process led to samples of 111 papers published in 76 journals (the complete reference list is presented in a separate reference list). The following SC cycle was considered:

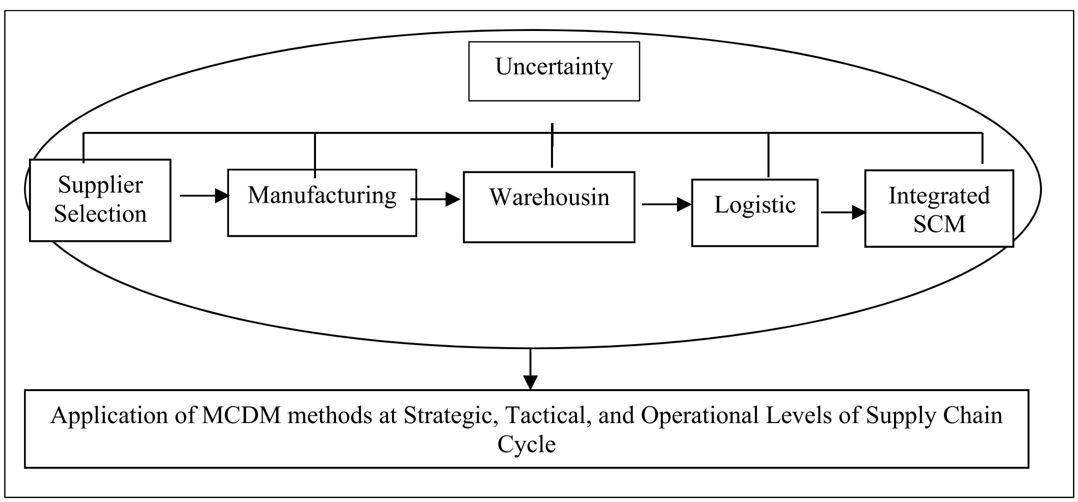

Figure 1.2 SCM functions for research methodology

1.3.2 Descriptive Analysis

According to Seuring & Gold (2012), in the descriptive analysis phase, at the very least, the distribution over the time period and different journals should be displayed as this provides readers with essential information about the literature review. Therefore, the proposed descriptive analysis includes information about the following aspects:

- Distribution of papers across journals
- Distribution of papers between 2005 and 2015
- Distribution of papers across considered SC, as mentioned in Figure 2.1 and defined in section 1.5
- Distribution of papers per country

1.3.2.1 Distribution across the main journals

In order to understand the multi-perspective view of MCDM methods applied in the considered SC, we sorted the articles based on the frequency of use, as mentioned in Table 1.4. From the table, it can clearly be observed that most of the articles covered have been published in reputable journals, such as Experts Systems with Applications, International Journal of Production Economics, Fuzzy Sets and Systems, Journal of Cleaner Production, and Computers and Industrial Engineering. Six conference papers and graduate dissertations were also included because of their importance in the field.

Table 1.4 Distribution of articles by journal in the period 2005-2015

S. No.	**Articles Published By Journals**	**Number of Articles**
1	Expert Systems with Applications	17
2	Conference papers/Graduate Dissertations	6
3	International Journal of Production Economics	5
5	Fuzzy Sets and Systems	4
6	Computers & Industrial Engineering	3
7	Journal of Cleaner Production	3
8	Applied Mathematical Modeling	2
9	International Journal of Production Research	2
10	Journal of Mathematics and Computer Science	2
11	Procedia Computer Science	2
12	Resources, Conservation and Recycling	2
13	Omega: The International Journal of Management Science	2
14	Benchmarking: An International Journal	2
15	Journal of Industrial Engineering	2
16	International Journal of Management Science and Engineering Management	2

Table 1.4 Distribution of articles by journal in the period 2005-2015 (continued)

17	Production Planning & Control	2
18	Applied Soft Computing, Automation in Construction, Business and Economics Research Journal, Decision Support Systems, Ecological Economics, Ecological Indicators, European Journal of Operational Research, Global Journal of Management and Business Studies, IEEE Systems Journal, Information Sciences, Interdisciplinary Journal of Contemporary Research Business, International Journal for Quality Research, International Journal of Business Innovation and Research, International Journal of Computer Science and Information Security, International Journal of Economics, Commerce and Management, International Journal of Environmental Science and Technology, International Journal of Fuzzy Logic Systems, International Journal of Hierarchy Process , International Journal of Human and Social Sciences, International Journal of Services and Operations Management, IOSR Journal of Engineering, Journal of Basic Applied Science Research, Journal of Applied Mathematics, Journal of Business Case Studies, Journal of Intelligent Manufacturing, Journal of Manufacturing Systems, Journal of Naval Science and Engineering, Management Report Journal , Mathematical and Computer Modeling, Mathematical and Computer Modeling, Procedia Engineering, The Management of Operations, Procedia-Social and Behavioral Sciences , Review of General Management, Promet – Traffic and Transportation, Przeglad Elektrotechniczny, Tsinghua Science and Technology, Scientia Iranica, Wseas Transactions on Systems, Transportation Research Part D, Transportation Research Procedia, Wseas Transactions on Information Science and Applications, Robotics and Computer Integrated Manufacturing, The Scientific World Journal, World Congress on Engineering and Computer Science. Mathematical Problems in Engineering, International Journal of Logistics Systems and Management, Waste Management, IOSR Journal of Business and Management, Resources, Conservation and Recycling, Annals of the Oradea University, International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering, International Journal of Management and MCDM, Review of Integrative Business and Economics Research, African Journal of Business Management	1 Each
	Total Number of Papers	**111**

1.3.2.2 Distribution across the time period

The yearly distribution of articles published from 2005 to 2015 is shown in Figure 1.3. Most of the articles were selected from recent publications. Only 30% (34 of 111) selected articles were published before 2011, while the remaining 60% (77 of 111) covered the period of 2011 to 2015. It is clear that the number of articles increased significantly over the last five years because of growing interest in the application of MCDM methods in SCM.

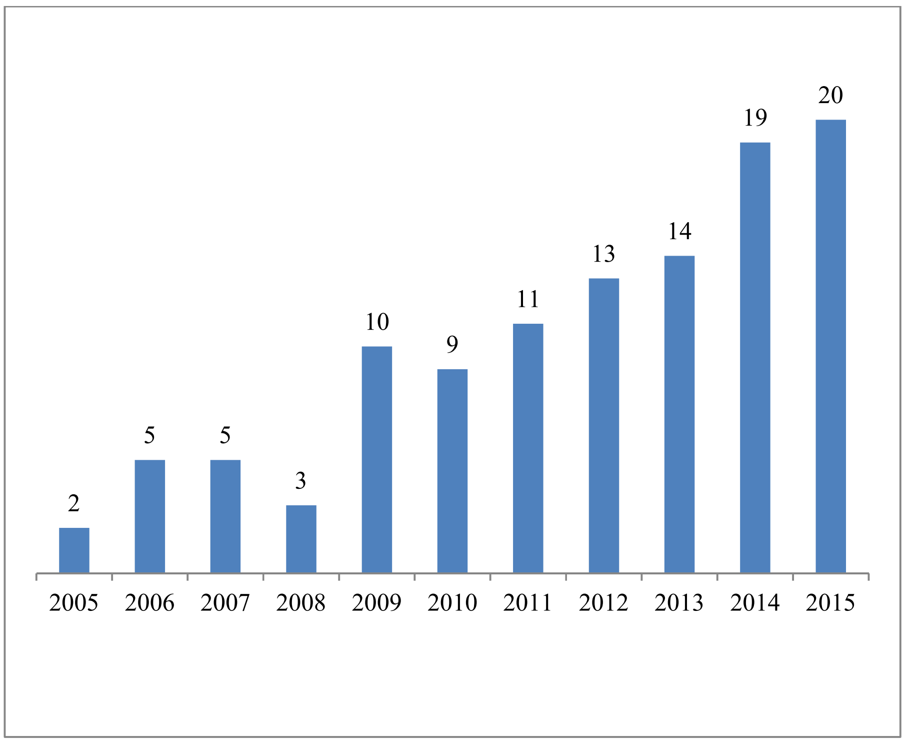

Figure 1.3 Annual distribution of publications across the period of study

1.3.2.3 Distribution across the SC cycle

The categories and framework used for the study are shown in Figure 1.4. As discussed in the last section, the literature on the application of MCDM methods are identified in the SC functions, which consists of i) Supplier selection, ii) Manufacturing, iii) Warehousing, iv) Logistics, and v) Integrated SC.

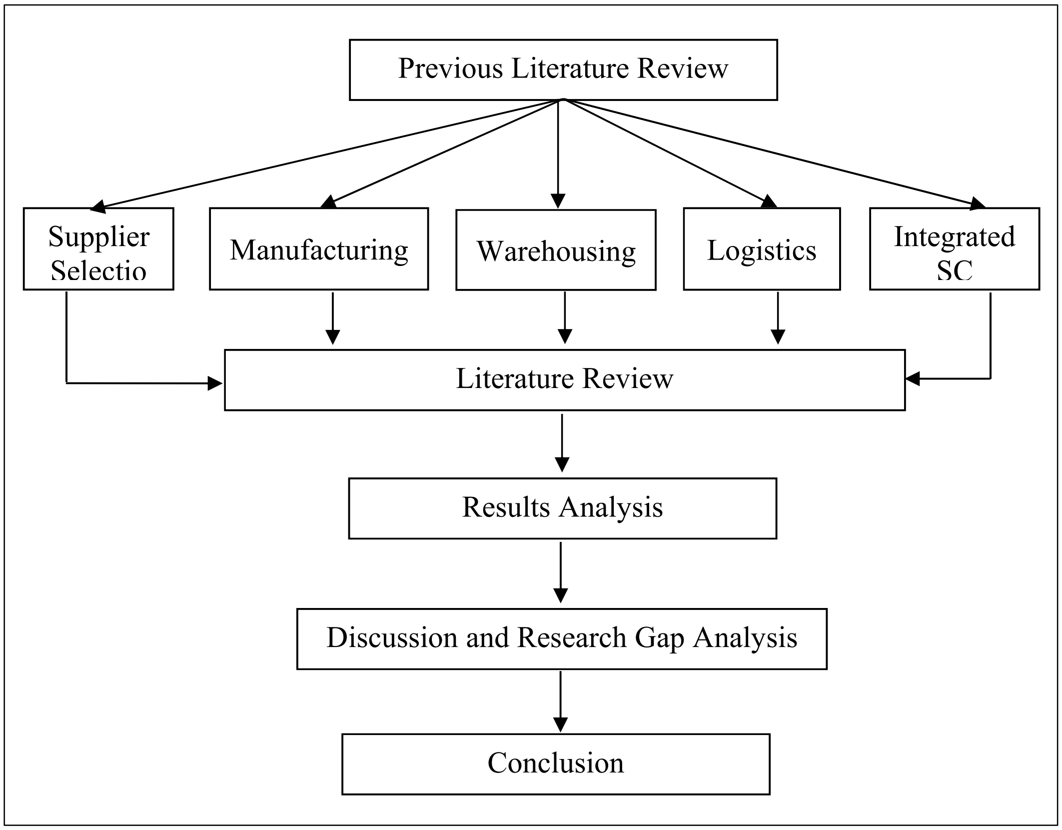

Figure 1.4 Category and framework used

Figure 1.5 shows the distribution of research articles related to the five major functions of an SC. It should be mentioned that the distribution of the application of MCDM methods in traditional functions of SC is more or less equal. However, its application in integrated SC function stands at 14%, which is less than for other functions of considered SC functions because the concept of integrated SC and its importance are relatively new.

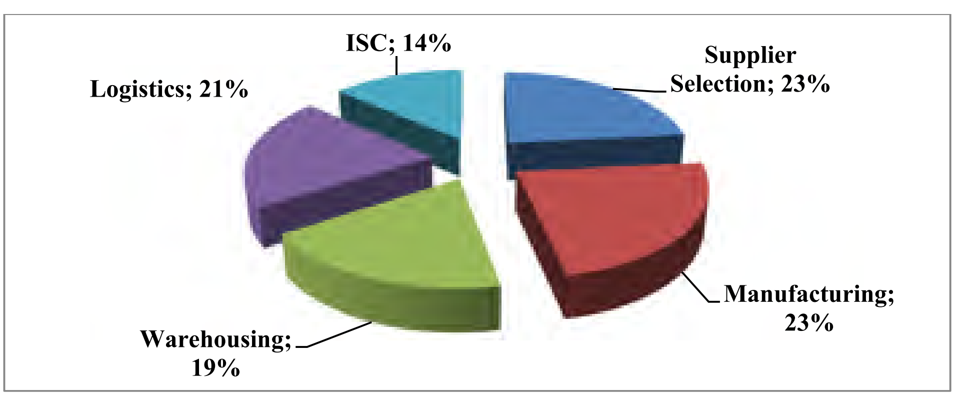

Figure 1.5 Distribution of research papers according to categories

1.3.2.4 Distribution of published papers per country

To obtain a holistic view of this study, we consider papers from different countries. Figure 1.6 shows the number of papers published by each country. Turkey (20 papers), India (17 papers) and Taiwan (15 papers) are the top three countries that applied MCDM methods in the considered SC functions.

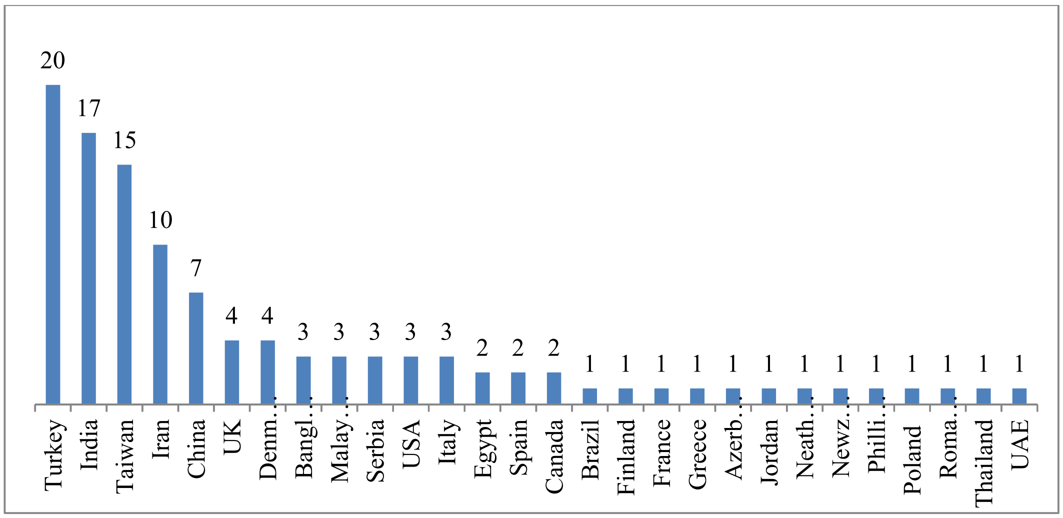

Figure 1.6 Number of papers published per country following detailed analysis of MCDM application in SCM

1.3.3 Category selection

Category selection is the most important and central part of any literature review paper. In this study, paper categories are developed based on the objectives set in above section, and to provide answers to the research questions mentioned above. Therefore, in this study, we categorized papers in terms of DM level, SC function considered, MCDM methods used, application area, and uncertainty (internal, external, and no uncertainty). Figure 1.7 shows the classification of categories we considered in our study.

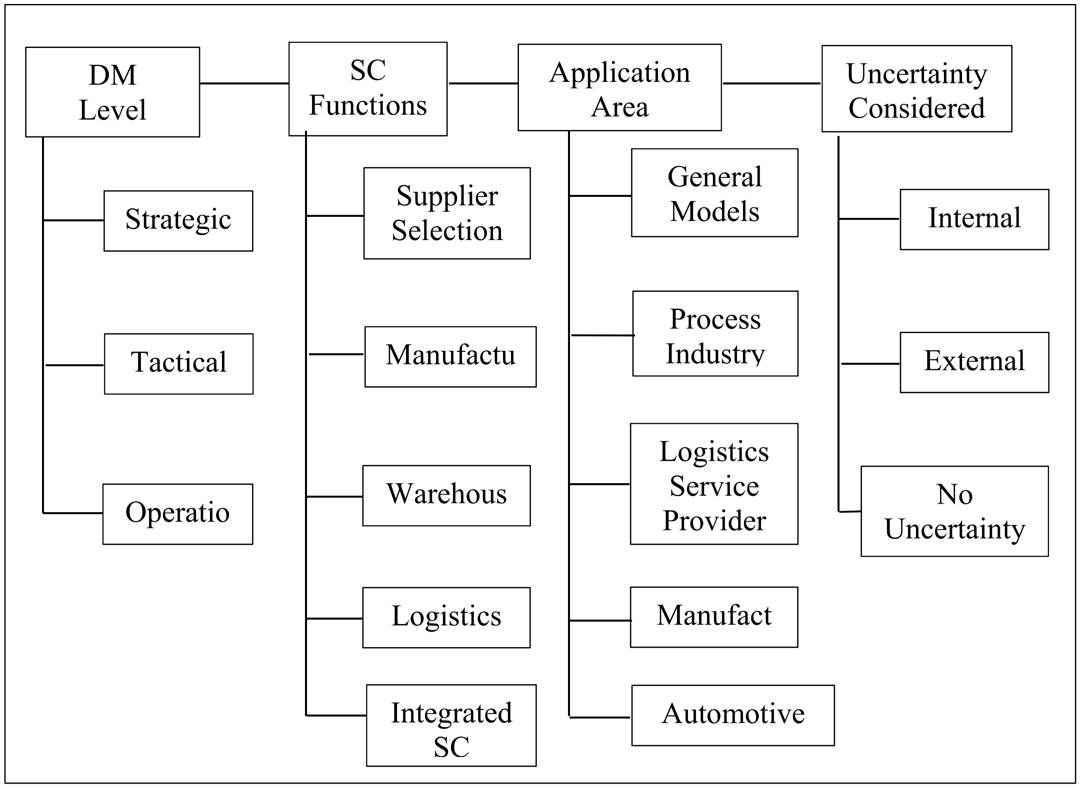

Figure 1.7 Classification of categories for application of MCDM methods

In this phase, each author assigned each paper to the specific category. Distribution of papers according to the DM level is aligned with the DM level definitions mentioned above, while the SC functions distribution is in line with the SC functions definition mentioned in section 1.2. Other dimensions, such as the application area and methods applied, were identified by reading the abstract, and in some cases, the conclusion of the article.

1.3.4 Material evaluation

Once the categories were identified, and the materials analyzed and sorted according to the structural dimensions and categories built (see Figure 2.6), the paper sample was reviewed according to the definitions of categories provided in section 1.5 (for SC functions), and of the DM level, defined in Table 1.3. Other categories, such as the application area and methods applied, were identified by reading the abstract, and in some cases, the conclusion of the article. As the categorization process was based on academic judgment, all authors of this study participated in the categorization process, and cross-checking was conducted to check consistency in paper classification assignment in order to avoid classification deviations. We proceeded with the following four-step procedure to ensure the quality, reliability, and validity of the review:

- We developed decision rules for assigning papers to each category. The rules were validated by authors of this study.

- All papers were read and classified by authors individually according to the developed decision rules.

- Next, sample papers were read by each author separately and classified in order to compare assignment decisions and address inter-coder agreement.

- When the researchers arrived at different conclusions in assigning categories, the authors sat as a group and went through the papers together and resolved the discrepancies. In this study, only 12% of papers had discrepancies in assigning categories, and these were resolved by redrawing the mind-maps, as mentioned in Seuring & Gold (2012).

In the discussion below, we first show qualitative results and then proceed with a quantitative analysis.

1.4 Results

In this section, a systematic review of the literature on the application of MCDM methods will be discussed. We divided the literature review into the functions of SCM considered, and according to the level of uncertainty considered, as stated in Figure 1.7 above.

1.4.1 Supplier selection

Many authors have used different MCDM methods to select suppliers strategically in different applications. For example, Orji & Wei (2015) presented a new modeling technique that proposes a more reliable and receptive decision support system, and that integrates information on supplier behavior in a Fuzzy environment with a system dynamics simulation modeling technique; Kannan, Govindan, & Rajendran (2015) applied a MCDM technique (Fuzzy Axiomatic Design, FAD) to select the best sustainable supplier for a Singapore-based plastic manufacturing organization; Karsak & Dursun (2015) used a Fuzzy multi-criteria group decision-making approach with QFD in a private hospital in Istanbul; Öztürk & Özçelik (2014) examined the problem of identifying the best supplier based on sustainability principles for supplier selection operations in SCs; Shen, Olfat, Govindan, Khodaverdi, & Diabat (2013) applied a Fuzzy multi-criteria approach to evaluate a supplier's environmental performance; Arikan (2013) proposed an interactive solution approach for multiple-objective supplier selection problems with Fuzzy AHP; Chamodrakas, Batis, & Martakos (2010) used the Fuzzy AHP method for supplier selection in electronic marketplaces; Kumar, Singh, Singh, & Seema (2013) proposed a model based on Fuzzy theory to solve the supplier evaluation problem in companies with bulk production costs associated with raw materials; Koul & Verma (2012) proposed a dynamic model based on the integration of Fuzzy-AHP; Liao & Kao (2011) proposed the use of an integrated Fuzzy methodology of TOPSIS and Multichoice goal programming (MCGP) to take into consideration both tangible and intangible criteria of supplier evaluation; Chamodrakas et al. (2010) suggested a two-stage supplier selection process: 1) initial screening of supplier through the enforcement of hard constraints on the selection criteria, and 2) final supplier evaluation by applying Fuzzy preference programming (FPP); Tseng (2010b) used Fuzzy set theory to evaluate GSCM criteria in supplier selection; Jadidi, Firouzi, & Bagliery (2010) applied the TOPSIS method to evaluate and select the best supplier by using interval Fuzzy numbers. Jadidi, Hong, Firouzi, & Yusuff (2009) discussed two methods that have been mentioned in the literature, after which they proposed a methodology based on TOPSIS and applied it to the supplier selection problem. Boran, Genç, Kurt, & Akay (2009) suggested a TOPSIS method that was combined with an intuitionist Fuzzy set to select the suitable supplier in a group decision-making environment; Wang, Zhao, & Tang (2008) applied a Fuzzy decision-making tool in a vendor selection problem and showed how Fuzzy variables such as quality, budget, and demand help in maximizing the total quality level; Xia & Wu (2007) proposed an integrated approach of AHP in the case of multiple sourcing, multiple products, with multiple criteria and with supplier capacity constraints, and Kumar & Alvi (2006) used the "Fuzzy Multi-Objective Integer Programming Vendor Selection

Problem" (F-MIP-VSP) formulation to assimilate the three most important objectives of the vendor selection process: cost minimization, quality maximization, and maximization of on-time delivery.

At the tactical level, supplier selection involves the administration of procurement activities. At this level of decision-making, products are usually procured from a selected supplier for the short term, without any expectation that the supplier will fulfill future demand and needs. In the literature, many authors, such as Moghaddam (2015), applied MCDM methods at the tactical level and proposed a Fuzzy multi-objective mathematical model to find the optimal number of new and refurbished parts and final products in a reverse logistics network configuration. Rezaei, Fahim, & Tavasszy (2014) investigated supplier selection in the airline retail industry and proposed a two-phase methodology. Dargi, Anjomshoae, Galankashi, Memari, & Tap (2014) developed a framework to support the supplier selection process in an Iranian automobile company. An integrated approach consisting of FTOPSIS and mixed integer linear programing was proposed by Kilic (2013) in a multi-product supplier selection problem. Roshandel, Miri-Nargesi, & Hatami-Shirkouhi (2013) proposed a hierarchical Fuzzy TOPSIS (HFTOPSIS) approach in which four suppliers of imported raw materials, "Tripolyphosphate (TPP)", are evaluated based on 25 effective criteria, and Chen, Lin, & Huang (2006) proposed the use of a Fuzzy approach in an SC system, and addressed the factors affecting the supplier selection process, which they assessed by assigning them ratings and weights based on linguistic values.

At the operational level, supplier selection usually involves one-time procurement due to unavoidable factors. At this level of decision-making, a small quantity of a product is usually procured from a supplier to run the production line. The associated risk at the operational level decision-making is high since a supplier is being selected for the short term, and consumers and buyers are not very familiar with each other's needs and expectations. However, since supplier selection is mainly a strategic and tactical decision, few authors use MCDM methods for operational decision-making. Shaverdi, Heshmati, Eskandaripour, & Tabar (2013) proposed a Fuzzy AHP approach for evaluating SCM sustainability in the publishing industry; Shaw, Shankar, Yadav, & Thakur (2012) used a combination of Fuzzy AHP and Fuzzy objective linear programming to select the best supplier, and Kilincci & Onal (2011) used a Fuzzy-AHP process for supplier selection in a washing machine company. Table 1.5 summarizes the use of MCDM approaches in supplier selection at different decision-making levels and uncertainty considered.

Table 1.5 Use of MCDM methods in supplier selection at different DM levels

Authors	**MCDM Methods Used**	**Sector / Application Area**	**DM Level**			**Country**	**Uncertainty Considered**		
			Strategic	Tactical	Operational		Internal	External	No Uncertainty
Orji & Wei (2015)	Fuzzy Systems	Gear Manufacturing	●			China		●	
Karsak & Dursun (2015)	Fuzzy-QFD	Hospital	●			Turkey	●	●	
Moghaddam (2015)	Fuzzy multi-objective	General		●		USA		●	
Kannan, Govindan, & Rajendran (2015)	Fuzzy Axiomatic Design	Plastic material manufacturer	●			Denmark	●	●	
Rezaei, Fahim, & Tavasszy (2014)	Fuzzy-AHP	Airline		●		Netherlands		●	
Dargi, Anjomshoae, Galankashi, Memari, & Tap (2014)	Fuzzy-ANP	Automotive		●		Malaysia		●	
Öztürk & Özçelik (2014)	Fuzzy-TOPSSIS	Energy	●			Turkey		●	
Shen, Olfat, Govindan, Khodaverdi, & Diabat (2013)	Fuzzy-TOPSSIS	Automotive	●			Iran		●	
Shaverdi, Heshmati, Eskandaripour, & Tabar (2013)	Fuzzy-AHP	Publishing Company			●	Iran	●	●	
Kilic (2013)	Fuzzy-TOPSSIS and Mixed integer linear programmin g	Air filter Manufacturing		●		Turkey		●	
Roshandel, Miri-Nargesi, & Hatami-Shirkouhi (2013)	Fuzzy-TOPSSIS	Detergent Manufacturing		●		Iran		●	
Arikan (2013)	Fuzzy-AHP	General	●			Turkey		●	

Table 1.5 Use of MCDM methods in supplier selection at different DM levels (continued)

Kumar, Singh, Singh, & Seema (2013)	Multi-input single-output	Fiber Manufacturing	●			India			●
Shaw, Shankar, Yadav, & Thakur (2012)	Fuzzy-AHP and Fuzzy Objective Linear Programming	Garment Manufacturing			●	India	●	●	
Koul & Verma (2012)	Fuzzy-AHP	General	●			India	●	●	
Kilincci & Onal (2011)	Fuzzy-AHP	Washing Machine Manufacturing			●	Turkey		●	
Liao & Kao (2011)	Fuzzy-TOPSSIS and Multi-choice goal programming	Watch Manufacturing	●			Taiwan	●	●	
Jadidi, Firouzi, & Bagliery (2010)	TOPSIS	General	●			Italy			●
Chamodrakas et al. (2010)	Fuzzy-AHP	Steel	●			Greece		●	
Tseng (2010b)	Fuzzy-AHP	Manufacturer of Medical Consumables	●			Taiwan	●	●	
Boran, Genç, Kurt, & Akay (2009)	Fuzzy-TOPSIS	Automotive	●			Turkey	●	●	
Jadidi, Hong, Firouzi, & Yusuff (2009)	TOPSIS-Grey Theory	General	●			Italy			●
Wang, Zhao, & Tang (2008)	Fuzzy System	General	●			China	●	●	
Xia & Wu (2007)	AHP - MILP	General	●			China			●
Chen, Lin, & Huang (2006)	Fuzzy-TOPSSIS	General		●		Taiwan		●	
Kumar & Alvi (2006)	Fuzzy Objective Linear Programming	General	●			India	●	●	

1.4.2 Manufacturing

Strategically, decision-making associated with manufacturing involves capacity constraints, manufacturing process selection, and make-or-buy decisions. Many authors have applied MCDM methods and techniques for strategic decision-making in manufacturing, including Govindan et al. (2015), who identified twelve common drivers of manufacturing using Fuzzy systems. Rostamzadeh, Govindan, Esmaeili, & Sabaghi (2015) developed a quantitative evaluation model to measure the uncertainty of green SCM (GSCM) activities; Ocampo, Clark, & Tanudtanud (2015) proposed a hybrid MCDM approach in the form of an integrated probabilistic Fuzzy analytic network process (PROFUZANP). Susilawati, Tan, Bell, & Sarwar (2015) used Fuzzy systems to model the problem to deal with the multidimensional concept, the unavailability benchmark, and uncertainty; Lin (2013) used Fuzzy set theory from a structural model to identify the cause and effect relationships between different criteria in manufacturing; Evans, Lohse, & Summers (2013) presented a distinct experience-based Fuzzy decision tree to calculate confidence factors for the successful adoption of potential technologies for a given set of requirements in manufacturing; Chakrabortty & Hasin (2013) proposed an interactive Fuzzy-Based Genetic Algorithm (FBGA) approach for solving a two-product and two-period aggregate production planning (APP) problem, Muralidhar, Ravindranath, & Srihari (2012) presented a novel decision-making group multi-criteria evaluation approach for green SCM strategies, using FTOPSSIS; Irajpour, Golsefid-Alavi, Hajimirza, & Soleimani-Nezhad (2012) proposed a Fuzzy DEMATEL-based methodology to study the effect and ranking of essential factors having an impact on green SCM in the automotive industry, and Bilgen (2010) applied a Fuzzy mathematical programming approach tackling the problem associated with production and distribution planning.

At the tactical level, the decisions considered relate to the production rate, demand forecast errors, utilization of manufacturing facilities, and administrative constraints. MCDM methods are widely applied at the tactical level of manufacturing decision-making. Raj, Vinodh, Gaurav, & Sundaram (2014) proposed a methodology based on Fuzzy-ANP and TOPSSIS for agile criteria weight, and determined that gaps were prioritized using the Fuzzy TOPSIS approach; Hashemzadeh & Hazaveh (2015) proposed factors based on Fuzzy DEMATEL that reduce production costs; (Govindan, Kannan, & Shankar, 2014) selected the best green manufacturing practices based on DEMATEL and ANP (DANP). Zarandi & Gamasaee (2013) proposed the use of type 2 Fuzzy methodology to identify the main reasons for the bullwhip effect in manufacturing; Kristianto, Helo, Jiao, & Sandhu (2012) proposed the use of an adaptive Fuzzy control to assist vendor-managed inventory (VMI) in manufacturing; Wu, Ding, & Chen (2012) conducted a study to understand the status of sustainable SCM practices among the world's largest manufacturing corporations; Lin (2011) selected a green product design, considering various factors in the manufacturing industry using DEMATEL and ANP; Campuzano, Mula, & Peidro (2010) developed a system dynamics with Fuzzy estimations of demand in a manufacturing environment; Feili, Moghaddam, & Zahmatkesh (2010) used the combined Fuzzy sets theory with material requirements planning (MRP); Elamvazuthi, Ganesan, Vasant, & Webb (2009) proposed a model based on a Fuzzy linear programming problem to determine the monthly production planning quotas and profits of a home textile group; Tozan & Vayvay (2008) assessed forecasting models in production planning performance quantifying demand variability using Fuzzy linear regression, Fuzzy time series and Fuzzy grey GM (1,1); (Aliev, Fazlollahi, Guirimov, & Aliev (2007) proposed the use of a Fuzzy integrated model with a Fuzzy objective function to maximize profit and reduce problems associated with aggregate production-distribution planning, such as uncertain market demands and production capacity, undefined process time, etc.

At the operational level, the decisions considered are related to the rejection rate during manufacturing, cycle time, and machine breakdown. A few authors have used MCDM methods at the manufacturing decision-making operational level, including Peidro, Mula, Poler, & Verdegay (2009), who proposed a Fuzzy mathematical programming model to address the uncertainties related to supply, demand and process. Table 1.6 summarizes the use of MCDM approaches in manufacturing at the different levels of decision-making and uncertainty considered.

Table 1.6 Use of MCDM methods in manufacturing at different DM levels

Authors	**MCDM Methods Used**	**Sector / Application Area**	**DM Level**			**Country**	**Uncertainty Considered**		
			Strategic	Tactical	Operational		Internal	External	No Uncertainty
Govindan et al. (2015)	Fuzzy System	General	●			Denmark	●		
Hashemzadeh & Hazaveh (2015)	Fuzzy-DEMATEL	General		●		Iran	●		
Ocampo, Clark, & Tanudtanud (2015)	Probabilistic Fuzzy-ANP	General	●			Philippines	●		
Rostamzadeh, Govindan, Esmaeili, & Sabaghi (2015)	Fuzzy-VIKOR	Hard Disk Mfg.	●			Malaysia	●		
Susilawati, Tan, Bell, & Sarwar (2015)	Fuzzy System	General	●			UK	●		
Raj, Vinodh, Gaurav, & Sundaram (2014)	Fuzzy-ANP and TOPSSIS	General		●		India			●
Govindan, Kannan, & Shankar (2014)	DEMATEL-ANP	Rubber, Tire and Tube Mfg.		●		Denmark			●
Sivakumar, Kannan, & Murugesan (2015)	AHP	Mining Industry		●		India			●
Evans, Lohse, & Summers (2013)	Fuzzy Decision Tree	Aircraft	●			UK	●	●	
Lin (2013)	Fuzzy-DEMATEL	General	●			Taiwan	●	●	
Zarandi & Gamasaee (2013)	Type 2 Fuzzy hybrid experts system	Steel Mfg.		●		Iran	●	●	
Chakrabortty & Hasin (2013)	Fuzzy Based Genetic Algorithm	General	●			Bangladesh	●	●	
Kristianto, Helo, Jiao, & Sandhu (2012)	Fuzzy System	General		●		Finland	●		
Muralidhar (2012)	Fuzzy-TOPSSIS	Cement Mfg.	●			India	●	●	
Irajpour, Golsefid-Alavi, Hajimirza, & Soleimani-Nezhad (2012)	Fuzzy DEMATEL	Automotiv e	●			Iran			●

Table 1.6 Use of MCDM methods in manufacturing at different DM levels (continued)

Wu, Ding, & Chen (2012)	ANP - VIKOR	Textile		●		USA			●
Tseng (2011)	ANP-DEMATEL	Mfg. Medical Consumables		●		Taiwan			●
Lin (2011)	DEMATEL	General		●		Taiwan	●	●	
Bilgen (2010)	Fuzzy mathematical programming	General	●			Turkey	●		
Campuzano, Mula, & Peidro (2010)	Fuzzy Sets	General		●		Spain	●		
Feili, Moghaddam, & Zahmatkesh (2010)	Fuzzy System	General		●		UK	●	●	
Peidro, Mula, Poler, & Verdegay (2009)	Fuzzy mathematical programming	Automotive			●	Spain	●		
Elamvazuthi, Ganesan, Vasant, & Webb (2009)	Fuzzy Linear Programming	Textile Industry		●		Malaysia		●	
Tozan & Vayvay (2008)	Fuzzy linear regression, Fuzzy time series, and Fuzzy grey GM	General		●		Turkey	●	●	
Hsu & Hu (2008)	Fuzzy-AHP	Electronics		●		Taiwan	●	●	
Aliev et al. (2007)	Fuzzy integrated model with Fuzzy objective function	Home Appliance Company		●		Azerbaijan	●	●	

1.4.3 Warehousing

Due to high client expectations, warehousing decisions are vital for organizations. At the strategic level, the decisions the authors and researchers in the literature considered were warehouse location selection, space utilization, and urban distribution center location. Warehousing decisions have a long-term impact on the overall SC, and as a result, trade-offs must be made between conflicting alternatives. Many authors have applied MCDM methods to warehouse location decisions, including Dobrota, Macura, & Šelmi (2015), who used a Fuzzy analytic hierarchy process (AHP) for the selection of distribution center locations; Dey, Bairagi, Sarkar, & Sanyal (2015) suggested three novel extended Fuzzy MCDM methodologies and effectively handled subjective and objective factors for the assessment and selection of the warehouse location; Rao, Goh, Zhao, & Zheng (2015) proposed the FMAGDM method to measure and select the CLC location based on sustainability; Cagliano, Pilloni, & Rafele (2014) proposed a Fuzzy inference process comprising rigorous but relatively simple decision-making methods in uncertain environments; Chang (2014) used the TOPSIS method to obtain the optimal warehouse site selection spot; Rezaeiniya, Ghadikolaei, Mehri-tekmeh, & Rezaeiniya (2014) described the research and development of hybrid FMCDM with ANP methods for greenhouse locations in Iran; Ashrafzadeh, Rafiei, Isfahani, & Zare (2012) proposed the application of Fuzzy-TOPSIS as an integrated MCDM method that includes both qualitative and quantitative criteria to select the best location for a warehouse; Dheena & Mohanraj (2011) applied MCDM Fuzzy set theory to determine ideal and anti-ideal points for warehouse location site selection; Boran (2011) suggested the use of an integrated intuitionist Fuzzy and TOPSIS method to select the best facility location; Awasthi, Chauhan, & Goyal (2011) proposed the use of Fuzzy theory to identify candidate locations, the selection of evaluation criteria, and finally, for selecting the best location; Awasthi, Chauhan, & Omrani (2011), presented a Fuzzy-TOPSSIS approach for location planning for urban distribution centers under uncertainty, Ekmekçioĝlu, Kaya, & Kahraman (2010) proposed an FTOPSIS-based method to select a suitable waste removal location for municipality solid waste; Ishii, Yung, & Kuang (2007) developed a model to select the warehouse location in order to maximize the degree of satisfaction, meet all demand points, and maximize chances of getting the preferred site, and Yang & Hung (2007) presented a study in which they explored the use of MCDM approaches in solving a layout design problem using Fuzzy-TOPSSIS.

At the tactical level, the decisions considered were warehouse layout design, cost per order, and response rate. Many authors applied MCDM methods for tactical warehousing decisions. Chen, Liao, & Wu (2014) integrated a Fuzzy technique for order preference by similarity to an ideal solution (TOPSIS) and multi-choice goal programming (MCGP) to obtain an appropriate DC from many alternative locations, for the airline industry; Bagum, Abul, & Rashed (2014) used an Analytical Hierarchy Process (AHP) and an

MCDM tool to evaluate important factors related to DC location and select the most appropriate location for DC; Zak & Węgliński (2014) presented the first stage of an MCDM/A-based two-stage procedure resulting in the selection of the most desirable location for a logistics center; Ding (2013) developed an integrated Fuzzy MCDM model to evaluate the best selection for a hub location for GSLPs; Xu & Li (2012) proposed a Fuzzy random multi-objective decision-making model, and Dweiri & Meier (2006) proposed a construction-type layout design heuristic based on Fuzzy set theory.

At the operational level, the decisions considered were damages, reconciliation errors, and order fulfillment rate. Only a few applications of MCDM methods can be found in the literature on warehousing decisions at the operational level. These include the multifactor Fuzzy inference system (FIS) for the development of facility layouts with fixed pickup/drop-off points proposed by Deb & Bhattacharyya (2005). Table 1.7 summarizes the use of MCDM approaches in warehousing at the different levels of decision-making and uncertainty considered.

Table 1.7 Use of MCDM methods in warehousing at different DM levels

Authors	**MCDM Methods Used**	**Sector / Application Area**	**DM Level**			**Country**	**Uncertainty Considered**		
			Strategic	Tactical	Operational		Internal	External	No Uncertainty
Dobrota, Macura, & Šelmi (2015)	Fuzzy-AHP	Retail Industry	●			Serbia	●	●	
Dey, Bairagi, Sarkar, & Sanyal (2015)	Fuzzy	General	●			India	●	●	
Rao, Goh, Zhao, & Zheng (2015)	Fuzzy Multi-attribute	General	●			China	●	●	
Cagliano, Pilloni, & Rafele (2014)	Fuzzy	General	●			Italy	●	●	
Zak & Węgliński (2014)	Electre III	General		●		Poland			●
Rezaeiniya, Ghadikolaei, Mehri-tekmeh, & Rezaeiniya (2014)	Fuzzy-ANP	General	●			Iran	●	●	

Table 1.7 Use of MCDM methods in warehousing at different DM levels (continued)

Chen, Liao, & Wu (2014)	FTOPSSIS - MCGP	Airline		●		Taiwan	●	●	
Bagum, Abul, & Rashed (2014)	AHP	Logistics Service Provider		●		Bangladesh			●
Chang (2014)	TOPSIS	Retailing Channel	●			Taiwan			●
Ding (2013)	Fuzzy System	Logistics Service Provider		●		Taiwan	●	●	
Ashrafzadeh, Rafiei, Isfahani, & Zare (2012)	Fuzzy-TOPSSIS	Home Appliances	●			Iran	●	●	
Xu & Li (2012)	Fuzzy random multi-objective DM model	Constructions		●		China	●		
Boran (2011)	Fuzzy-TOPSSIS	Automotive	●			Turkey	●		
Dheena & Mohanraj (2011)	Fuzzy-TOPSSIS	General	●			India	●	●	
Awasthi, Chauhan, & Goyal (2011)	Fuzzy System	Logistic Company	●			Canada	●	●	
Awasthi, Chauhan, & Omrani (2011)	Fuzzy-TOPSSIS	Logistic Company	●			Canada	●	●	
Ekmekçioĝlu, Kaya, & Kahraman (2010)	Fuzzy-TOPSSIS	General	●			Turkey	●		
Yang & Hung (2007)	Fuzzy-TOPSSIS	IC Packaging Plant	●			Taiwan	●		
Ishii, Yung, & Kuang (2007)	Fuzzy	General	●			Taiwan	●	●	
Dweiri & Meier (2006)	Fuzzy System	General		●		Jordon	●	●	
Deb & Bhattacharyya (2005)	Fuzzy inference system	General			●	India	●		

1.4.4 Logistics

Logistics plays an important role in overall SC performance. At the strategic level, the decisions researchers considered were logistics provider selection, service reliability, and freight cost. Many authors applied MCDM methods and techniques at the strategic level of decision-making in logistics. These include Uygun, Kaçamak, & Kahraman (2015), who proposed DEMATEL and Fuzzy ANP MCDM techniques for the evaluation and determination of an outsourcing provider. Tadić, Zečević, & Krstić (2014) proposed a framework for the selection of the CL using Fuzzy-DEMATEL, ANP, and VIKOR. Jayant, Gupta, Garg, & Khan (2014) developed a decision support system to assist the company's upper management in the selection and evaluation of different 3PRL using TOPSSIS-AHP. Tadic, Zecevic, & Krstic (2014) proposed a Fuzzy analytic hierarchy process (FAHP) and TOPSIS methodology in logistics system scenario selection for the central business district (CBD) of the city confronted with significant urban changes. An integrated approach using quality function deployment (QFD), Fuzzy set theory and an analytical hierarchy (AHP) process approach to analyze and select the most cost-effective 3PL service provider was developed by Ho, He, Lee, & Emrouznejad (2012). A Fuzzy analytic hierarchy process (FAHP) approach based on TOPSIS method for evaluating and selecting an appropriate logistics service provider has been proposed by Kabir (2012). Erkayman, Gundogar, & Yilmaz (2012) proposed a Fuzzy MCDM approach to effectively select the most appropriate provider. Erkayman, Gundogar, Akkaya, & Ipek (2011) proposed a Fuzzy TOPSIS approach to a logistics center location selection problem. Çakir, Tozan, & Vayvay (2009) proposed a logistics service provider selection decision support system based on the Fuzzy analytic hierarchy process (FAHP) method.

At the tactical level, decisions considered relate to logistics network design, mode of transport, and the establishment of the logistic center. Many authors applied MCDM methods at the tactical level: Jain & Khan (2015) formulated the Reverse Logistics service provider selection as an MCDM problem, and developed a methodology to select the two best reverse logistics service providers; Liu, Chen, & Zhong (2012) proposed a model for selecting 3PL providers based on SVM and FAHP, and best 3PRLP section Fuzzy environment, Kannan, Pokharel, & Kumar (2009) proposed and implemented an MCGDM technique.

At the operational level, the decisions considered were damages, delayed shipment rate, cost per delivery and operational performance (wrong delivery rate, for instance). A few authors applied MCDM techniques at the operational level, including Gupta, Sachdeva, & Bhardwaj (2010), who developed a methodology based on Fuzzy Delphi to select 3PLSP;

Soh (2010) proposed a method suitable for selecting 3PLP, and demonstrated the methodology using a case study; ÇAKIR (2009) used the Fuzzy-AHP approach for a logistics service provider selection decision support system to validate the conceptual design of such a system, and Jharkharia & Shankar (2007) used ANP in selecting the logistics service provider. Table 1.8 summarizes the use of MCDM approaches in logistics at different levels of decision-making and uncertainty considered.

Table 1.8 Use of MCDM methods in logistics at different DM levels

Authors	**MCDM Methods Used**	**Sector / Application Area**	**DM Level**			**Country**	**Uncertainty Considered**		
			Strategic	Tactical	Operational		Internal	External	No Uncertainty
Uygun, Kaçamak, & Kahraman (2015)	DEMATEL and Fuzzy ANP	Telecommunication	●			Turkey	●		
Făgărăşan & Cristea (2015)	Electre III	General	●			Romania			●
Hwang & Shen (2015)	Fuzzy	Semiconductor Mfg.		●		Taiwan	●		
Vahabzadeh, Asiaei, & Zailani (2015)	Fuzzy-VIKOR	General	●			New Zealand	●	●	
Jain & Khan (2015)	AHP	Injection Molding		●		UAE			●
Akman & Baynal (2014)	Fuzzy-AHP and Fuzzy-TOPSSIS	Tire Mfg.		●		Turkey	●		
Tadić, Zečević, & Krstić (2014)	Fuzzy DEMATEL, Fuzzy ANP, and Fuzzy VIKOR	City Logistics	●			Serbia	●	●	
Rapee (2014)	FAHP	Logistics Company	●			Thailand	●		
Tadic, Zecevic, & Krstic (2014)	Fuzzy-AHP and Fuzzy-TOPSSIS	City Logistics	●			Serbia	●	●	
Jayant, Gupta, Garg, & Khan (2014)	TOPSSIS-AHP	Telecommunication	●			India			●
Bayazit & Karpak (2013)	AHP	Aerospace		●		USA			●
Ho, He, Lee, & Emrouznejad (2012)	QFD with the Fuzzy-AHP	Hard Disk Component Manufacturer	●			UK	●	●	
Kabir (2012)	Fuzzy-AHP	FMCG	●			Bangladesh	●	●	

Table 1.8 Use of MCDM methods in logistics at different DM levels (continued)

Liu, Chen, & Zhong (2012)	Fuzzy-AHP	Garment Material Mfg.		●		China	●		
Erkayman, Gundogar, & Yilmaz (2012)	Fuzzy-Delphi	Logistic Company	●			Turkey	●		
Gupta, Sachdeva, & Bhardwaj (2010)	Fuzzy-TOPSSIS	Automotive			●	India	●	●	
Perçin, S. (2009)	AHP-TOPSIS	Automotive		●		Turkey			●
Çakir, Tozan, & Vayvay (2009)	Fuzzy-AHP	Logistic Company			●	Turkey	●	●	
Soh (2010)	Fuzzy-TOPSSIS	Logistic Company			●	Turkey	●		
Çakir (2009)	Fuzzy-AHP	Logistic Company	●			Turkey	●	●	
Kannan, Pokharel, & Kumar (2009)	Interpretive Structural Modeling (ISM) and Fuzzy technique	Battery Manufacturing Company		●		Denmark	●		
Jharkharia & Shankar (2007)	ANP	FMCG			●	India			●

1.4.5 Integrated SC

The concept of SC integration is relatively new as compared to other traditional functions of SC functions. At the strategic level decision makers needs to know the impact of their decisions on overall SC. Several authors applied many MCDM methods at the strategic level. Evelyn & EdmondYeboah (2015) used the Analytical Hierarchy Process (AHP) method to rank agricultural SC risk. Jakhar & Barua (2014) proposed a detailed measuring technique that could be useful in aligning SC performance and provide insights to DM for improvement. Agami, Saleh, & Rasmy (2014) introduced an innovative approach to SC performance management based on Fuzzy, with trend impact analysis; Samvedi, Jain, & Chan (2013) made an effort to quantify the risks in an SC and to consolidate the values into a comprehensive risk index; Sofyalıoğlu & Kartal (2012) suggested the use of Fuzzy-AHP to determine the most important SC risk and complementing risk management strategy; Ganga & Carpinetti (2011) proposed a model based on Fuzzy decision-making that would predict performance, helping managers in the SCM performance management decision-making process, and a Fuzzy multiple-attribute decision-making (FMADM) method based on the Fuzzy linguistic quantifier was proposed by Chang, Wang, & Wang (2006).

At the tactical level of the application of MCDM techniques, Hariharan & Rajmohan (2015) proposed a methodology based on AHP, TOPSIS and FAHP to rank SC risks identified from the literature, and implemented it in a case bicycle manufacturing company; Selim, Yunusoglu, & Yılmaz Balaman (2015) proposed a group decision-making-based risk assessment framework for supplier risk assessment in multi-national SCs; Sahu, Datta, Patel, & Mahapatra (2013) proposed a performance measurement index system to gather evaluation information data on overall SC performance measure metrics; El-Baz (2011) applied Fuzzy-AHP theory for measuring the performance of an SC in the manufacturing industry; and Moeinzadeh & Hajfathaliha (2009) proposed a methodology in which SC risks are identified, and a risk index classification structure is created.

At the operational level, Wang & Shu (2005) developed a Fuzzy decision methodology to help in determining a framework to handle SC uncertainties. Table 1.9 shows the use of the MCDM approach in SC at different decision levels and uncertainty considered.

Table 1.9 Use of MCDM approach in integrated SC at different decision levels

Authors	**MCDM Methods Used**	**Sector / Application Area**	**DM Level**			**Country**	**Uncertainty Considered**		
			Strategic	Tactical	Operational		Internal	External	No Uncertainty
Evelyn & EdmondYeboah (2015)	AHP	Agriculture	●			China			●
Hariharan & Rajmohan (2015)	TOPSSIS-FAHP	Bicycle Mfg.		●		India	●	●	
Selim, Yunusoglu, & Yılmaz Balaman (2015)	TOPSSIS	General		●		Turkey			●
Jakhar & Barua (2014)	Fuzzy-AHP	Textile	●			India	●	●	

Table 1.9 Use of MCDM approach in integrated SC at different decision levels (continued)

Agami, Saleh, & Rasmy (2014)	Fuzzy DM with trend impact analysis	Shipping Company	●			Egypt	●	●	
Samvedi, Jain, & Chan (2013)	Fuzzy-AHP and Fuzzy-TOPSIS	Steel Company	●			India	●	●	
Sahu, Datta, Patel, & Mahapatra (2013)	Fuzzy set theory, entropy, ideal, and grey relation	General		●		India	●	●	
Sofyalıoğlu & Kartal (2012)	Fuzzy-AHP	Iron and Steel Mfg.	●			Turkey	●	●	
Ganga & Carpinetti (2011)	Fuzzy System	General	●			Brazil	●	●	
El-Baz (2011)	Fuzzy-AHP	Mfg.		●		Egypt	●	●	
Najmi & Makui (2010)	AHP-DEMATEL	Automotive	●			Iran			●
Moeinzadeh & Hajfathaliha (2009)	ANP – Vikor under Fuzzy environment	General		●		Iran	●	●	
Chang, Wang, & Wang (2006)	Fuzzy Multi-Attribute DM	General	●			France	●	●	
Lin, Chiu, & Chu (2006)	Fuzzy	General	●			Taiwan			
Wang & Shu (2005)	Fuzzy System	General			●	Taiwan	●	●	

1.4.6 Distribution of papers in terms of uncertainty

In addition to the inherently dynamic nature of SC, high internet and technology penetration, globalization, customer product awareness, digitization and competition among organizations increase uncertainty in the entire SC. The following sections will discuss uncertainty in the considered SC functions.

1.4.6.1 Uncertainty in supplier selection

Orji & Wei (2015) proposed a dynamic MCDM model to compare results from the systems dynamics modeling perspective to solve the challenges of imprecise data and ambiguous human judgment in the supplier performance under sustainability objectives. Moghaddam (2015) proposed a modeling approach that captures the inherent uncertainty in customers' demand, suppliers' capacity, and percentage of returned products. Rezaei, Fahim, & Tavasszy (2014) developed a methodology for supplier selection, which considers external uncertainty and was applied to one of the largest airlines in Europe, the Royal Dutch Airlines (KLM). Dargi, Anjomshoae, Galankashi, Memari, & Tap (2014) developed a methodology which they implemented in the Iranian automotive industry, which considered external uncertainty factors, such as the technical capability of suppliers, production capacity, etc. Öztürk & Özçelik (2014) proposed the FTOPSIS method to select sustainable suppliers, considering external uncertainty such as policy and regulation, market forces, etc. Shen, Olfat, Govindan, Khodaverdi, & Diabat (2013) proposed the FTOPSIS method to select a sustainable supplier, considering external uncertainty; Kilic (2013) developed a two-stage methodology based on FTOPSIS, in which suppliers were selected based on external factors, namely, quality, cost, delivery, etc. Roshandel, Miri-Nargesi, & Hatami-Shirkouhi (2013) proposed the FTOPSIS method to select the supplier while considering external performance indicators such as quality, price, flexibility, and due date. Arikan (2013) proposed a FAHP-based methodology in which the supplier is selected, considering three external uncertainties which are aggregate demand, on-time delivery, and percentage of the accepted units delivered by the supplier (main sources of fuzziness), and that can be used effectively used to obtain non-dominated solutions. Kilincci & Onal (2011) applied a FAHP process-based methodology to select the best supplier firm providing the highest customer satisfaction for the criteria determined and external uncertainty such as product performance, service performance, and supplier performance factors. Chamodrakas et al. (2010) developed a FAHP method in order to tackle the issue of inconsistency/uncertainty of human preference models and uncertainty in supplier selection. Chen, Lin, & Huang (2006) developed a FTOPSIS model for supplier selection to handle external uncertainty related to factors which are technical capability, conformance quality, and supplier reputation.

Karsak & Dursun (2015) proposed a method capable of managing non-homogeneous information in a decision setting with multiple information sources, of handling both internal and external uncertainty. In order to select the appropriate sustainable supplier, Kannan, Govindan, & Rajendran (2015) proposed a methodology based on Fuzzy axiomatic design and implemented in a case company, considering internal and external uncertainty criteria. Shaverdi, Heshmati, Eskandaripour, & Tabar (2013) developed a FAHP method to select the supplier in a publishing company, considering internal and external uncertain criteria. Shaw, Shankar, Yadav, & Thakur (2012) developed and implemented a FAHP-based methodology, considering factors such as cost, quality, late delivery, and sustainability criteria such as gas emission, and uncertain criteria like a demand. Koul & Verma (2012) proposed a FAHP method to provide a mathematical system that captures the uncertainties (internal and external) associated with human cognitive processes in order to select the supplier. Liao & Kao (2011) proposed an integrated FTOPSIS and MCGP approach to solve the supplier selection problem by considering internal and external uncertainty. Tseng (2010b) proposed a combined Fuzzy grey relational analysis-based method to deal with the study objective and handle internal and external uncertainty. Boran, Genç, Kurt, & Akay (2009) proposed a TOPSIS method combined with an intuitionistic Fuzzy set to select the appropriate supplier in a group decision-making environment and to minimize uncertainty in group decision-making and internal and external uncertainty. Junyan et al. (2008) characterized budget and quality (internal uncertainty) and demand (external uncertainty) and developed two models which are fuzzy vendor selection expected value model and a fuzzy vendor selection chance-constrained programming model to maximize the total quality level. Kumar & Alvi (2006) considered both internal and external uncertainty in a supplier selection problem. Kumar *et al.* (2013) proposed a new model to handle the various attributes associated with supplier evaluation problems. Jadidi, Firouzi, & Bagliery (2010) applied the TOPSIS method to evaluate and select the best supplier by using interval factors without considering any uncertainty. Jadidi, Hong, Firouzi, & Yusuff (2009) described two previous grey theory based methods which are grey prediction and grey rational theory and then proposed a new method based on TOPSIS concepts in grey theory to deal with the problem of selecting suppliers.

1.4.6.2 Uncertainty in manufacturing

Tozan & Vayvay (2008) applied Fuzzy linear regression, Fuzzy time series and a Fuzzy grey GM-based methodology which considers external uncertainty such as the cost of performance and functional performance in manufacturing. Hashemzadeh & Hazaveh (2015) proposed the Fuzzy-DEMATEL approach to extract the relationships between the main cost-related factors and their sub-factors that can reduce the production costs. With the integration between a green strategy and the manufacturing strategy, Ocampo, Clark, & Tanudtanud (2015) presented a decision framework considering internal factors which are the goal, corporate strategy, business strategy, manufacturing strategy, strategic responses, manufacturing strategy decision categories, policy areas, and policy options. Rostamzadeh, Govindan, Esmaeili, & Sabaghi (2015) developed a quantitative evaluation model to measure the uncertainty of Green SCM (GSCM) activities and applied an approach based on the VIKOR method, and considering internal green aspects. To deal with uncertainty, benchmarking and non-availability resulting from human judgment, which is Fuzzy and subjective, Susilawati, Tan, Bell, & Sarwar (2015) proposed a lean manufacturing method. Raj, Vinodh, Gaurav, & Sundaram (2014) provided an effective solution in the form of a hybrid ANP technique for order performance, using TOPSIS in agile manufacturing implementation projects. A decision support system was proposed by Evans, Lohse, & Summers (2013) to measure the confidence level of technology selection for the manufacturing activities. Muralidhar (2012) dealt with the application of a Fuzzy AHP method for evaluating GSCM strategies for a cement manufacturing company and considered internal factors which are internal quality standards, production schedule, process design and backup system. Campuzano et al. (2010) measured the performance of demand estimations, which is Fuzzy, rather than forecasted demand in multi-period manufacturing. Feili, H. et al. (2010) proposed a Fuzzy production planning model under conditions of uncertainty. Elamvazuthi et al. (2009) proposed a methodology based on Fuzzy linear programming to consider the different operations of the textile industry (cutting, sewing, pleating, and packaging) to maximize profit in a Fuzzy Environment. Lin (2011) examines the influential factors among eight criteria (green purchasing, green design, Supplier/customer collaboration, recovery and reuse of used products, environmental performance, economic performance, regulation, and Stakeholders' pressures) based on Fuzzy. Zarandi & Gamasaee (2013) evaluated and reduced the bullwhip effect in Fuzzy environments by means of type 2 Fuzzy methodology in a manufacturing company. An interactive Fuzzy Based Genetic Algorithm (FBGA) methodology was proposed by Chakrabortty & Hasin (2013), in which they considered and provided a solution for a two-period two-product APP with some uncertain internal and external limitations, such as demand and variable cost consists of manufacturing to solve the production planning problem. Kristianto, Helo, Jiao, & Sandhu (2012) proposed an adaptive Fuzzy control application to support a vendor-managed inventory (VMI), considering both internal and external uncertain factors. Irajpour, Golsefid-Alavi, Hajimirza, & Soleimani-Nezhad (2012) used the Fuzzy DEMATEL method to study the influence of the most important factors and to determine the ranking of critical factors in a green SCM in automotive corporations, and considering both internal and external factors. Bilgen (2010) addressed the production and distribution planning problem in a SC system involving internal factors such as allocation of production volumes among the different production lines in the manufacturing plants, and external factors such as the delivery of products to distribution centers. Peidro, Mula, Poler, & Verdegay (2009) proposed a Fuzzy mathematical programming model for SC planning which considered supply, demand and process uncertainties (internal and external). Hsu & Hu (2008) implemented a consistency approaches by factor analysis that determines the adoption and implementation of sustainable SCM in in a manufacturing company based in Taiwan, considering both internal and external factors. Aliev, Fazlollahi, Guirimov, & Aliev (2007) developed a Fuzzy integrated multi-period and multi-product production and distribution model in a SC, considering internal and external factors.

1.4.6.3 Uncertainty in warehousing

Dobrota, Macura, & Šelmi (2015) proposed a FAHP method for the selection of a distribution center location, by considering both internal and external uncertain factors; Dey, Bairagi, Sarkar, & Sanyal (2015) proposed an FMCDM method to select a warehouse location, considering subjective and objective (internal and external) uncertainty; Rao, Goh, Zhao, & Zheng (2015) considered both internal and external uncertainty in location selection of CLS by considering a green perspective; Cagliano, Pilloni, & Rafele (2014) proposed a general decision criterion based on a Fuzzy inference process in uncertain environment, that was helpful in facility location selection; Chen, Liao, & Wu (2014) integrated FTOPSIS and multi-choice goal programming (MCGP) to obtain an appropriate logistics center from many alternative locations for the airline industry in an uncertain environment; Rezaeiniya, Ghadikolaei, Mehri-tekmeh, & Rezaeiniya (2014) described the research and development of hybrid FMCDM methods for a warehouse location in Iran, considering both internal and external risk; Ding (2013) develop an integrated FAHP model to evaluate the best hub location selection for global shipping carrier-based logistics under fuzziness; Ashrafzadeh, Rafiei, Isfahani, & Zare (2012) presented a FTOPSIS approach for selecting a warehouse location under partial or incomplete information (uncertainty); Dheena & Mohanraj (2011) proposed an FTOPSIS method for location site selection under uncertainty; Awasthi, Chauhan, & Omrani (2011) and Awasthi, Chauhan, & Omrani (2011) proposed an FTOPSIS method in location planning for urban distribution centers in which they considered uncertainty arising from a lack of real data in location planning for new urban distribution centers; Ishii, Yung, & Kuang (2007) developed a Fuzzy system to select a facility location, considering uncertainty (internal and external); and Dweiri & Meier (2006) considered uncertainty in facility layout planning and location selection.

Xu & Li (2012) proposed a multi-objective construction site location selection in a dynamic environment and considering internal uncertain factors which are flow of parts, raw materials, work-in-process and finished products between departments, communication (oral or reports) between facilities, number of employees from one or both facilities that perform tasks from one facility to another, number of material handling equipment (trucks, mixers, etc.) used to transfer materials between facilities, level of safety and environmental hazards, measured by the safety concerns, which may arise when two facilities are close to each other, and project manager's desire to have the facilities close to or apart from each other. Boran (2011) developed a TOPSIS method combined with an intuitionistic Fuzzy set to select an appropriate warehouse location in a group decision-making environment under internal uncertainties which are expansion possibility, community consideration, distance to market, and availability of material. An FTOPSIS method was proposed in the selection of an adequate waste disposal method and site considering uncertainties which are the net cost per ton, emission level, and waste recovery by Ekmekçioĝlu, Kaya, & Kahraman (2010).

1.4.6.4 Uncertainty in logistics

Uygun, Kaçamak, & Kahraman (2015) proposed a Fuzzy integrated MCDM method for the evaluation and determination of an outsourcing logistics provider for a telecommunication company under uncertainty. Hwang & Shen (2015) identified the key 3PL selection criteria by employing the non-additive Fuzzy integral approach considering internal uncertain factors. Akman & Baynal (2014) presented an integrated Fuzzy approach for the evaluation and selection of third party logistics service providers, considering internal uncertain factors which are on time delivery, flexibility, reputation, and product availability. Rapee (2014) proposed a multiple MCDM approach (AHP and FAHP) to understand "what is best criteria for selecting C2C logistics companies", "which decision techniques help buyer and seller identify important factors," "how many key factors are suitable for selecting C2C logistics companies. The new integrated model of Liu, Chen, & Zhong (2012) was proposed for selecting 3PL providers based on a support vector machine (SVM) and FAHP. Erkayman, Gundogar, & Yilmaz (2012) and Erkayman, Gundogar, Akkaya, & Ipek (2011) proposed an FTOPSIS method in selecting a logistics center location, considering uncertainties such as geographical location, socio-economic factors, etc. Soh (2010) proposed an evaluation framework and methodology for selecting a suitable 3PL provider under uncertainty which are financial stability, compatibility, logistics cost, and security and safety. Kannan, Pokharel, & Kumar (2009) proposed a method based on ISM and FTOPSIS to select 3PL, considering internal uncertain factors such as cost, quality, and rejection rate.

Jain & Khan (2015) applied AHP in selecting a third party RL service provider without considering uncertainty; in order to evaluate and select different 3PRLSP, Jayant, Gupta, Garg, & Khan (2014) proposed a decision support system based on AHP-TOPSIS without uncertainty; Bayazit & Karpak (2013) showed how the AHP is used to help companies make decisions related to the selection of the most capable 3PL service provider for an aerospace company without uncertainty; a two-phase AHP and TOPSIS methodology to evaluate 3PLSP without uncertainty was been proposed by Perçin, S. (2009); and Jharkharia & Shankar (2007) presented a comprehensive methodology for the selection of a logistics service provider using AHP without uncertainty.

The Vahabzadeh, Asiaei, & Zailani (2015) FVIKOR method using interval-valued trapezoidal Fuzzy numbers was proposed in a green decision-making model in reverse logistics, considering both internal and external uncertainties which are climate change, air quality, noise, land use and biodiversity, waste management, and growth. Tadic, Zecevic, & Krstic (2014) presents the procedure for logistics system scenario selection for the central business district (CBD) of the city using Fuzzy extensions of conventional multi-criteria decision-making (MCDM) methods. Fuzzy "analytical hierarchy process" (FAHP) is applied to determine the relative weights of evaluation criteria, and fuzzy "technique for order preference by similarity to ideal solution" (FTOPSIS) is applied to rank the logistics systems scenarios. Kabir (2012) proposed an FAHP method to select a logistics service provider, considering internal and external factors. A Fuzzy Delphi method was developed to select 3PLSP, considering uncertainty, by Gupta, Sachdeva, & Bhardwaj (2010). ÇAKIR (2009) and Çakir, Tozan, & Vayvay (2009) proposed logistics service provider selection decision support system based on the FAHP method, which has commonly been used for MCDM while considering uncertainty.

1.4.6.5 Uncertainty in integrated SC

Evelyn & EdmondYeboah (2015) used the AHP method to rank an integrated agricultural SC in Ghana based on agricultural sector categories, which include Crops, Livestock, Forestry and Logging and Fishing; Selim, Yunusoglu, & Yılmaz Balaman (2015) proposed maintenance planning considering the whole SC; an integrated AHP and DEMATEL approach was developed to rank an integrated SC performance by Najmi & Makui (2010); an integrated approach was developed based on ANP and VIKOR to measure integrated SC risk under a Fuzzy environment; Hariharan & Rajmohan (2015) identified various risks in the bicycle SC and ranked them using different MCDM techniques; a detailed measuring technique considering internal and external uncertainty was developed by Jakhar & Barua (2014) to measure integrated SC performance; and an integrated Fuzzy trend impact analysis approach been developed by Agami, Saleh, & Rasmy (2014) to quantify the effects of internal and external factors on SC performance.

Samvedi, Jain, & Chan (2013) proposed an integrated approach based on FAHP and FTOPSIS to quantify internal and external risk in an integrated SC. Sahu, Datta, Patel, &

Mahapatra (2013) developed an efficient decision support system (DSS) to facilitate supply chain performance appraisement, benchmarking and related decision-making, considering both internal and external factors. Sofyalıoğlu & Kartal (2012) proposed FAHP to determine the most important SC risks (internal and external) and the corresponding risk management strategies; a Fuzzy logic and SCOR-based method were proposed to know the SC performance, considering both internal and external uncertainty. El-Baz (2011) presented a Fuzzy decision-making approach to handle the performance measurement in SC systems, considering internal and external manufacturing uncertainty; Chang, Wang, & Wang (2006) proposed a Fuzzy multiple-attribute decision-making (FMADM) method based on the Fuzzy linguistic quantifier, considering both internal and external uncertainty of the entire product life cycle; Lin, Chiu, & Chu (2006) developed a Fuzzy agility index (FAI) based on agility providers using Fuzzy logic, considering internal and external factors of entire the SC; and a Fuzzy decision system was developed by Wang & Shu (2005) to measure SC inventory strategies, considering uncertainty in available data.

1.5 Results analysis

Today, competition is shifting from individual company performance to SC performance, thus making it essential for companies to measure their SC performance effectively and efficiently. To that end, they need to identify appropriate methods for evaluating the measurement of the performance of the entire SC cycle. This study will help managers, practitioners and researchers select the most appropriate MCDM method for managing their SC cycle. Figures 1.8, 1.9, 1.10 show the number of papers covering each MCDM approach at different strategic, tactical and operational levels of SC decisions.

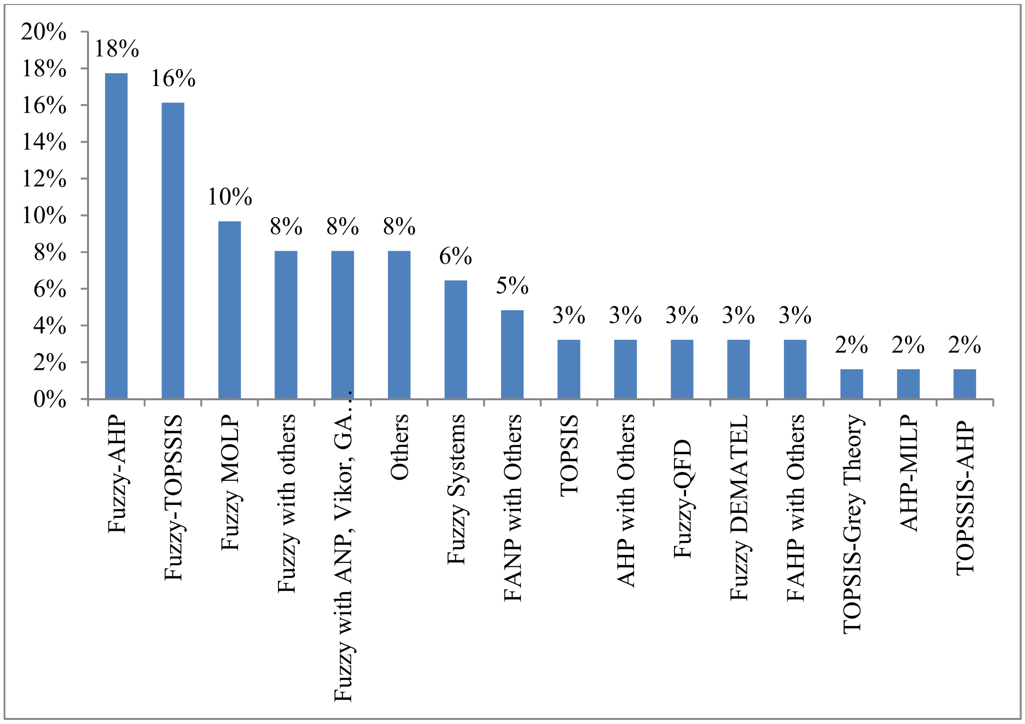

Figure 1.8 MCDM methods at strategic level

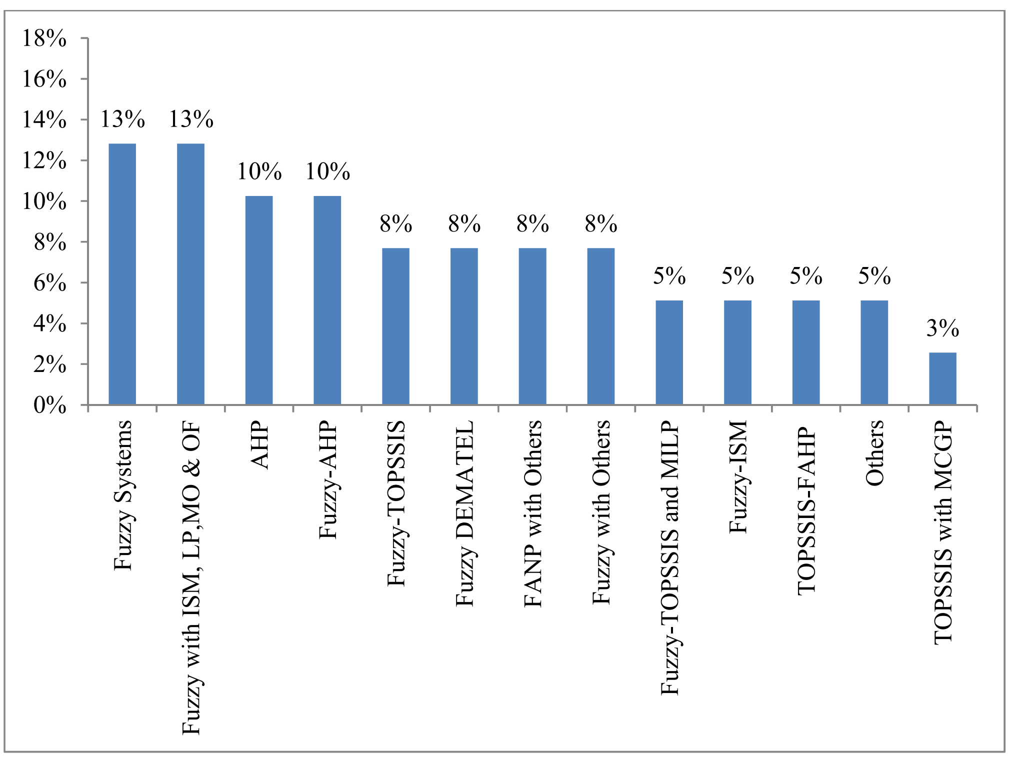

Figure 1.9 MCDM methods at tactical level

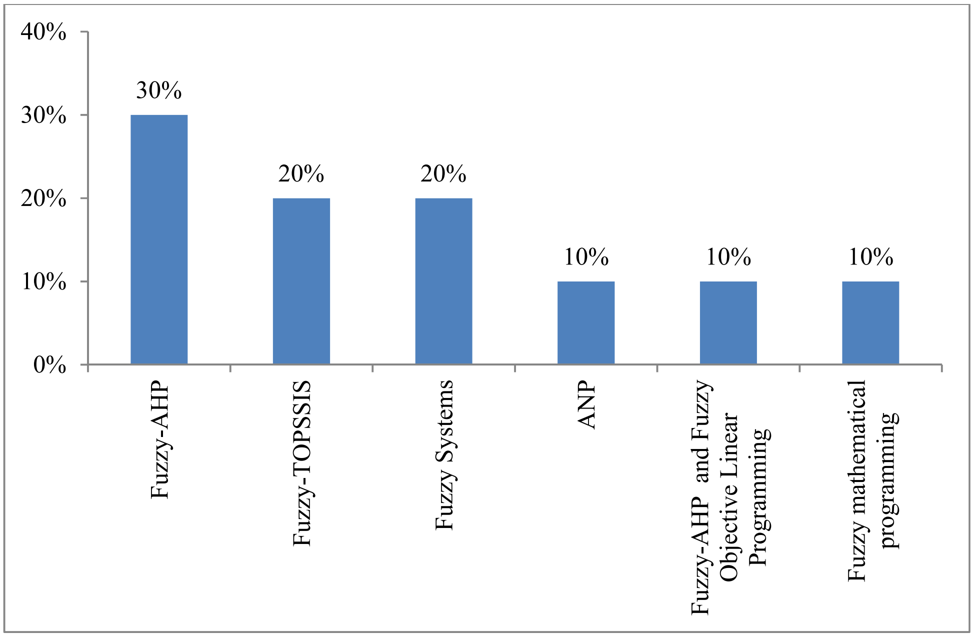

Figure 1.10 MCDM methods at operational level

1.5.1 Results of MCDM methods of SC cycle considered

The literature review covered in this chapter presents the effective and extensive application of MCDM methods, specifically Fuzzy decision-making and its combination with TOPSIS, AHP, ANP, mixed integer linear programming, genetic algorithm, goal programming and linear regression analysis at different levels of SCM decision-making. After summarizing the methods at the strategic, tactical and operational levels of decision-making, researchers and practitioners can now easily select the two best widely used methods in SC decision-making.

Further, this research will help managers select a suitable technique from widely used MCDM methods for supplier selection, manufacturing, warehousing, logistics, sustainable SC and SC performance and risk management. Figures 1.11 to 1.15 show the top three MCDM supplier selection, manufacturing, warehousing, logistics, and integrated SC.

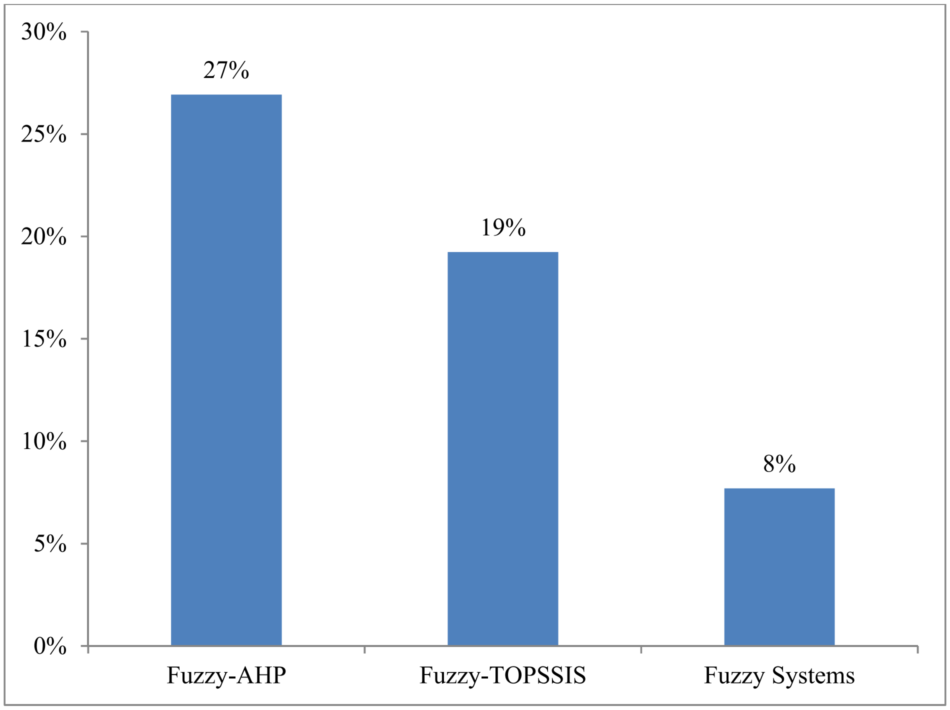

Figure 1.11 Top three MCDM methods for supplier selection

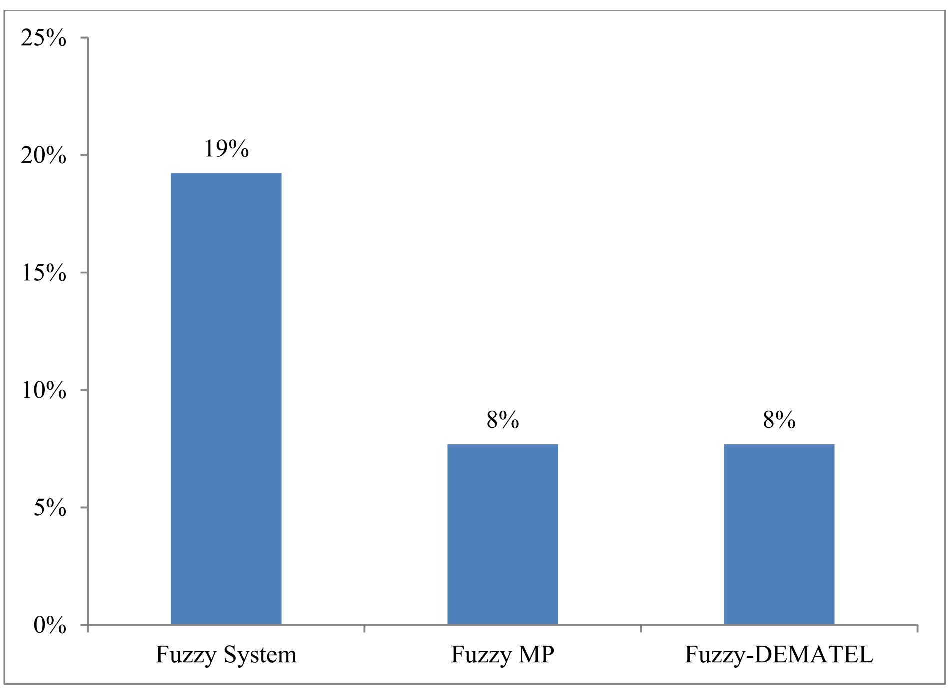

Figure 1.12 Top three MCDM methods for manufacturing

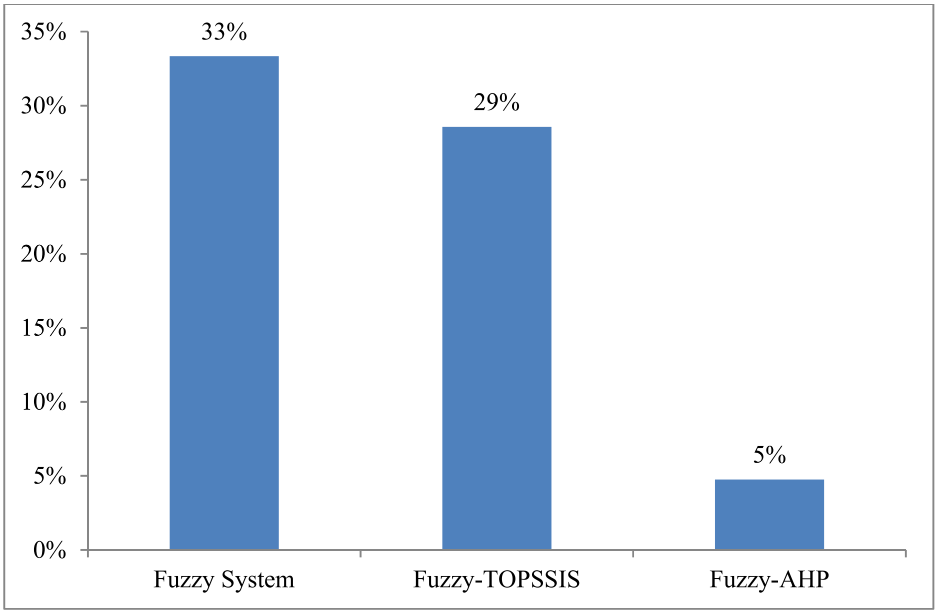

Figure 1.13 Top three MCDM methods for warehousing

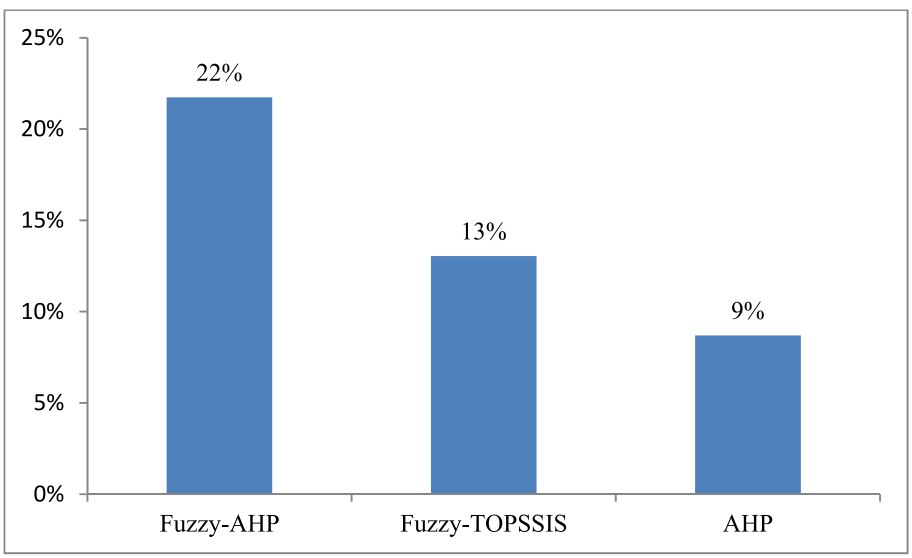

Figure 1.14 Top three MCDM methods for logistics

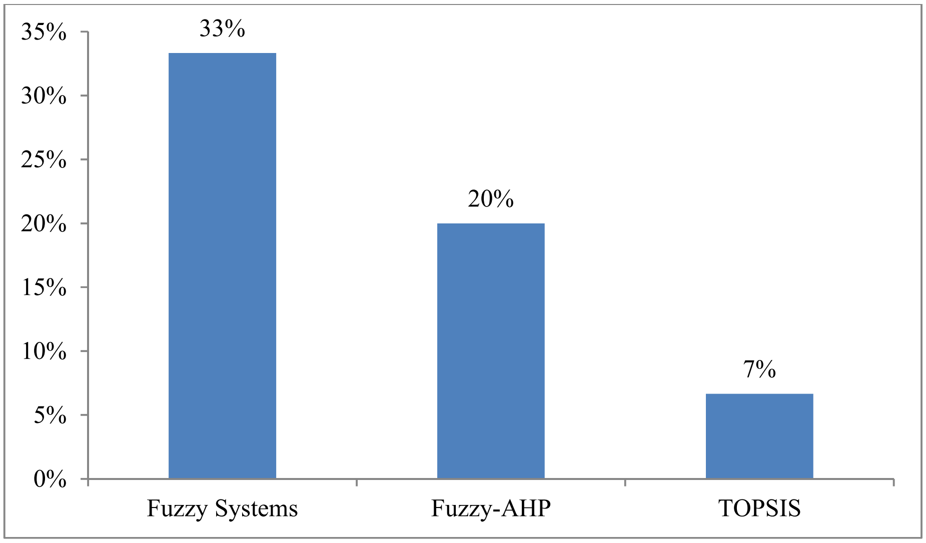

Figure 1.15 Top three MCDM methods for integrated SC

1.5.2 Distribution of MCDM methods with respect to application area

This study considered the application of MCDM methods in almost all sectors. After an extensive literature review, we found that many authors, managers, and researchers have applied MCDM methods in many sectors. The top five areas of application are i) General models, ii) Manufacturing, iii) Logistics service provider, iv) Automotive, and v) Process industry. Figure 1.16 shows the percentage distribution of the application areas for MCDM methods.

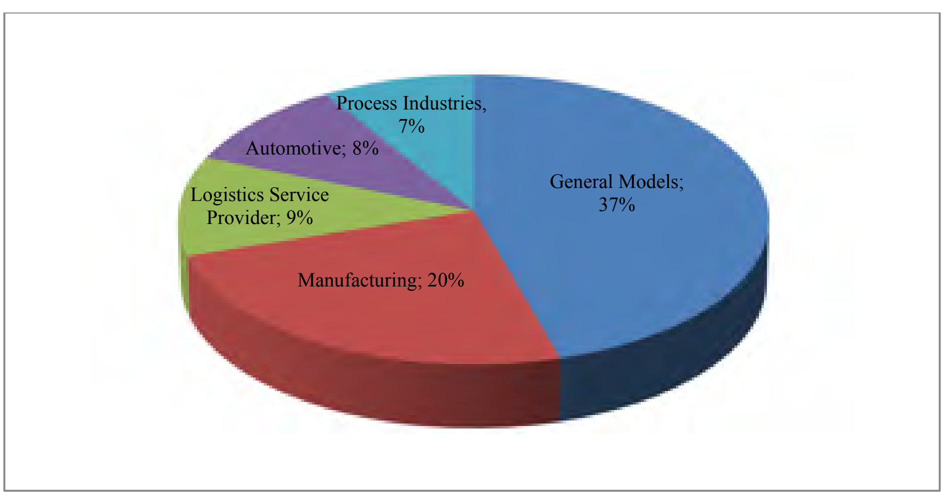

Figure 1.16 Top Five MCDM methods in terms of area of application

1.5.3 Paper Distribution at Different Levels of Decision-making

This study analyzed selected papers and categorized them into three levels of decision-making, namely, Strategic, Tactical and Operational. The study shows that 56% of the papers seen applied MCDM methods at the strategic level, 35% at the tactical level, and 9% at the operational level. Figure 1.17 shows the results.

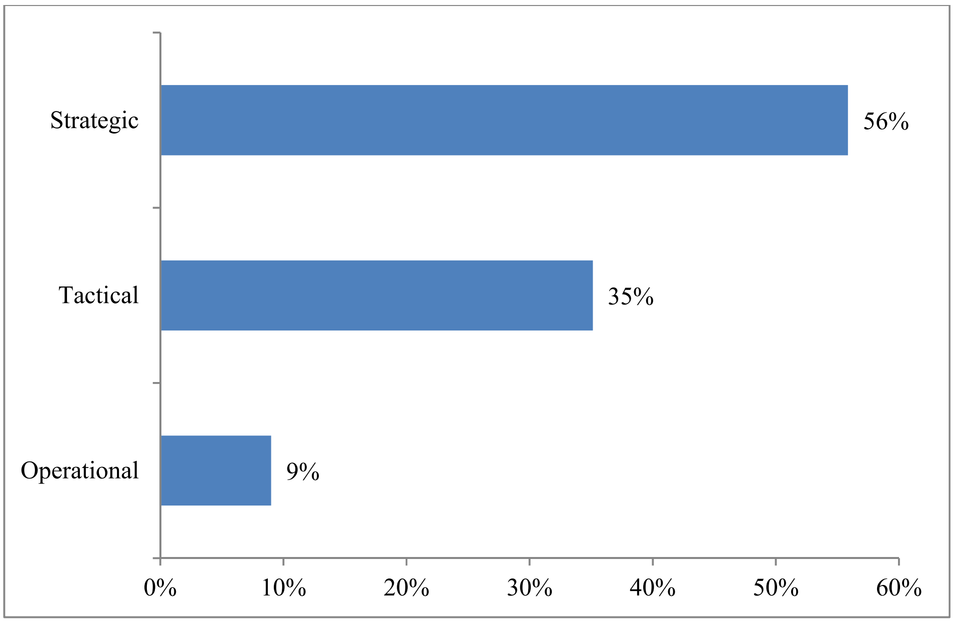

Figure 1.17 Paper distribution at different levels of DM

1.5.4 Paper distribution at different levels of decision-making

Managers and decision makers need to select the best method at each level of decision-making in the entire SC. Figure 1.18 shows the use of MCDM methods at each level of decision-making in the entire considered SC cycle. We can infer from the figure that at a strategic level, 67% of papers applied MCDM methods in warehousing decisions; at a tactical level, 58% of papers used MCDM methods in manufacturing; and at an operational level, 17% of papers used MCDM methods in Logistics.

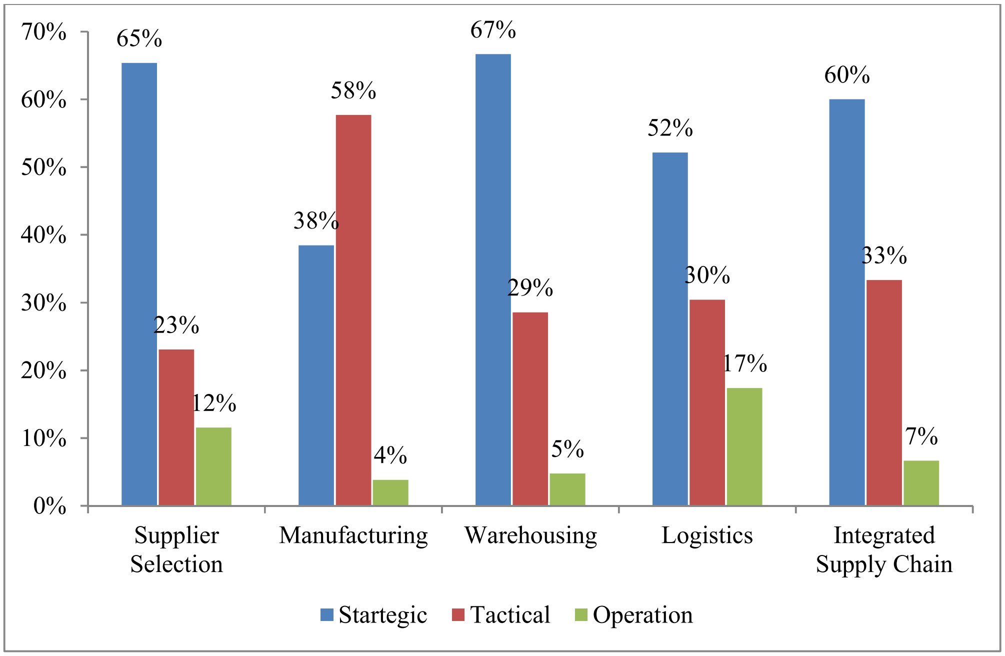

Figure 1.18 Paper distribution at different levels of DM of considered SC functions

1.5.5 Paper distribution at different levels of uncertainty

Uncertainty is inherent in SC functions and information related to different parameters (delivery time, quality of the product, machine downtimes, etc.) is vague and uncertain. Thus, this study analyzed selected papers and categorized them into four sub-categories, namely, internal uncertainty, external uncertainty, no uncertainty and both internal and external uncertainty considered. Figure 1.19 shows that in applications of MCDM methods, internal uncertainty is not considered (0%) at all in supplier selection and integrated SC. Similarly, in applications of MCDM methods in integrated SC, the highest number of papers (80%) considered both internal and external uncertainty in the DM process.

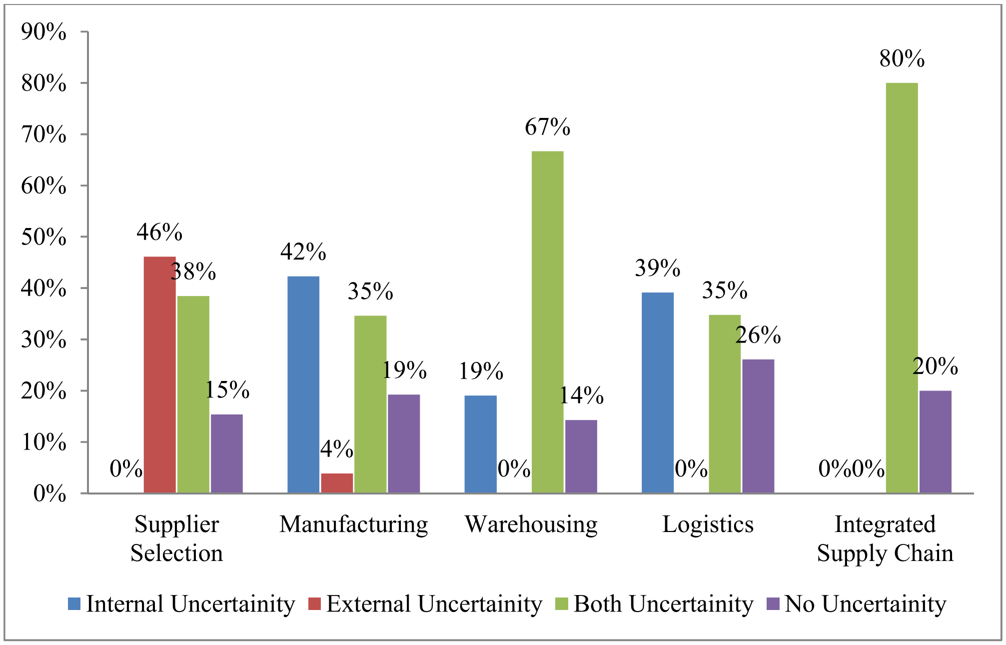

Figure 1.19 Paper distribution at different uncertainty levels in considered SC functions

1.6 Discussion

The systematic literature review on the application of MCDM methods in SCM demonstrates the richness of MCDM to take different DM perspectives in the decision process. At the early stage of application, most of the methods focus on the fragmented SC structure with inefficient processes at the supply, manufacturing, warehousing and logistics levels. The subsequent integration of SC processes motivates the application of MCDM to improve the global decision process (more holistic). However, the integration comes with many challenges. First, more criteria have to be considered in the decision process. Second, the number of decision makers increases. Finally, more uncertainty becomes present in the decision process.

For long-term decisions (strategic and tactical), the decision process involves many criteria resulting from the information collected through the different SC functions. Also, most often, different decision makers (SC actors) are involved in the decision process. Thus, the use of MCDM methods is more suitable for Long and mid-terms decisions (more than 91%). However, the application of MCDM for short-term decisions (operational/real time) is limited to only 9%. Indeed, operational decisions are made very rapidly, and only partial information is usually available due to a lack of data. Thus, the application of MCDM is not predominant and sometimes more difficult to implement.

For the supplier selection process, a detailed analysis (Figure 1.18) shows that MCDM methods are commonly used for long-term (strategic and tactical) decisions (88%). This result can be explained by the intensification of global commerce due to globalization and ever-greater competition, where supplier selection is critical. Thus, the appropriate supplier selection plays a vital role in organizational success. Conversely, the smallest number of researchers and DMs (12%) used MCDM methods at the operational level because of the fact that supplier selection and evaluation decisions have an impact on product quality, delivery, the cost of material, and service level. Therefore, decisions such as make-or-buy and the establishment of long-term contracts with suppliers must be aligned with the strategic goals of an organization, and cannot merely be taken at the operational level.

Regarding the manufacturing process, long-term (strategic and tactical) decisions are also critical and include the development of technology selection and capacity expansion strategies to overcome the shortage, minimize cost and maximize overall production efficiency. Again, the literature review analysis shows that 96% of MCDM methods are applied for long-term (strategic and tactical) decisions. For short-term manufacturing decisions, we are usually in the execution process of production, and there is less flexibility is decision-making. Thus, we notice that only 4% of the studies used MCDM methods for short-term MCDM (operational level).

Long-term warehousing decisions include the location and the design (technology choice and capacity) of the facility, which is one of the drivers of SCM. Moreover, the number of facilities (Warehouses and Distribution Centers) determines the total cost as well as the response time. For that reason, different criteria are used to make the appropriate decisions. A significant amount of MCDM methods are applied in this context (95%). However, only 5% of papers applied MCDM methods at the operational level has been reported in our study.

For logistics activities, Figure 1.18 shows that many researchers and decision makers applied MCDM methods for long-term (strategic and tactical) efforts (approximately 83%). An effective and efficient logistics system requires long-term planning by considering future expansions, mergers, and globalization. Long-term decisions help organizations reduce transportation cost and increase delivery service. For short-term decisions (operational), decision makers are obliged to take rapid action because of uncertainty caused by the manufacturing or logistics service provider. Therefore, this study shows that 17% of researchers and decision makers applied MCDM methods for short-term DM (operational), which is highest among all considered SC functions.

An integrated SC approach increases the complexity of the decision process since information and the relationship between SC functions are no longer independent. This integration allows decision makers to take a holistic view and better evaluate the performance. The integration forces SC visibility. The literature on SC DM and SC performance measurement shows that integrated SC is essential for effective and efficient management of SC (Wong et al. 2007; Lambert & Pohlen 2001; Asadi, 2012).

Integrated SC makes it difficult for DM to make effective and efficient decisions due to the fact that global organizations are selecting manufacturing sites anywhere around the globe while having to meet local product standards. Similarly, managers and DMs have to find a way to adopt sustainability in their logistics, manufacturing, while minimizing overall SC cost. Moreover, in integrated SC, managers, and DMs have to deal with uncertainty related to all functions of SC, such as fuel prices, increasing awareness of customers and legislations related to sustainability in SC; ever rising customer demand; technological changes; new means of transportation, etc. Furthermore, each SC function has its own objectives, and most often, they are conflicting in nature. All these factors make DM in integrated SC more and more complex. In order to cope with these challenges, we need hybrid MCDM that capture uncertainty in integrated SC and rank priorities to deal with conflicting objectives. Our study also reflects the fact that many MCDM methods (53%) applied in SCM used Fuzzy and hybrid Fuzzy methods.

In the context of uncertainties, results from the previous sections (see Figures 1.19) demonstrate that the Fuzzy sets theory is widely used at different decisions levels of the

SC. It is also important to notice that this progress is in line with the evolution of SCM in the last 20 years. Indeed, we observe more complexity of SC networks and offshoring that lead to various sources of uncertainty through the different SC functions. Moreover, the reduction in product life cycle forces us to move toward a more agile and flexible SC with highly unpredictable demand. Thus, the decision process must be more sensitive to this reality and useful to handle uncertainty in different SC criteria and data, more specifically for long-term decisions (strategic and tactical). MCDM methods have been successfully applied in the major SC functions. For supplier selection, many attributes are uncertain, and decision makers have to consider external and internal uncertainty. Poor quality or lead time, technological capabilities are among the internal factors. External uncertainties such as a change in the political situation, disruptions in suppliers' suppliers, variation in quality of delivered products and on time delivered products are also among the factors considered in many studies. This finding in our study shows that many decision makers applied MCDM methods in supplier selection decisions, and considered both internal and external uncertainty together (38%) and only external uncertainty (46%). Only a few applications (15%) did not consider uncertainty at all in their supplier selection DM.

Dealing with internal uncertainty in manufacturing decisions is challenging because of the availability of vague information. The vague internal information which causes internal uncertainty is related mainly to machine downtime, worker strikes, staffing/operator problems, quality problems due to mishandling at shop floor, etc. Furthermore, in manufacturing decisions, we cannot consider only external uncertainty. External uncertainties are usually associated with the reliability of supplier performance, customer preference change, cancellation or modification of existing orders, and technological change. This is also reflected in our study, as well the fact that 42% of decision makers considered internal uncertainty, followed by 35% of papers that considered both internal and external uncertainty in the application of MCDM methods in manufacturing decisions.

Warehousing decisions have a significant impact on SC performance. In deciding about the selection of the warehouse location or size, decision makers must consider both internal and external uncertainty for efficient and effective decisions. Consideration of internal or external uncertainty alone is not sufficient, and we need to consider both internal and external uncertainty together in order to take more realistic decisions. External uncertainty factors are labor unavailability, labor cost, tax tariff, etc. and internal uncertainties are space utilization, variable cost, and cost of utilization associated with material handling equipment. Our study also shows that a majority (62%) of papers considered both internal and external uncertainty in applying MCDM methods.

Appropriate logistics decisions increase the service level and increase client satisfaction. However, essential activities associated with logistics operations cannot be done perfectly due to the presence of uncertainty in meeting desired logistics objectives. External uncertainties such as vehicle condition (e.g., breakdown), route uncertain (e.g., a vehicle stuck in a traffic jam) will affect deliveries, and short-notice amendments will be needed for suppliers. Internal uncertainties are mainly due to customer order changes, lack of information sharing among different internal stakeholders, and variability in logistics service providers. For effective and efficient logistics DM, decision makers should include internal uncertainty alone or both uncertainties (internal and external). This is also reflected in our study, where a majority of papers (74%) dealing with the application of MCDM methods considered internal uncertainty (39%) and internal and external uncertainty (35%) in the DM process.

Finally, effective management of uncertainty among SC functions is the major factor for improving overall SC performance. It is challenging for SC managers to manage SC in dynamic and uncertain environments, where information is unclear and predicting distribution is not easy. In order to meet customer demand in this challenging environment, decision makers must include uncertainty from all functions of SC, which consists of initial material supply, manufacturing, distribution, and consumer market. This is also reflected in our study, which shows that a significant number of papers (73%) applied MCDM methods, considering both internal and external uncertainty together, while only 27% of decision makers applied MCDM methods while not considering uncertainty at all. This demonstrates that in integrated SC, both certainty and uncertainty must be considered together. This will provide a holistic view of the uncertainty of the whole SC and help decision makers prevent and plan expected disruptions.

1.7 Limitations and further research directions

This literature review has a number of limitations, detailed as follows:

- This review is limited to academic reviewed journals and conferences. Therefore, unpublished work, non-reviewed articles, working papers, and practitioners' articles can be included in a future extension of this research.

- This review spanned 11 years (2005-2015) , and we believe it is representative of the literature on the application of MCDM methods in SCM. Although this study is not exhaustive, it is, however, comprehensive (111 papers) enough to allow a conclusion.

- In this systematic literature review, we followed guidelines provided by Seuring & Gold (2012) and Seuring, Müller, Westhaus, & Morana, 2005). Any disagreements on including particular keywords or articles were solved through discussion. As inspired by Seuring & Gold (2012) and Leiras, Brito Jr, Peres, Bertazzo, & Yoshizaki (2014), our focus was on the latest research in the field of MCDM applications in SCM.

- This review considered a combination of both standard (Supplier selection, Manufacturing, Warehousing, Logistics) and emerged (Integrated SC) concepts of SC functions. Additional SC functions such as reverse logistics and subcontracting can be included in future research.

- In the allocation of DM levels (strategic, tactical, and operational) in a particular paper, we followed the definition of DM level by David Simchi-Levi, Kaminsky, & Simchi-Levi (2008) as mentioned in table 1.2.

- In this study, the distribution of papers that considered uncertainty is based on criteria and sub-criteria considered in each paper and across considered SC functions only.

- The allocation of papers for a particular uncertainty category (internal, external, both, and no uncertainty) depends on the definition by Stewart and Durbach (2016) as mentioned in sections 1.2.6, 1.2.7 and 1.2.8.

In SC, there are many criteria that have to be considered while making decisions. These criteria are often conflicting in nature and MCDM methods, and their integration with other methods are able to provide a framework for DMs in solving SCM problems and challenges. Moreover, with more globalization and digitalization, data availability is increasing, and the potential application of MCDM methods in tackling SCM problems under uncertainties becomes inevitable but need a transformation. Based on this study, the following future research directions are proposed:

- In future, selected papers of this study can be further analyzed to know uncertain criteria have been used for internal and external uncertainty in considered SC functions.

- Today, organizations and decision makers are eager to understand the performance of their entire SC rather than specific SC function, and so we need to utilize the application of hybrid MCDM methods in measuring overall SC performance.

- Integration and linking between SC functions are the keys to meet today's challenges, and as a result, utilizing MCDM methods in developing an integrated framework to measure and improve overall SC performance will be helpful for DMs and managers.

- Managers and DMs will like to see the effect of short-term decisions and decision criteria and on long-term decisions and decisions criteria. This will help them in making appropriate decisions and they will be able to see the impact of their decision on overall SC performance. Hybrid MCDM methods will be efficient in fulfilling the development of such a framework.

Notwithstanding the above-mentioned limitations and future research direction, we strongly believe that this study is in a very important area, namely, applications of MCDM methods in SCM and should fill a gap in the literature.

1.8 Concluding remarks

This chapter presented a systematic literature review on the application of MCDM methods in considered SC functions, namely, supplier selection, manufacturing, warehousing, logistics, and integrated SC. 111 papers covering a time span of eleven (11) years from a well-known database were gathered, analyzed, and categorized in terms of a long-term and short-term (strategic, tactical, and operational) DM perspective, MCDM method considered, and application area. This study concludes that the research and application of MCDM methods in SCM have grown significantly in recent years. This study will help managers and decision makers select appropriate MCDM methods at a specific level of DM (strategic, tactical, and operational) and provide guidelines to managers to see which application area uses which MCDM methods. It is evident from the literature that MCDM methods are capable enough of handling uncertainty and providing decisions by considering practical situations.

Furthermore, this study shows that Fuzzy sets and its integration with other MCDM have been effectively and efficiently applied at every level of the SC decision-making process as well as in the considered SC functions. This is because of the fact that due to digitalization and massive data available in the organization, the perspective of SC has been totally changed. Organizations and decision makers need to change their traditional thinking when it comes to how to manage SC. Moreover, due to the availability of real time data and information, the application of MCDM for short term decisions will add great value to the decision process and reduce uncertainty in managing SC. Fuzzy sets are well-known and proven methods for capturing uncertainties and quantifying vagueness. Giving a value to something like “responsiveness,” which is of great importance, could be tricky. It is difficult to measure “responsiveness.” Fuzzy logic can easily be used in situations that have uncertainty and imprecision (Sirigiri, Gangadhar, & Kajal, 2012). Therefore, we believe that this systematic literature review answers all research questions that were raised, and achieved the main objectives of our research.

CHAPTER 2

LITERATURE REVIEW ON EXISTING SUPPLY CHAIN PERFORMANCE MEASUREMENT SYSTEMS

Management of SC is becoming challenging by each passing day to SC managers due to high competition, ever rising customer demand, globalization, digitalization, and the internet of thing (IoT). In order to cope up with these challenges, SC managers need a responsive and effective way to manage their SC. SC effectiveness cannot be improved without measuring SC performance efficiently and taking decisions at the right time and at the right MCDM level. Each and every decision is important and essential for SC performance and has an impact (directly and indirectly) on overall SC performance. Due to this fact, importance of supply chain performance measurement systems (SCPMS) has been increased significantly. Therefore, the purpose of this chapter is in two folds: First we will review all existing SCPMS, categorize them into different dimensions (MCDM levels, functions/perspective considered, financial / non-financial, integrated SC functions). Secondly, we will identify their limitation in line with emerging trend of managing SC and provide guidelines of new proposed SCPM system that overcome the limitations of existing SCPMS. In last future of SCPMS will be discussed.

2.1 Introduction

The importance of SCPMs, in the context of overall organizations performance, is seen by the considerable amount of research and extensive published literature in this field. There are several perspectives of SCPMs explained by the researchers and practitioners like cost and non-cost perspective, strategic, tactical and operational perspective, business process perspective and financial perspective. It has been suggested by several researchers and practitioners in their studies that a lot of the performance measurement frameworks require being established through additional studies. In addition, creating appropriate SCPM is fairly difficult due to the complexity in SC network. In performance measurement of SC, we need to get information and provide it to top management. At the same time, we need to identify what kind of SC performance systems considers which MCDM level. Managers and decision makers need to know how well your SC is performing (Sillanpää, 2015).

SCPM helps management in monitoring and improving and helps organizations in gaining a competitive edge. According to Taghipour et al. (2015), evaluation of several performance measure frameworks already recommends that SCPM can be perceived under different categories such as “cost and non-cost; strategic and operational level; financial and business process perspective; customer, financial, internal operation, learning, and growth perspective.” As stated by Ambe (2014), measuring SC performance can facilitate a greater understanding of the SC, positively influence actors’ behaviors, and improve its overall performance. There are many indicators of performance that can be deployed in an organization.

Similarly, Charan et al. (2008) mentioned that “SCPMs serve as an indicator of how well the SC system is functioning.” Managers are keen to gauge the performance of the system that they execute. The existence of a mere model is not important alone. It is important that the model is used to assess the organization’s performance and as a reference point, internally and externally, for effective and efficient development (Dweiri & Khan, 2012).

2.2 Supply chain performance

In order to improve any system, you need to measure current performance of a system. If you are not able to quantify your performance, it is difficult to improve your system. Performance can be defined as *“Production of valid results.”*

This shows that you have to measure your performance by calculating results. Once you are able to measure performance, you need an appropriate way to manage your performance. Performance management can be defined as *“A process, a metrics or a set of metrics that used to quantify both the efficiency and effectiveness of actions.”*

It means that we need a systematic way to measure performance. This requires effective and efficient performance management systems. Performance management system can be defined as *"Provides data that will be collected and analyzed to use in MCDM."*

Performance measurement plays a vital role in aligning customer satisfaction with MCDM and company's objectives. Moreover, it helps decision makers in identifying which area needs improvement. Neely et al. (2005) mentioned that if you are able to measure your performance and able to express it in terms of number, you will be able to improve it. Similarly, Gunasekaran et al. (2001) highlighted the importance of SC performance systems and said effective performance is as necessary as SCM.

Wong et al. (2007) pointed out that literature on performance measurement had not seen SC as a separate entity, therefore making it difficult to evaluate performance with several inputs and outputs to the system. Lambert & Pohlen (2001) affirmed that SC metrics are in reality about internal logistics performance measures that have an inner focus and do not show how the firms make value or profitability in the SC. It has been suggested that SC performance indicators should be measured in the form of input-output ratios, despite their qualitative or quantitative characteristic (Asadi, 2012). The use of basic performance measures are inadequate and might be conflicting with the strategic objectives of an organization. Based on the discussion above, this article combines relevant literature and suggests why it has been difficult in defining and collecting what SC indicators are.

Several indicators of performance can be implemented in an organization. However, as mentioned by Folan & Browne (2005), there are a comparatively small number of vital dimensions that contribute more than proportionally to success or failure in the market, which has been named key performance indicators. Therefore key performance indicators should relate to both effectiveness and efficiency of the SC and its actors. Van der Vorst (2000) stated that a division should be made among performance indicators using three different levels which are i) the SC level, which includes availability of manufactured product, its quality, reliability, and responsiveness towards delivery, and total SC cost; ii) the process level which includes responsiveness, production time, process yield and costs related to process; and iii) the organization level which includes inventory level, throughput time, responsiveness, delivery reliability and total organizational costs.

Pettersen (2009) stated that four main indicators should be used in order to improve SC efficiency and effectiveness which are; profit, lead-time performance, delivery promptness and waste elimination. There are following challenges in measuring SC performance.

- Nature of SC Cycle
- Dependency in SC
- Linguistic and non-linguistic Criteria
- Financial and Non-Financial Measures
- Consideration of Different MCDM Levels
- Integration of entire SC Cycle

2.3 SCPM systems

As defined by Neely et al. (2005), "Performance Measurement System (PMS) is a balanced and dynamic system that facilitates support of decision-making processes by gathering, elaborating and analyzing information." Taticchi et al. (2010) further explained this definition by "commenting on the concept of 'balance' and "dynamicity." 'Balance' refers to the need of using different measures and perspectives which, when tied together, give a holistic view of the organization". "Dynamicity" refers to the need of creating a system that constantly monitors the internal and external context and reviews objectives and priorities. SCPMS was defined by Bititci et al. (1997) as a "reporting process that gives feedback to employees on the outcome of actions." Tangen (2005) suggested that "performance could be defined as the efficiency and effectiveness of action, which leads to the following definitions: (i). A performance measure is defined as a metric used to calculate the efficiency and/or effectiveness of an action; (ii). Performance measurement is the process of calculating the efficiency and effectiveness of action; and (iii). Performance Management System is a set of metrics used to quantify the efficiency and effectiveness of an action". Christensen, Germain et Birou (2007) stated that "effective SCM has been connected with a variety of benefits which include increased customer value, increased profitability, reduced cycle times and standard inventory levels and improved product design."

Tangen (2005) mentioned that "the purpose of SCPM, therefore, has to aid and enhance the efficiency and effectiveness of SCM. The key goal of SCPM models and frameworks is to support management by aiding them in measuring business performance, analyze and improve business operational efficiency through better decision-making processes". Similarly, Charan, Shankar & Baisya (2008) highlighted the importance of SCPMS and stated that "A useful, integrated and balanced SCPMS can employ the organization's PMS as a medium for organizational change. SCPM can facilitate inter-understanding and integration among the SC members. It makes a crucial contribution to MCDM in SCM, particularly in re-designing business goals and strategies, and re-engineering processes".

Over the last decade, many authors conducted a literature review in SCPMS, classified them in terms of different categories, methodology and criteria. Maestrini et al. (2017) conducted a literature review for the period of 1998 to 2015 and provide a complete review of SCPMS literature in terms of general characteristics and content of articles, discusses the challenges and future research direction of SCPMS. Manikandan & Chidambaranathan (2017) developed a two-dimensional framework to classify SCPM literature from 2000 to 2015 in terms of methodology, approaches, and models. Similarly, Gopal & Thakkar (2012) gathered published articles in the field of SCPMS and categorized them in terms of three phases of performance measurement system life cycle. Cuthbertson & Piotrowicz (2011) performed literature review in SCPMS to categorized papers from 1998 to 2009 in terms of methodology and content of considered articles. Akyuz & Erkan (2010) gathered articles in the field of SCPMS from 1999 to 2009 and categorized them from in terms of different issues such as general issues in SC, considered approaches, issues related to performance management and matrices. Gunasekaran & Kobu (2007) conducted a literature review in SCPMS and review papers from 1995 to 2004. Reviewed papers have been categorized in terms of different perspectives such as MCDM level, the perspective of balanced scorecard and nature of PMs. Considering the importance of SCPMS especially in the context of current challenges that SC managers and decision makers are facing, this chapter is an attempt to overcome the limitation of previous literature review papers and contributed in SC and SCPMS literature as follows:

- This chapter reviews existing SCPMS and highlight their focus area and limitations.

- This chapter categorized all existing SCPMSs in terms of MCDM level, in terms of perspectives considered, financial and non-financial PMSs, and integration between SC functions.

- This chapter discusses the trends and transformation of future SCPMS based on challenges that SC is facing because of advancement in technologies.

2.4 Review of existing SCPMS

Many authors developed SCPM frameworks specifically for their needs or for specific organization types. This section will explain existing performance measurement frameworks and highlights their limitations in the context of today's competitive, dynamic and demanding SC cycle. Figure 2.1 shows the classification of literature in SC performance management.

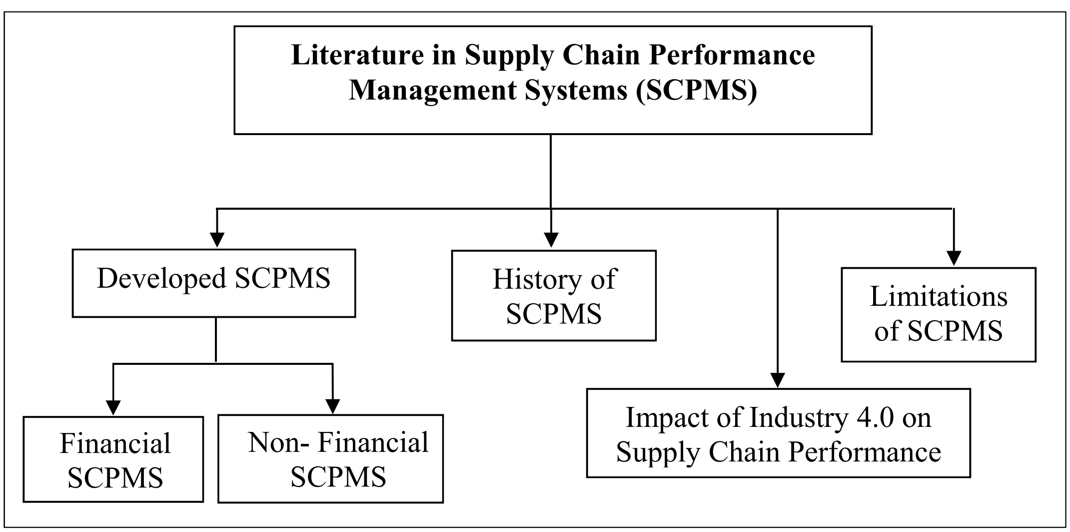

Figure 2.1 Classification of SCPMS Literature

Literature associated with developed SC performance management system is considerably large in number. Available literature is scattered. However, several authors have tried to collect major supply chain performance management systems into different perspectives such as Kurien & Qureshi (2011), for example, condensed nine theoretical SCPM frameworks which are i) Balance scorecard (BSC), ii) Performance prism, iii) Performance pyramid, iv) Theory of Constraints, v) Medori and Steeple's Framework, vi) The Supply-Chain Operations Reference (SCOR) Model, vii) Data Envelopment Analysis (DEA), viii) Time-based Performance Measures and ix) Other Frameworks of supply chain performance.

Agami et al. (2012) and Kurien & Qureshi (2011) organized SCPM frameworks and models into two main categories, namely, financial and non-financial and nine sub-categories of non-financial categories which are portrayed in figure 2.2.

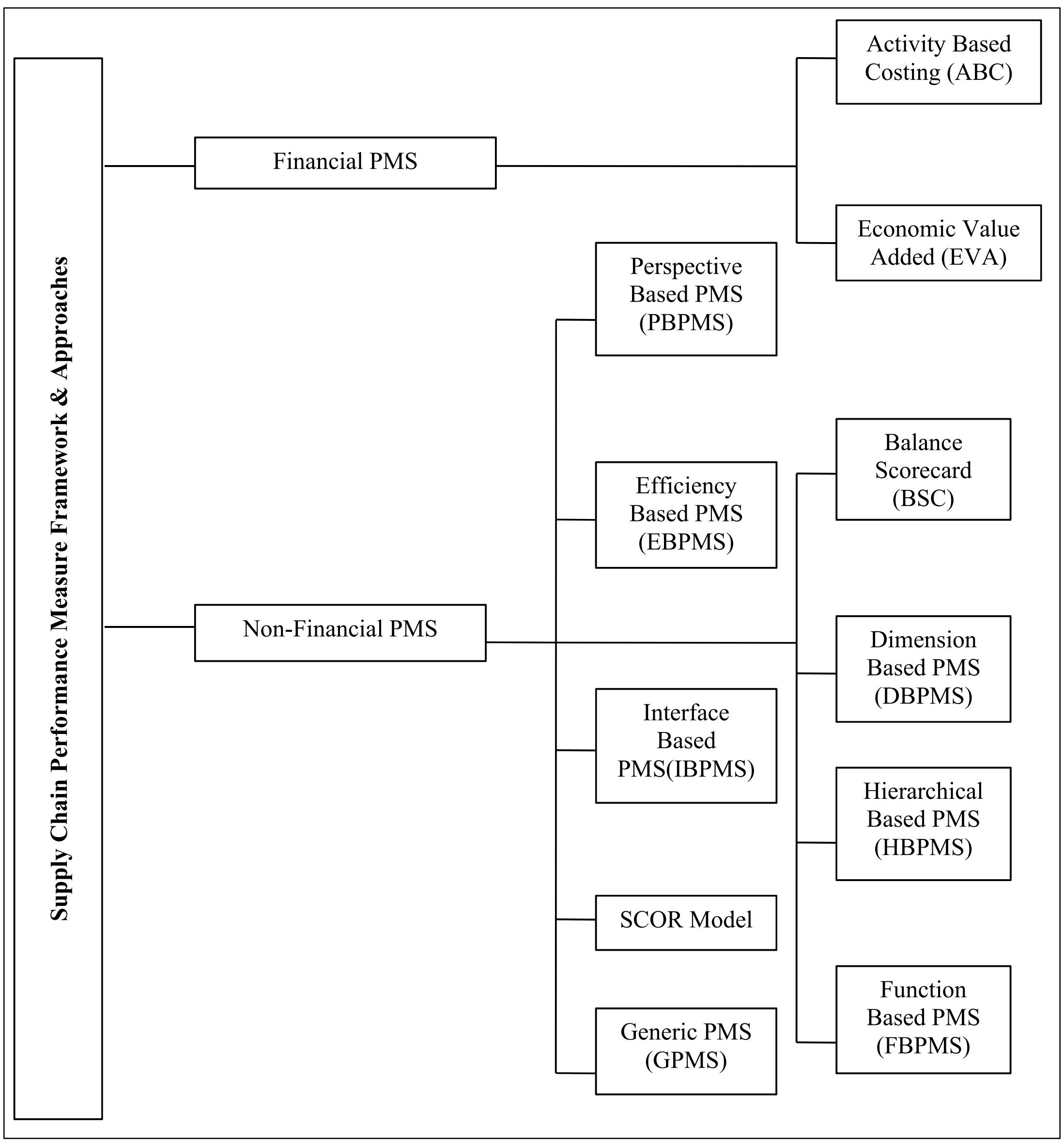

Figure 2.2 Supply Chain Performance Management Systems Classification (Developed from Agami et al. 2012 and Kurien & Qureshi, 2011)

2.4.1 History of SCPMS

As mentioned by Beamon (1999) and Gunasekaran et al.(2001) "Over the last decade, there have been multiple articles in which the theory and practice of SCM have been studied. SCM performance or capability does not have so much consideration in the SCM research field". Organizations have recognized a huge potential in developing SCM. This is one of the reasons for SCM capability measure metrics being required. The most important way to start development work of the whole SCM is by measuring SCM competence.

A history of performance measurement was presented by Morgan (2004), and he stated that "the background of performance measurement lies in 15th century , when accounting was discovered with the creation of double entry book keeping. The double-entry book accounting measurement system was doing well until the early 1900s. Since then concepts of performance measurement have been challenged by accounting professionals. Morgan divided traditional performance measures into four parts: financial, operations, marketing, and quality. Financial measures are common measures like stock turnover, ROE, ROCE, current ratio, gross profit, gearing, etc.". The problem of using financial metrics is that they are not relevant in day-to-day operations because these metrics are available after some time period when the production action has already been carried out. Essentially financial metrics are most in use at top level management where the strategic decisions are made. Operations measures include operations lead-time, labor utility, set-up time, machine utility, process, etc.

As suggested by Ramaa et al. (2009) "the performance indicators first came out in the form of a combination of financial and non-financial criterion. The performance indicators in the 19th century were in the following forms: the cost per yard and the cost per metric ton. At the start of the 20th century, expansion and authorization have brought on the reformation of performance measurement". The environment faced by companies, after the Second World War, was filled with ambiguity and variation and it had to stabilize the relationship between the different stakeholders such as “sales and marketing,” “research and development,” “personals and human resource” and “accounts and finance.” Therefore, different indicators including “financial and non-financial” came into sight (Ramaa, Rangaswamy & Subramanya, 2009).

In the 1990’s, many researchers developed different SC performance measurements systems which are based on time and inventories. Levy (1995) set up “performance measures such as average finished goods inventory and demand fulfillment.” Christopher also presented some SC performance measures such as “order cycle time,” “order completeness” and “delivery reliability.” Christopher (2005) to SC performance measures included delivery performance, lead-time, the level of defects and responsiveness.

Davis presented “inventory levels, inventory investment, order fill rate, line item fill rate and an average number of day’s late measures.” Davis (1993) measures showed by Lee & Billington (1992) were “inventory turns, line item fill rate, order item fill rate, total order cycle time, total response time to an order, average back order levels and average variability in delivery.” Lee & Billington (1992) and Neely et al. (1995) “introduced various ways for measuring SCM performance.” Additionally, other researchers introduced further approaches to performance measurement which are “the BSC (Kaplan & Norton, 1992), the performance measurement matrix (Keegan, Eiler & Jones, 1989), performance measurement questionnaires (Dixon et al, 1990), and criteria for measurement system design (Globerson, 1985)”. Neely et al. (1995) “have been cited by many researchers of SCM measurement (Beamon 1999; Beamon & Chen 2001; Gunasekaran et al. 2001; Gunasekaran et al. 2004)”.

Neely stated that “performance measurement could be analyzed on three levels: the individual metrics, the set of measures or PMS as a body and the relationship between the measurement system and the internal and external environment in which it operated. The capability could be measured by calculating the five SC processes: plan, source, make, deliver and return or customer satisfaction; whether they measure cost, time, quality, flexibility and innovativeness; and, whether they are quantitative or qualitative (Shepherd & Gunter 2006; Neely et al. 1995)”. SCM performance measurement was presented using different approaches in the 2000s such as “Shepherd & Gunter (2006) classify SC performance measurement research into operational, design and strategic research (Shepherd & Gunter 2006). Operational research creates mathematical models for increasing SC performance (Lin et al. 2006; Smith, Lancioni, & Oliva 2005). Design research focuses on optimizing performance through redesigning the SC (Shepherd & Gunter 2006). Design research can be classified according to the type of research model: deterministic analytical models (Chen et al. 2006); stochastic simulation models (Hwarng, Chong, Hie, & Burgess, 2005); and strategic research assesses how to match the SC with a firm’s strategic objectives (Balasubramanian & Tewary, 2005)”.

2.4.2 Financial performance measurement systems (FPMS)

It is apparent from the literature that a lot of firms measure SC performance in the perspective of financial measure only. Agami et al. (2012) suggested that financial measure primarily focuses on indicators which rely on financial parameters and so constantly question for not being suitable because they do not take into account critical strategic non-financial measures which were discussed before. Several authors sort out financial PMS into various categories. Nevertheless, literature showed two very famous financial measurement systems which are as follow:

2.4.2.1 Activity based costing (ABC)

Activity based costing approach was essentially an effort to combine operational performance with financial performance. Kaplan & Bruns (1987) created this approach and developed the breakdown structure and separated activities into single tasks in order to estimate resources in terms of cost. This was the initial attempt in the improved evaluation of the productivity and cost of SC process. Even though it measures the productivity of the whole SC, this approach has a drawback as the total approach relies on financial measures and metrics. Marwah et al. (2014) similarly explained that ABC is an accounting approach that links cost to each activity instead of products or services. It was developed to primarily look over the deficiency in traditional accounting methods for linking financial measures with operation performance (Agami et al., 2012).

2.4.2.2 Economic value added (EVA)

Stern et al. (1995) built an approach called economic value added so that to estimate the return on capital in terms of value added. Agami et al. (2012) stated that this approach utilizes operating profits that are added to the invested capital (debt and equity) in an attempt to contend the value created by a firm. Despite the fact that EVA is helpful for determining high-level executive contribution and long-term value for shareholders, it has its limitation for indicating operational SC performance as it observes only financial indicators (Agami et al., 2012).

2.4.3 Non-financial performance measurement systems (NFPMS)

It is established that several non-financial SCPMs have been developed till now due to the extensive literature review. Numerous authors addressed these non-financial PMSs. Cuthbertson & Piotrowicz (2011); Akyuz & Erkan (2010); Kurien & Qureshi (2011); Ramaa et al. (2009); Lauras et al. (2011); and Estampe et al. (2013) categorized available non-financial SCPMS into nine groups according to their criterion of measurement. Following is the explanation of the nine non-financial PMSs (Agami et al., 2012).

2.4.3.1 SC balance scorecard

Kaplan & Norton (1992) made a balanced scorecard as a performance measurement tool. Over the year, after its development, it became a leading tool for performance measurement for researchers and practitioners. It offers a framework for firms to execute corporate strategies. As a way to measure success, balance scorecard separated the performance into four main perspectives which are Financial Perspective, Internal business process, perspective Learning and Growth perspective and Customer perspective. Mathiyalagan et al. (2014) stated that in balanced scorecard, indicators are chosen according to the firm’s strategic objectives. Goals are set that need to be accomplished in a particular period of time. Goals are very precise, practical, and measurable and time bound. They are set in a way to take the organization to its strategic objective. The balanced scorecard can, therefore, give an accurate picture of reality. The balanced score card can also facilitate the company to improve itself in all areas both internally and externally. Yet, the balanced scorecard is not delivering coordination along the SC network, poor performance cause and effect are not evident, and decision makers decisions is lacking in synchronization in the SC network (Agami et al., 2012).

2.4.3.2 SC Operations reference model (SCOR)

SC Council created the first version of SCOR model in 1996. The reason was to help organizations boost the effectiveness of their SC. SCOR model is competent to communicate with the SC partners as a decision procedure in terms of Plan, Source, Make and Deliver. SCOR model is excellent for benchmarking and best practice with other organizations, as it explains measures that develop on one another and procedures to be measured. The core objective of the model is to explain, examine and assess SCs (Poluha, 2007). This model illustrates some essential operations that every firm has and presents a detailed description, analysis and assessment of SC. SCOR model stresses heavily on the information flow. Still, it does not contain all processes, overall performance measurement is rather complex, and has no flexibility if you alter measures (Agami, Saleh & Rasmy, 2012).

2.4.3.3 Dimension-based measurement systems (DBMS)

Ramaa et al. (2009) introduced a new idea in the field of SCPM and stated that every SC performance could be measured in terms of dimensions. The foundation of the dimension based measurement system is this. This system is typically simple, adaptable to the environment, i.e., easy to execute and flexible. Nevertheless, the key limitation of this system is that it is not able to reflect the performance of sub-criteria of any main criteria in the entire SC network because dimension based measurement system mainly focuses on the major criteria (Agami et al., 2012).

2.4.3.4 Interface-based measurement systems (IBMS)

Lambert & Pohlen (2001) launched interface based measurement system and proposed a framework in which they connected performance of each player on the SC network.

According to Agami et al. (2012) the proposed model that starts with the relationship with the main company and moves outward one link at a time. This bounded perspective gives way for bringing into line the performance from the point of source to the point of use with the general purpose of increasing the shareholder value for the complete SC along with each individual company. Nonetheless, Ramaa et al. (2009) argued that this approach, in theory, seems well but in the real business situation, it requires openness and total distribution of information at all stages which is eventually difficult to implement.

2.4.3.5 Perspective based measurement system

Otto & Kotzab (2003) created perspective based measurement system in which they identified six major perspectives so that SC performance in terms of perspectives could be measured. These are System Dynamics, Operations Research, Logistics, Marketing, Organization, and Strategy. In order to measure the SC performance, this system needs a separate metric for every perspective. Perspective based measurement system gives diverse visions to evaluate SC performance. However, the decision maker has to made a choice between one perspective and the other perspective (Agami et al., 2012).

2.4.3.6 Hierarchical-based measurement systems (HBMS)

In 2004, Gunasekaran et al. (2004) developed hierarchal based management system in order to assess performance measure at different MCDM levels; strategic, tactical and operational. The thinking behind this measurement system is to give management a framework to make fast and fitting decisions. Agami et al. (2012) suggested that the metrics are divided as financial or non-financial. This system maps the performance measure with the aims and purposes of the organization. Yet, there were no clear guidelines to decrease different levels of conflicts in the complete SC network.

2.4.3.7 Function-based Measurement Systems (FBMS)

Christopher (2005) made a function based measurement system to assess a comprehensive performance measure so that different measures of different SC process can be combined. Regardless of the fact that this system is simple to execute, it is not competent of measuring the performance of top level players in the SC. Function based performance measure only focuses functions separately and in isolation and so the effect of function among each other is not attended in this system (Agami et al., 2012).

2.4.3.8 Efficiency-based measurement systems

Several authors have developed frameworks and measured SC performance in terms of efficiency. Ramaa et al. (2009); Charan et al. (2008); (Wong et al., 2007); and Sharma & Bhagwat (2007) offered a framework and proposed approaches in this perspective. The majority of approaches are based on Data Envelopment Analysis, measuring internal SC performance relating to efficiency. All the proposed approaches linked to efficiency based measurement system measure efficiency relative with each other, despite being a valuable measurement system. (Agami et al., 2012).

2.4.3.9 Generic performance measurement systems (GPMS)

Since the 1980s, many models and frameworks that measure SC performance, in general, have been developed. These frameworks are not particularly for SC performance, but many authors used this generic performance measures framework in the perspective of SC. Kurien & Qureshi (2011) reviewed the most mentioned and used performance measures in SC which are as follow:

- **Performance prism**
  The performance prism gives a better widespread view of various stakeholders as compared to other frameworks. It is a framework that offers different perspectives to calculate performance. The perspectives contain; stakeholder satisfaction, strategies, processes, capabilities and stakeholder contributions (Neely, 2005). According to Kurien & Qureshi (2011) performance prism is able to consider new stakeholders such as suppliers, joint ventures, and employees. Although performance prism is unlike traditional performance measurement frameworks and approaches, it gives little information about

how the performance is going to be identified and selected (Agami et al., 2012).

- **Performance pyramid**

  It is a top down approach, and the aim of the performance pyramid is to offer a link between firm's goals with objectives. It calculates the performance from the bottom up and provides customers perspective importance. The main focus of performance pyramid is to join strategic and operational decisions. Yet, this method does not provide any means to point out key performance indicators; neither has it combined the continuous improvement concept (Agami et al., 2012).

2.5 Limitations of existing SCPMS

After reviewing the literature of above mentioned SCPMs frameworks and approaches, table 2.1 describes the focus area and limitations of existing SCPM framework.

Table 2.1 SC performance management systems: focus area and limitations

S. No.	SCPMs	Focus Area / Measurement Criteria	Limitations
1	Financial Performance Measurement System (FPMS)	Mainly focused on financial indicators	Ignores important strategic non-financial measures and tying financial measures to operational performance
2	SC Balance Scorecard (BSC)	Measure performance in terms of four Perspectives which are Customer, Financial Internal business, and Innovation.	Not providing coordination along the SC network, bad performance cause and effect are not visible
3	SC Operations Reference Model (SCOR)	Communicate between SC partners as decision process in terms of Plan, Source, Make, and Deliver	it does not include all process, overall performance measurement is quite difficult, and not flexible if measures change
4	Dimension-based Measurement Systems (DBMS)	SCPM in terms of dimensions	Not reflect the performance of sub-criteria of any major criteria within the SC network

Table 2.1 SC performance management systems: focus area and limitations (continued)

5	Interface-based Measurement Systems (IBMS)	Linked performance of each player on the SC network	It requires openness and total sharing of information at every stage which is difficult to implement
6	Perspective Based Measurement System (PBMS)	Identified six major perspectives which are System Dynamics, Operations Research, Logistics, Marketing, Organization, and Strategy and measure performance in terms of perspectives	Needs separate metric for each perspective in order to measure performance of SC and decision maker has to make a trade-off between one perspective to the other perspective
7	Hierarchical-based Measurement Systems (HBMS)	Hierarchal based management system to evaluate performance measure at different MCDM level, which are strategic, tactical and operational	No clear guidelines to reduce different levels conflicts in the entire SC network
8	Function-based Measurement Systems (FBMS)	Combine different measures of different SC process to evaluate a detailed performance measure	Performance measure only focuses function separately / independently and in isolation.

Above table clearly, highlights the limitations of existing SC performance management systems. Due to the competitive environment, now a day's many organizations are not getting success in maximizing their SC surplus. The main reason is that they failed to establish and develop adequate performance management systems that will integrate all functions of their SC and measure overall SC performance. Today's competitive environment and ever rising customers demand organizations are forced to take appropriate SC decisions at each level of MCDM (strategic, tactical, operational), financial and non-financial, etc. Table 2.2 is categorizing existing SCPM frameworks in terms of MCDM levels, functions/ perspective and financial and non-financial measures and identifying research gap.

Table 2.2 Research Gap in Existing SCPMS

SCPM Framework	DM Level Considered			Functions/ Perspective Considered ?	Financial ?	Non-Financial ?
	Long Term DM		Short Term DM			
	Strategic	Tactical	Operational			
FPMS	√		√		√	
PBPMS				√		√
GPMS				√		√
EBPMS				√		√
BSC	√			√	√	√
SCOR			√	√	√	√
DBPMS						√
HBPMS	√	√	√		√	√
FBPMS				√		√
IBPMS				√		√

Based on extensive literature review, we can identify problems in existing SC performance management systems which are as follows.

- The inadequate balance between financial and non-financial measurement exists in current SC performance management system.

- Due to a large number of existing SCM performance systems, it is quite difficult for decision makers to identify the most suitable performance management system to measure their SC performance.

- Existing SC performance management systems are not sufficient enough to establish a connection between short term and long term MCDM of SC network.

- Lacking in measuring overall SC performance.

- Deficiency in highlighting underperformed function of SC network.

Table 2.2 categorized existing SCPM frameworks in terms of MCDM levels, functions/perspective and financial and non-financial measures. This shows that none of the above-mentioned SCPM frameworks is covering all criteria and measuring overall SC performance. This led to the conclusion that there is a need of integrated SCPM framework to cover all aspects of SC cycle such as financial or non-financial and MCDM and covers all aspects of SC.

2.6 Discussion and future SCPMS

Due to advancement in technology, shorter product life cycle and innovations increases the complexity of SC environment. Organizations should adopt "smart" way of managing their SC. Traditional SCPMS are not adequate and capable enough to cope up with these complex SC and meet the desired level of satisfaction to managers and decision makers. We need fast decisions to manage our SC effectively and efficiently. To do that we need "smart" SCPMS that provides indications of underperformed SC functions and allow decision makers to take fast decisions. Unfortunately as mentioned in table 3.2, existing SCPMS are lacking in providing such information. In this section, we will discuss the proposed framework characteristics (as mentioned in table 2.3) that are necessary to tackle new trends of SCPM systems. Following are the anticipated trends in need of efficient SCPM:

- **Visibility**

Nowadays once the customers placed their orders, they need to trace their order at every stage of order processing. Visibilities in SC functions improve inventory levels and optimize SC operations. Visibility in SC functions also helps in minimize bottlenecks and minimize risk and uncertainty. This shows the importance of visibility in SC and organizations need to be transparent in their order processing and provide a continuous feedback and status of the order to their customers. This will puts pressure on the companies to improve their order processing and supply chain performance. To do that they need a system to measure their supply chain performance and provide the basis for decision makers to make rapid fast decisions to meet desired service level. However, existing SCPMS are not adequate to provide decision makers a basis for rapid and fast decisions. Therefore, in order to cope up with this trend, we need a supply chain performance measurement system that will be able to meet upcoming challenging trends in SCM.

- **Collaboration**

Collaboration among different functions of SC is also one of the essential components in improving supply chain performance. Decision makers need to collaborate each other for a better understanding of their needs and expectations and for a clear understanding of each other responsibilities. This will help in minimizing the repetition of tasks, improve the performance of each function, and improve quality and efficiency of deliveries to the customers. Collaborative SC also provides insights of SC functions. Above mentioned SCPMS are lacking in providing strong collaboration between each function of SC and lacking in to find ways improve SC performance as a whole. Therefore we need a smart SCPM system that collaborates different functions of SC and improve SC performance as a whole.

- **Digitalization**

Digitalization is to collect, store and analyze information and data in digital format. After the introduction of the Internet of Thing (IoT), many organizations are focusing on designing digital SC. However, it was not the case in previous SC’s and its management. Digitalization will help organizations in keeping track of all the events and activity electronically and provide decision makers and stakeholders a holistic view of overall SC. Another advantage of digital SC is that decision makers and organization will transform their decisions from "information driven" to "data driven" MCDM. This will also help them in making quick and rapid corrective decisions related to SC functions. Organizations can take benefits of digitalization in measuring and improving SC performance. However, existing SCPM systems are not adequate to utilize the benefits of digitalization measure and improve overall SC performance. Therefore, we need a SC performance measurement system that utilizes benefits of digitalization and measure and improves overall SC performance.

- **Integrated SC**

Integration between SC functions is now essential for efficient SC. Integrated SC minimizes bullwhip effect and improves overall SC performance. With the help of digitalization and collaboration, integrated SC will help in minimize wastes (time, cost, resources) and improve the efficiency of overall SC functions. Integration is also essential to provide a link between long-term (strategic and tactical) and short-term (operational) decisions and decision criteria. This will help in making appropriate decisions and know the impact of the decision on overall SC performance. Therefore we need an integrated SCPM system that integrates all functions of SC, provide a link between decisions and decision criteria and measure overall SC performance. However, existing SC performance measurement systems are lacking in achieving this. In future, we need to find a way to develop an integrated supply chain PMS that consider all perspective, integrates SC functions, and consider MCDM levels.

2.7 Short-term and long-term decision criteria (attributes)

As per Ezra Taft Benson, *"You are free to choose, but you are not free to alter the consequences of your decisions."* It is a fact that whatever decision we will take now has an impact on the future outcome. It is impossible to go back and correct decisions that we made, we should think before taking any decisions and see its impact in future. In order to do so, we need a systematic approach and system that will tell us the impact of our short-term decisions on long-term. This will help us in taking a correct decision and minimize the chances of error. Due to shorter product life cycle and frequent changes in customer behavior, now a day's originations and decision makers are considering only short-term (operational) and long-term decisions (strategic and tactical) as compared to previous decisions levels which are strategic, tactical, and operational. Therefore in this study, we considered short-term and long-term decision criteria of considered SC functions. In literature, many authors developed SCPM systems by considering different criteria that are specific in nature and evaluate SC functions separately. After careful review, table 2.3 below summarizes short-term criteria that are widely used in performance evaluation. Similarly, table 2.4 shows long-term criteria (attributes) that were used in measuring supply chain performance. Here we would like to mention that classification of criteria in terms of short-term and long-term were categorized based on short-term and long-term decisions. Short term decisions are usually operational level decisions and refer to monthly, weekly or day-to-day decisions such as scheduling, lead time quotations, routing, and truck loading. Long-term decisions have a long lasting effect on the firm and usually take between 5-10 years. This includes decisions regarding the location, number, and capacity of warehouses and manufacturing facility, and the material flow through the logistics network. These criteria are usually related to one or more SC function.

Table 2.3 Short-term Decision Criteria (attributes)

SC Function	**Decisions Drivers**	**Decision Criteria**	**Reference**
Supplier Selection	Cost	Price	Kaplan & Norton (2004) Lambert and Pohlen (2001) Shepherd and Gunter (2006)
	Supplier Delivery Performance	Rejection rate	Kaplan & Norton (2004)
		On time delivery	Gaudenzi & Borghesi (2006) Gunasekaran et al. (2004) SC Council
		Lead time	Otto and Kotza (2003) Bhagwat & Sharma (2007) Gaudenzi & Borghesi (2006)
		Delivery Flexibility	Otto and Kotza (2003) Bhagwat & Sharma (2007) Gaudenzi & Borghesi (2006) Shepherd and Gunter (2006)
	Supplier Sustainability	Air/Water/L and Emission	Azzone and Noci, (1998), Agarwal, Olugu, Wong and Shaharounand,(2010), and Vijayvargy, (2012),

Table 2.3 Short-term Decision Criteria (attributes) (continued)

Manufacturing	Meeting Production Target	On time delivery/cycle time	Otto and Kotza (2003) Gunasekaran et al. (2004)
	Quality of Manufactured Product	% defect	Gunasekaran et al. (2004) Gaudenzi & Borghesi (2006) Bhagwat & Sharma (2007)
	Cost	Cost / operation hour	Beamon (1999) Gunasekaran et al. (2004) Gunasekaran et al.(2001) Shepherd and Gunter (2006)
	Effective Utilization of Resources	Productivity	Gunasekaran et al. (2004)
	Sustainable Operations	Air/water/ land emission or Solid/ Hazardous/ water waste	Azzone and Noci, (1998), Agarwal, Olugu, Wong and Shaharounand,(2010), and Vijayvargy, (2012),
		% of crushed material	Gunasekaran, Tirtiroglu, and Patel, (2001), Hu and Hsu, (2010), and Rao and Holt, (2005)
Warehousing	Cost	Cost / order	Gunasekaran et al. (2004) Gunasekaran et al.(2001) Otto and Kotza (2003) Shepherd and Gunter (2006)
	Material Handling	Damaged Inventory	SC Council Gunasekaran et al. (2004)
	Delivery Performance	On time delivery	Gunasekaran et al. (2004) Gaudenzi & Borghesi (2006) Shepherd and Gunter (2006)
		Order fill rate	Gunasekaran et al. (2004) SC Council Gaudenzi & Borghesi (2006)
		Order accuracy	Bhagwat & Sharma (2007) SC Council Kaplan & Norton (2004)
	Inventory Management	Inventory Turn	Beamon (1999)

Table 2.3 Short-term Decision Criteria (attributes) (continued)

Logistics	Performance of Goods Delivered	Quality of Goods Delivered	Gunasekaran et al. (2004)
		Faulty Deliveries	Gunasekaran et al.(2001) Gunasekaran et al.(2004) Gaudenzi & Borghesi (2006)
		On time Delivery	Gunasekaran et al.(2004) Gaudenzi & Borghesi (2006) Shepherd and Gunter (2006)
	Operation Cost	Cost / unit delivered	Gaudenzi & Borghesi (2006) Shepherd and Gunter (2006)
	Sustainability Cost	Cost/unit delivered of RL	Diabat and Govindan, (2011), Mondragon and Lalwani, (2011)
		Air/water/land emission or Solid/ Hazardous/ water waste	Azzone and Noci, (1998), Agarwal et.al, (2010), and Vijayvargy, (2012),

Table 2.4 Long-term Decision Criteria (attributes)

SC Function	**Decisions drivers**	**Decision Criteria**	**References**
Supplier Selection	Cost	Monetary Value	Gunasekaran et al.(2001) Gunasekaran et al.(2004)
	Supplier Performance Management	Supplier delivery performance	Gunasekaran et al.(2001) Gunasekaran et al.(2004)
	Sourcing	Geographical Location	Wong and Shaharounand, (2010) Mondragon and Lalwani, (2011)
	Sustainable Supplier	Environmental Friendly Supplier	Hu and Hsu, (2010)
Manufacturing	Maintenance Management	OEE	Mondragon and Lalwani, (2011)
	Improving Machine Uptime	Capacity Utilization	Otto and Kotza (2003) Gunasekaran et al.(2001) Gunasekaran et al.(2004)
	Inventory Policies	Inventory	Gunasekaran et al.(2001) Gunasekaran et al.(2004)
	Sustainable Mfg. Op.	Env. Friendly Operations	Hu and Hsu, (2010) Gunasekaran et al.(2004)

Table 2.4 Long-term Decision Criteria (continued)

Warehousing	Size, Design, ASRS of Warehouse	Storage utilization	Otto and Kotza (2003) Gunasekaran et al.(2001) Gunasekaran et al.(2004)
	Inventory Management Systems	Inventory count accuracy	Gunasekaran et al.(2001) Gunasekaran et al.(2004)
	Order Management System	Order fulfillment	Bhagwat & Sharma (2007) Gaudenzi & Borghesi (2006)
	Finished Product Inv. Policy	Inventory Level	SC Council Gunasekaran et al. (2004)
Logistics	Fleet Variety	Flexibility	Gunasekaran et al.(2001) Gunasekaran et al.(2004) Shepherd and Gunter (2006)
	Transportation Quality	Delivery Reliability	Gunasekaran et al.(2001) Gunasekaran et al.(2004)
	Long-Term Contract with Logistics Service Provider	Transportation cost	Gunasekaran et al.(2001) Gunasekaran et al.(2004)
	Sustainable Transportation	Environmental friendly transportation	Hu and Hsu, 2010,

2.8 Conclusion

This chapter reviews existing SCPM systems categorized them in terms of DM levels, functions and perspective considered (financial and non-financial) and provides insights of all existing performance measurement systems. It also highlights the lacking of existing SCPMS and discussed the future of SC and characteristics of SCPM systems. After analyzing above mentioned impact of Industry 4.0 on SC activities, shortcomings of existing SCPM systems, and to cope-up with future trends of SC, we can conclude that if organizations implement Industry 4.0 technology and its concepts, design digital SC, and adopt technological changes such as Bi-technologies, Smartphone apps, RFID-technologies and smart data tools will play the vital role in these technological changes.

This shows that in future, integration among each activity of SC is essential to improve productivity, quality and effective and efficient fulfillment of customer demand in cost effective manner. In summary, new technologies and shorter product life cycle increasing the complexity of SCM. It is essential for organizations to utilize this technology advancement and develop an integrated system which integrates all functions of SC, enhance MCDM process so that organizations will always be ahead with new trends of business and compete in the market.

This also leads to the conclusion that, in order to improve SC performance we need an integrated framework that incorporates all activities of the SC, links long term decisions (strategic/tactical) with short term decisions (operational) and measures overall SC performance. This chapter reviewed all existing SCPMS, highlights their focus area, identified limitations, and categorized them in terms of MCDM level, perspective considered, integration of SC functions and their alignment with industry 4.0. Moreover, we identified long term and short term decision criteria (attributes) that require measuring overall SC performance.

Above analysis of existing SCPMSs and detailed analysis of need and characteristics of future SCPMS, it is evident that we need an integrated SCPMS which integrates short-term and long-term decisions and decisions criteria, utilized experts and decision makers knowledge and evaluate overall SC performance. We need to find a way to integrate short-term decisions and decision criteria and their associated importance weights with long-term decisions and decisions criteria and their associated importance weights through a knowledge base system based on experts knowledge and experience. Integrated knowledge base system can be developed using integrated multi-criteria decision making (MCDM) technique. Due to the advancement of technology, data collection and its storage become easy. These collected and stored data at the operational level will be easy to store and further utilized to evaluate overall SC performance through integrated knowledge base system.

2.9 Learning from literature

Chapter one (1) and chapter two (2) summarize the literature review. In the following, we list knowledge that we learned from literature has been found and identify the motivations for our work:

- This literature review concludes that the research and application of MCDM methods application in SCM have grown significantly in recent years. Many authors applied MCDM methods in most of the field at different MCDM level. However, systematic way to select MCDM method at long-term and short-term MCDM is not been discussed in the literature. Since many authors considered SCM as a MCDM problem. Therefore, it is important to have a guideline to select appropriate MCDM methods that are essential for decision makers. We consider this point as our first motivation for which to focus our research on identifying MCDM methods application in considered SC functions.

- Application of MCDM methods in literature shows that many researchers and decision makers applied Fuzzy-AHP very frequently. Moreover, it is also evident from the literature that hybrid Fuzzy-AHP application is useful at any level of DM (strategic, tactical, and operational). Therefore, our proposed integrated framework to evaluate overall SC performance will be based on hybrid Fuzzy-AHP.

- Literature review shows an inadequate balance between financial and non-financial measurement exists in the current SCPMS. Existing SCPM systems are not sufficient enough to establish a connection between short term and long term MCDM of SC network. Hence they are lacking in measuring overall supply chain performance. This provided a major motivation for our research to focus on developing integrated SCPM systems that integrates all functions of SC and provide a link between long-term and short-term decisions and decisions criteria and measure overall supply chain performance.

- SC design is a complex and demanding process, and organizations are facing problems. Although literature highlights the importance of SC design with respect to overall supply chain performance, however very little attention has been given to linking long-term decision criteria of supply chain performance measurement with SC design. Do organizations need to know what criteria should be focused more on SC design phase to improve supply chain performance? What is the link between SC design and supply chain performance criteria? This point motivated us to develop a model which design SC by considering underperformed long-term decision criteria and allows decision makers to incorporate underperformed criteria in designing phase and improve overall supply chain performance.

2.10 Research gap

In this theoretical part of thesis which is consists of chapter 1 and chapter 2, we briefly summarize the MCDM methods application in SCM, limitations of existing SCPM systems, identified long-term and short-term decision criteria, and there is a lacking in supply chain design models that consider under-performed criteria and reviewed papers related to these topics.

From the reviewed literature, several research opportunities have been identified to bridge the knowledge gaps which are as follows:

- Existing SCPMS are lacking in establishing a relationship between decisions (short term and long term) and decision criteria with SC functions.

- Deficiency in highlighting underperformed function of SC network and in measuring overall SC performance.

- The inadequate balance between financial and non-financial measurement exists in current SCPM system, and due to a large number of existing SCPM, it is quite difficult for decision makers to identify the most suitable performance management system to evaluate their SC performance.

- DM knowledge is not used efficiently to obtain a better evaluation of the SC performance.

- Integration between long-term and short-term decisions and decisions criteria not exist.
- Integration of SC functions at design phase does not exist.

2.11 Overall Conclusion

Chapter 1 presented a systematic literature review on the application of MCDM methods application in considered SC functions which are supplier selection, manufacturing, warehousing, logistics, and integrated SC. It is apparent from the literature that MCDM methods are capable enough to handle uncertainty and provide decisions by considering the practical situation. In addition to that, this study showed that Fuzzy and its integration with other MCDM had been effectively and efficiently applied at every level of the SC decision-making process as well as in considered SC functions. This is because of the fact that due to digitalization and after introduction Internet of Things (IoT), the perspective of SC has been totally changed. Organizations and decision makers need to think other than the traditional way of managing SC. Moreover, due to the availability of real time data and information, uncertainty in managing SC has increased in addition to dynamic nature of SC. Fuzzy sets are well known and proven method to capture uncertainties and quantifying vagueness.

Chapter 2 reviewed all existing SCPMS, highlights their focus area, identified limitations, and categorized them in terms of MCDM level, perspective considered, integration of SC functions and their alignment with industry 4.0. We can conclude that if organizations implement Industry 4.0 technology and its concepts, we have to go through technological change. These technological changes will be specifically for procurement, production and distribution process. Bi-technologies, Smartphone apps, RFID-technologies and smart data tools will play the vital role in these technological changes. This shows that in future, integration among each activity of SC is essential to improve productivity, quality and effective and efficient fulfillment of customer demand in cost effective manner. This also leads to the conclusion that, in order to improve supply chain performance we need an integrated framework that integrates all activities of SC, link long term decisions (strategic/tactical) with short term decisions (operational) and measure overall supply chain performance. The proposed framework will utilize experts experience and knowledge.

CHAPTER 3

A KNOWLEDGE BASE SYSTEM FOR OVERALL SC PERFORMANCE MEASUREMENT: A MULTI-CRITERIA DECISION-MAKING APPROACH

Due to the advancement of technology that allows organizations to collect, store, organize and use data information system for efficient MCDM, a new horizon of supply chain performance evaluation starts. Today, MCDM is shifting from “information-driven” to “data-driven” for more precision in overall supply chain performance evaluation. Based on real time information, fast decisions are important in order to deliver product more rapidly. Performance measurement is critical to the success of the SC. In managing SC, there are many decisions that have to be taken at each level of MCDM (short-term or long-term) because of many decisions and decision criteria (attributes) that have an impact on overall supply chain performance. Therefore, it is essential for decision makers to know the relationship between decisions and decision criteria on overall SC performance. However, existing supply chain performance models (SCPM) are not adequate in establishing a link between decisions and decisions criteria on overall SC performance. Thus, the purpose of this chapter is to develop an integrated KBS based on of Fuzzy-AHP that establishes a relationship between decisions and decisions criteria (attributes) and evaluate overall SC performance. The proposed KBS assists organizations and decision makers in evaluating their overall SC performance and helps in identifying under-performed SC function and its associated criteria.

3.1 Existing SC performance evaluation systems

Many authors developed SC performance evaluation frameworks specifically from a unique or a specific perspective. A history of performance evaluation was presented by Morgan (2004), and he mentioned that “the background of performance evaluation lies in 15th century when accounting was discovered with the creation of double entry book keeping. The double-entry book accounting evaluation system was doing well until the early 1900s”. Since then concepts of performance evaluation have been challenged by accounting professionals. Literature associated with SC performance management is considerably large in number. Available literature is scattered. However, several authors have tried to collect major SC performance management systems into different perspectives. Kurien & Qureshi (2011) for example, condensed nine theoretical SC performance evaluation frameworks and Agami et al., (2012) and Kurien & Qureshi (2011) organized SC performance evaluation frameworks and models into two main categories, namely, financial and non-financial and nine sub-categories of non-financial categories.

SC Operation Reference (SCOR) model and Balance Score Card (BSC) are the most widely used performance evaluation system. All SC performance evaluation systems are specific to organizations and not flexible. Financial performance evaluation systems (FPMS) mainly focused financial indicators (Agami et al., 2012 and Kurien & Qureshi 2011). Balanced scorecard (BSC) evaluates performance in terms of four Perspectives which are Customer, Financial Internal, Business, and Innovation. BSC not providing coordination along the SC network, bad performance cause and effect is not visible. Similarly, SC operations reference model (SCOR) communicates between SC partners as decision process in terms of Plan, Source, Make and Deliver. However, it does not include all process; overall performance evaluation is quite difficult and not flexible if evaluations change. Dimension based performance evaluation systems (DBMS) evaluate SC performance in terms of dimensions and not reflect the performance of sub-criteria of any major criteria within the SC network (Agami et al., 2012 and Kurien & Qureshi 2011). Perspective based evaluation systems (PBMS) consider perspectives such as system dynamics, operations research, logistics, marketing, organization, and strategy and evaluate performance in terms of perspectives (Agami et al., 2012 and Kurien and Qureshi 2011). Hierarchal based evaluation systems (HBMS) evaluate performance at different MCDM levels, which are strategic, tactical and operational however no clear guidelines to reduce different levels conflicts in the entire SC network (Agami et al., 2012 and Kurien and Qureshi 2011). Function based performance evaluation systems (FBMS) combine different evaluates of different SC process to evaluate a detailed performance evaluation, but performance evaluation only focuses function separately / independently and in isolation (Agami et al., 2012 and Kurien & Qureshi 2011). Efficiency based evaluation systems (EBMS) evaluate SC performance in terms of efficiency (Agami et al., 2012 and Kurien & Qureshi 2011). This system is able to evaluate the different units

SC efficiencies which are relative to each other but not against the target value or benchmarking. This creates ambiguity for MCDM.

Based on literature review we can identify some limitations in existing SCPM systems which are as follows:

- Existing SCPMS are lacking in establishing a relationship between decisions (short term and long term) and decision criteria with SC functions.

- Deficiency in highlighting underperformed function of SC network and in measuring overall SC performance.

- The inadequate balance between financial and non-financial measurement exists in current SCPM system, and due to a large number of existing SCPM, it is quite difficult for decision makers to identify the most suitable performance management system to evaluate their SC performance.

3.2 Fuzzy systems, AHP, and supply chain performance evaluation

Effective management of uncertainty among SC functions is the major factor for improving overall SC performance. It is challenging for an organizations to manage SC in dynamic and uncertain environments, where information is unclear, and prediction is not easy. In order to meet customer demand in this challenging environment, decision makers must include uncertainty from all functions of SC, which consists of initial material supply, manufacturing, distribution, and consumer market. This demonstrates that in integrated SC, both certainty and uncertainty must be considered together.

Decision makers can make decisions in the absence of clearly defined boundaries based on their experience and knowledge. Fuzzy MCDM is the technique that is useful in modeling complex and vague system in which information is uncertain or unavailable and required linguistic input from experts. Since SC is a complex and uncertain and we need a system that transforms linguistic information from decision makers. Fuzzy MCDM and its integration with other MCDM such as AHP have been effectively and efficiently applied at every level of the SC decision-making process as well as in the considered SC functions. This is because of the fact that due to digitalization and massive data available in the organization, the perspective of SC has been totally changed. Organizations and decision makers need to change their traditional thinking when it comes to how to manage SC. Moreover, due to the availability of real time data and information, the application of MCDM for short term decisions will add great value to the decision process and reduce uncertainty in managing SC. Fuzzy sets are well-known and proven methods for capturing uncertainties and quantifying vagueness. Giving a value to something like “responsiveness,” which is of great importance, could be tricky. It is difficult to evaluate “responsiveness.” Fuzzy logic can easily be used in situations that have uncertainty and imprecision (Sirigiri, Gangadhar & Kajal, 2012).

Traditional evaluation systems consist of structured systems that use quantifiable and non-quantifiable measures for evaluating. Quantifying performance dimensions is a difficult task. Giving a value to something like “responsiveness,” which is of great importance, could be tricky. It is difficult to evaluate “responsiveness.” Fuzzy logic can easily be used in situations that have uncertainty and imprecision. Problems like subjectivity, fuzziness and imprecise information are tackled with performance evaluation techniques. Usually, many important performance parameters in SC Management are difficult to quantify and are indicated by linguistic terms which are subjective and hence are ambiguous (Sirigiri et al., 2012). A number of performance evaluation systems have been singled out that could be easily used for analysis of SC, but are not used in SC modeling research. This is due to the qualitative nature of these characteristics, although these could be of such great importance if integrated into SC analysis (Nomesh et al., 2012).

SC performance appraisal can be associated with an action comprising of various criteria/attributes, where most of them are immaterial in nature and hence requires the subjective judgment of the decision-makers. On the other hand, even quantitative appraisal of the SC performance metrics is difficult as the performance evaluation systems are vague and ill-defined (Nomesh et al., 2012). Jung (2011) proposed Fuzzy-AHP-GP approach in manufacturing systems. Similarly, Govindan et al. (2015) and Ocampo et al. (2015), used Fuzzy systems and Fuzzy-ANP methodology in manufacturing. Almost all important performance parameters in a SC are difficult to quantify as all are specified by subjective linguistic terms and are characterized by ambiguity (Smolová & Pech, 2012). Tadic et al. (2013) proposed an integrated approach based on Fuzzy-AHP and TOPSIS in logistics service provider selection. Ashrafzadeh et al., (2012) applied Fuzzy-TOPSIS in warehousing location selection. Fuzzy theory is mainly considerate of quantifying and reasoning using natural language in which many words have vague and unclear meanings. The fuzzy logic methodology has been used by a number of researchers to evaluate SC performance such as (Kanda & Deshmukh, 2007; Rajkumar & Kumar, 2004; Chan & Qi, 2002; Unahabhokha et al., 2007).

Similarly, in entire SC some of the criteria have a greater impact on overall SC performance as compared to the others. Thus pairwise comparison of Analytical Hierarchal Process (AHP) which ensures the consistency of decision makers when assigning the importance of one factor over another is used to find the weights of these criteria. Bhagwat and Sharma (2007b) used analytical hierarchy process to ranked SCM metrics and other performance metrics level. This paper also utilizes AHP to prioritize different BCS perspectives for SCM evaluation. Chan (2003) applied AHP as a tool of MCDM to judge the ranking of performance evaluations. Yang (2009) came up with the logarithm triangular fuzzy number-AHP method to develop a model of SC performance evaluation system. Askariazad and Wanous (2009) used "AHP methodology for pair wise comparisons of the prime SC functions, processes, and criteria, to develop a dependable framework for measuring the overall SC performance." To align BSC to petroleum industry SC strategy, Varma et al. (2008) utilized AHP in combination with BSC. Bhagwat and Sharma (2009) explained how an integrated AHP-PGP (preemptive goal programming) model could be used in performance evaluation while optimizing the overall performance. Dobrota et al. (2015) applied Fuzzy-AHP in warehouse location selection. Dargia et al. (2014) used Fuzzy-ANP in supplier selection. Ding (2013) applied fuzzy systems in logistics network design. For optimal overall performance evaluation of SCM for SMEs, Bhagwat et al. (2008) exercised AHP and linear programming techniques. Taking into consideration the hierarchy presented by Bhagwat and Sharma (2007b) they used AHP to prioritize SCM parameters in the model. Drzymalski et al. (2010) developed a methodology using both the AHP and Analytic Network Process

(ANP) techniques to gauge the SCM's performance based upon the intra and inter-organizational, the two types of dependencies that exist in a multi-echelon SC.

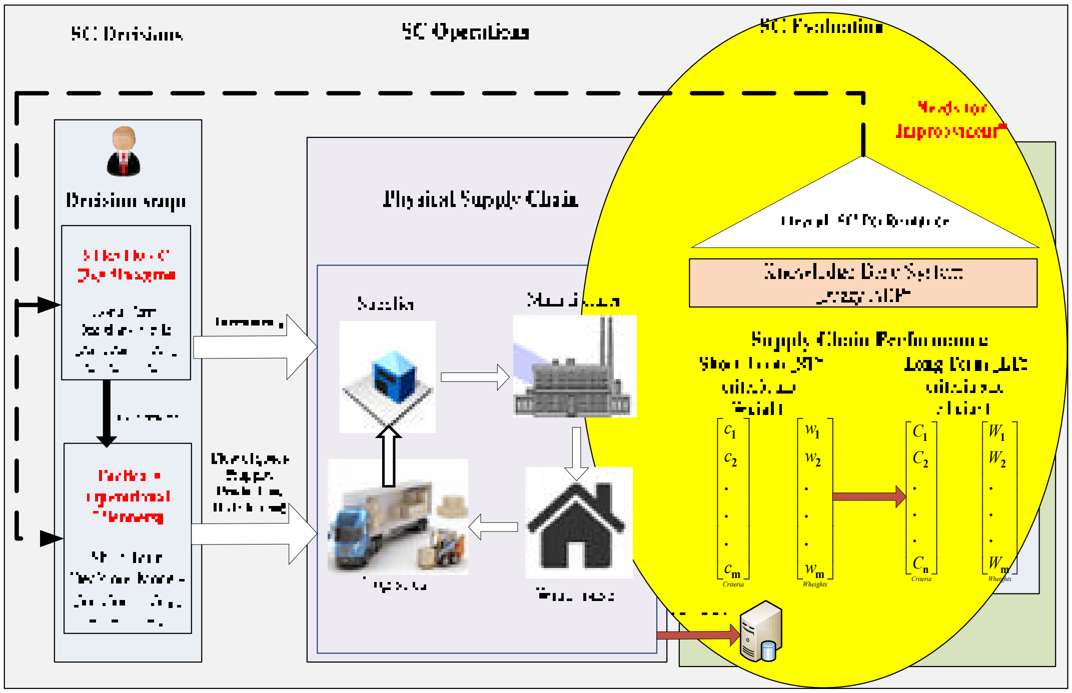

Figure 3.1: SC Evaluation

As shown in figure 3.1, the vector (X_{10}, X_{20}, …,X_{n0}) are the initial strategic (long term / Investment) decisions made by top managers to design the SC based on the strategy characterized by some specific long-term criteria [C_1, C_2, …,C_n] and their respective weights (W_{10}, W_{20}, …, W_{n0}). Once the SC network has been implemented, we will measure results based on different short term attributes (c_1, c_2, …, c_n). These attributes are operational data that can be collected from company's information systems such as enterprise resource planning (ERP), manufacturing execution system (MES), transportation management system (TMS), order management system (OMS), and warehouse management system (WMS), etc.

These attributes are also the results of different initial decisions (Y_{10}, Y_{20}, …,Y_{n0}) at the tactical and operational levels of planners and their respective weights (w_{10}, w_{20}, …, w_{n0}).

By using LT decisions criteria (C_1, C_2, . . . C_n) and their importance weight (W_1, W_2. . . Wn) and ST decisions criteria (c_1, c_2, . . ,c_m) and their importance weight (w_1, w_2. . . w_m), we will evaluate overall SC performance based on the proposed KBS. If overall SC performance is not up to the mark, we will go back to decisions that we took at initial stages and calibrate long term and short term decisions by changing the weights for long term and short term criteria (W_1, W_2. . . W_n ; w_1, w_2,. . . ,w_m) to improve the overall SC performance. It's a continuous process where we will calibrate decisions until we achieve the desired overall SC performance.

3.3 Proposed KBS based on Fuzzy-AHP

The proposed framework is considering major functions of SC (supplier, manufacturer, warehousing, and logistics) that most of the organizations have, considers decisions criteria that are common to most of the organizations and can fulfill the purpose of SC performance evaluation for most of the organizations. Each criterion (long-term and short-term) of considered SC functions covers all major aspects of SC including reverse logistics, sustainability aspects, and sales and distribution. Therefore we believe that the performance evaluation framework is general in nature since it is covering most of the functions of SC and considering most of the common criteria that are similar to many organizations. Moreover, our generalized SC performance evaluation framework provides a different organization common performance evaluation platform, allow sharing of information among different SC functions and evaluate overall SC performance. Therefore, as the main purpose of this chapter is to develop an integrated SC performance evaluation framework that integrates SC functions, establish a relationship between SC decisions criteria, and evaluate overall SC performance. In order to do so we need a systematic methodology that is generalized for most of the organizations and consists of systematic steps as mentioned in figure 3.2 below:

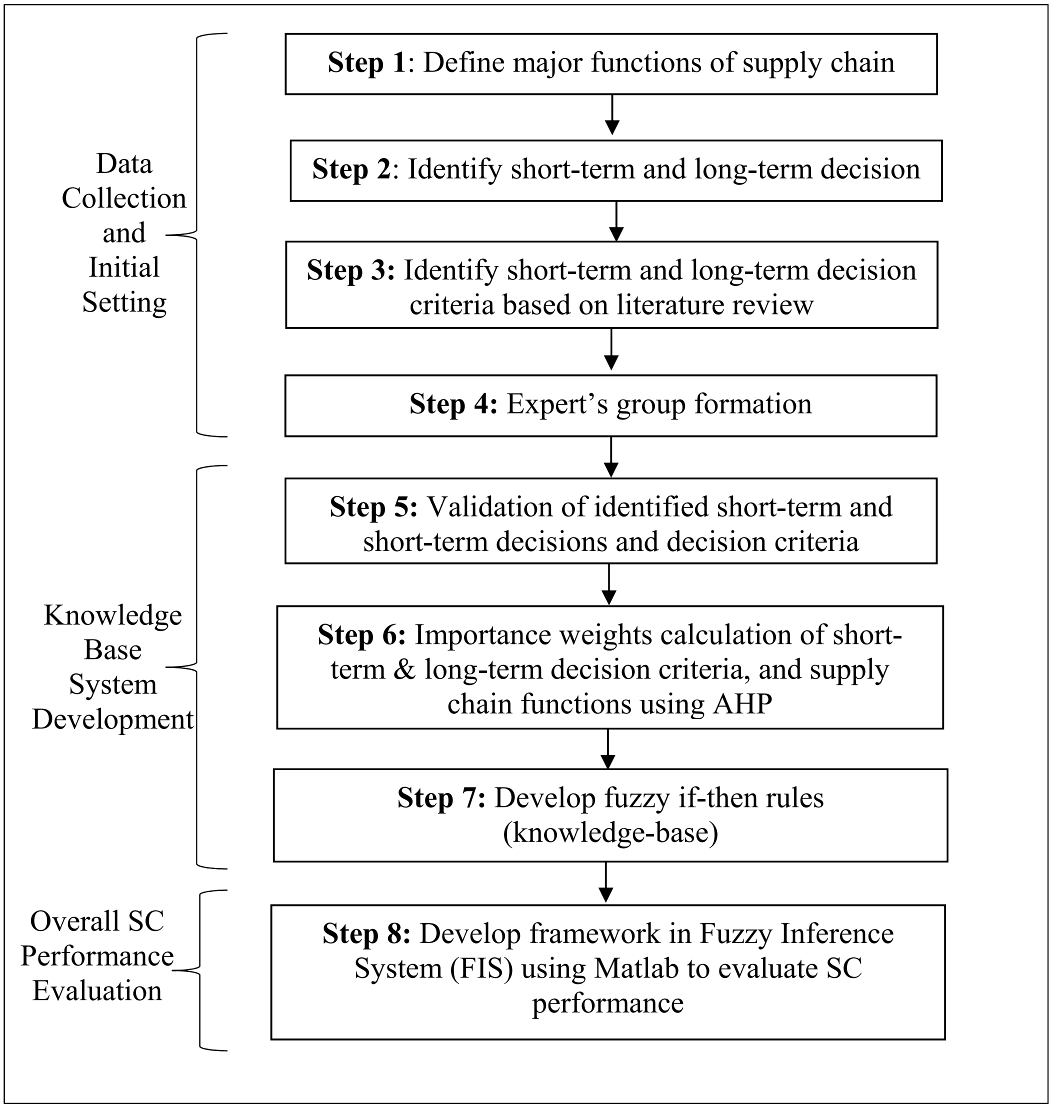

Figure 3.3 Proposed Methodology Steps

3.3.1 Data Collection and Initial Setting

Step 1: Define major functions of SC

SC functions depend on segments and changes from sector to sector. In this step, we need to define the major functions of SC that are common for most of the organization's sectors. Our selections of major SC functions are inline with BSC considered functions (plan, source, make, and deliver). Figure 3.3 shows considered SC functions that are common to many organizations, and we will consider in evaluating overall SC performance.

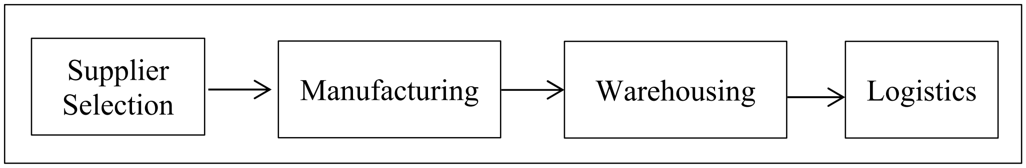

Figure 3.4 Considered SC Functions

Step 2: Identify Short-term and long-term decisions

Since the main purpose of the proposed knowledge based system is to identify the link and establish the relationship between short-term and long-term decisions and see their impact on overall SC performance. We identified short-term and long-term decisions as mentioned in Annex 1, table AI-1 and table AI-2 respectively.

Step 3: Identify short-term and long-term decision criteria based on literature review

In an integrated system, each decisions and decisions criteria (attributes) of each SC function has relation with each other, and has an impact on overall SC performance. In this step, we will identify short-term and long-term decision criteria based on a literature review or most widely used performance indicators as mentioned in AI-1 and table AI-2 as mentioned in Annex 1. Categorization of criteria at particular decision level (short-term and long-term) is aligned with the guideline provided by David Simchi-Levi et al., (2008) and as mentioned in Annex I, table AI-3.

Step 4: Expert's group formation

In order to implement a proposed methodology to evaluate overall SC performance, we need experts who can validate identified criteria from literature, and it is relevant to most of the organization, establish relationship between SC decision criteria, perform pair-wise comparison on identified criteria at short-term and long-term MCDM, and develop fuzzy knowledge base (if-then-else rules). In order to make it general, we propose that there should be a detailed survey has been done by a group of experts to generalized criteria that we found from literature, develop a fuzzy knowledge base, and perform the pair-wise comparison.

3.3.2 KBS Development

Step 5: Validation of identified short-term and long-term decision criteria

The detailed and extensive survey should be done as similar to step 3 to review the identified criteria for short-term and long-term decision criteria and check the relevancy with most of the different business segment.

Step 6: Importance weights calculation of short-term & long-term decision criteria, and SC functions using AHP

In this step, similar to step 3, we need to conduct the survey from experts and to perform a pair-wise comparison based on Saaty's scale to calculate importance weights of short-term & long-term decision criteria, and SC functions using AHP and applicable to most of the organizations.

Here it is important to give a brief introduction about Analytical Hierarchal Process (AHP) so that it will be easy for readers to get an idea how AHP works. AHP is a widely used MCDM method. It is developed by Saaty in 1980 "to help in solving decision problems by taking into account both subjective and objective evaluation measures. It breaks a problem into hierarchy or levels" as shown in figure 3.5 below:

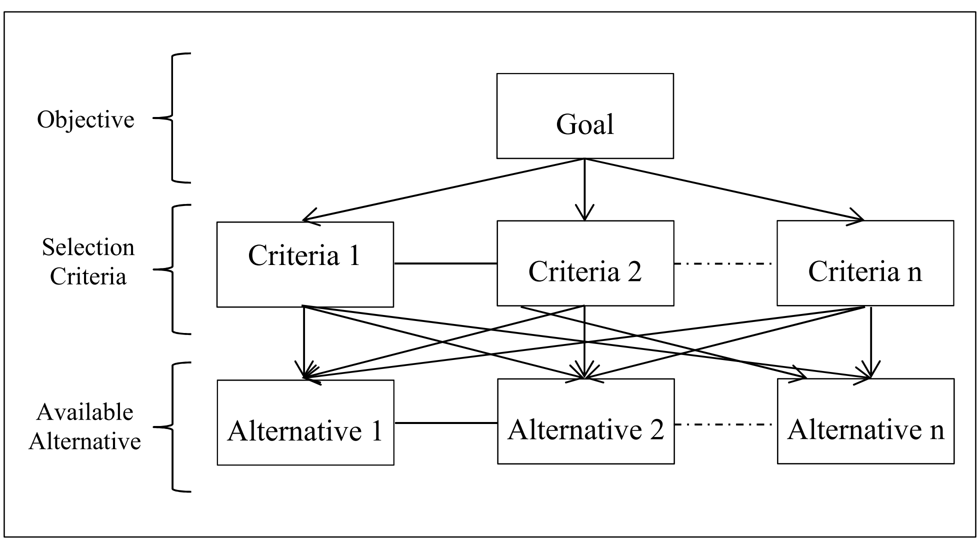

Figure 3.5 General AHP Structure

As per Saaty's (2008) "AHP uses a pair-wise comparison of the criteria importance with respect to the goal. This pair wise comparison allows finding the relative weight of the criteria with respect to the main goal. If quantitative data is available, the comparisons can be easily performed based on a defined scale or ratio and this cause the inconsistency of the judgment will be equal to zero which leads to perfect judgment. If quantitative data is not available, a qualitative judgment can be used for a pair wise comparison. This qualitative pair wise comparison follows the importance scale" suggested by Saaty (1980) as shown in Table 3.1.

Table 3.1 Importance scale of factors in pair-wise comparison (Saaty's 1980)

Importance Scale	**Importance Description**
1	Equal Importance of "i" and " j"
3	Weak Importance of " i" over " j"
5	Strong Importance of " i" over " j"
7	Demonstrated Importance of " i" over " j"
9	Absolute Importance of " i" over " j"
Note: 2, 4, 6 and 8 are intermediate values.	

Saaty (2008) stated that "the same process of pair-wise comparison is used to find the relative importance of the alternatives with respect to each of the criteria. Each child has a local (immediate) and global priority (weight) with respect to the parent. The sum of priorities for all the children of the parents must equal 1. The global priority shows the alternatives relative importance with respect to the main goal of the model". Readers can read Saaty (2008) for a detailed example of AHP which explained the step by step approach of AHP.

Step 7: Develop fuzzy if-then rules (knowledge-base)

In this step, through survey experts were asked to develop a fuzzy knowledge base (fuzzy if-then rules) and the relationship between SC decision criteria at short-term and long-term based on their experience. These developed rules (knowledge-base) will be applicable to most of the organizations. The general structure of short-term and long-term decisions criteria of considered SC functions are illustrated in figure 3.6 below.

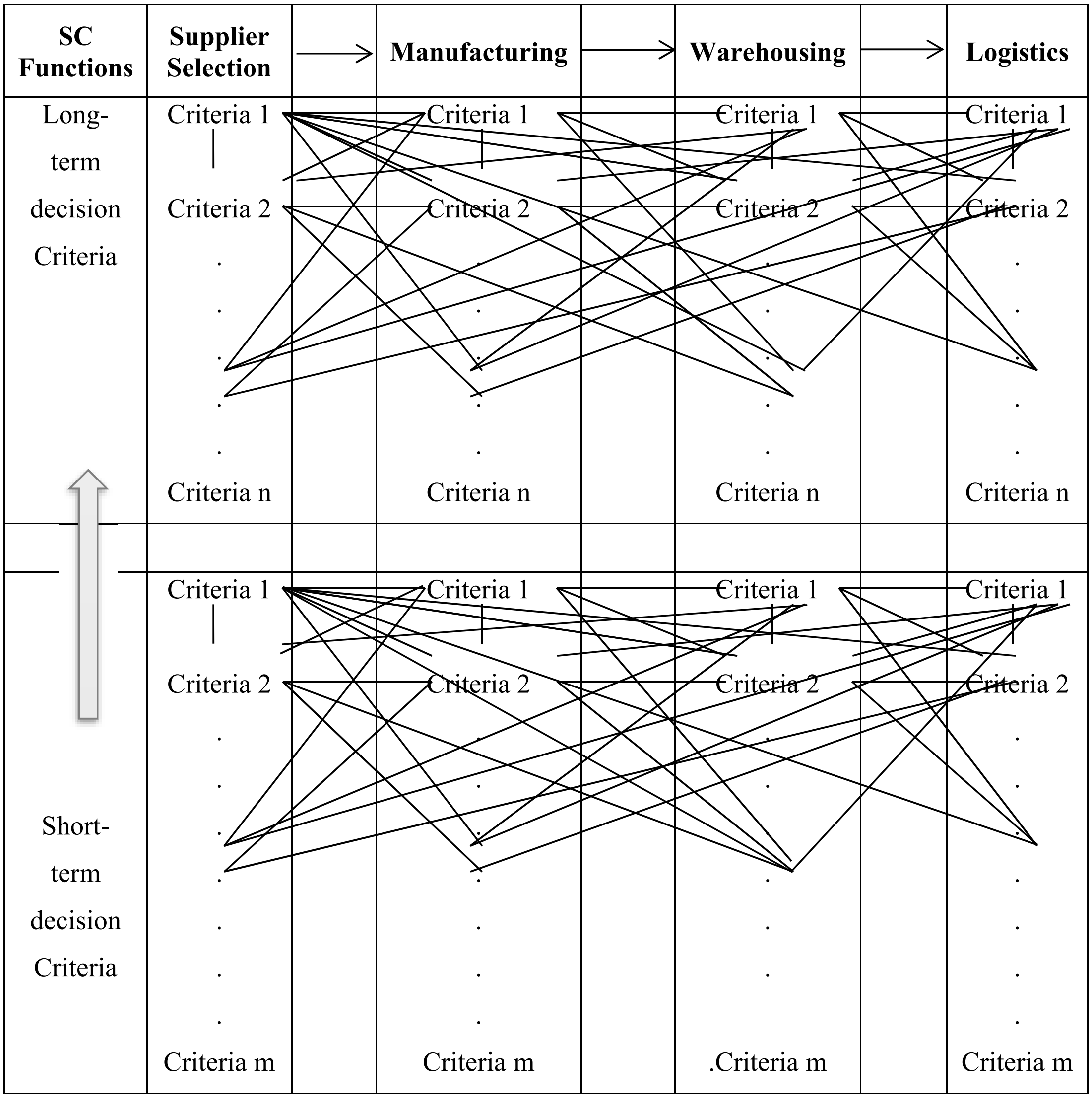

Figure 3.6 Relationship between considered SC functions decisions criteria

Decision Flow

Relationship between decision criteria across considered SC functions

The above-mentioned figure shows that in considered SC functions, there are many possible relationships are possible, and these relationships (knowledge base) will be developed and established by experts.

3.3.3 Overall SC Performance Evaluation

Step 8: Develop framework in Fuzzy Inference System (FIS) using Matlab to evaluate overall SC performance

In order to develop integrated fuzzy inference system to evaluate overall SC performance, we need to build inference system in three phases. In phase 1, we will develop a fuzzy inference system (FIS) to see the impact of short-term decision criteria on long-term decision criteria of each function of considered SC function. Each short-term decision criteria effects will be evaluated on long-term decision criteria based on input attributes of short-term decision criteria and decision criteria weights (calculated based on experts opinion and through AHP) and the relationship developed in step 6. In the second phase, we will calculate the effect of long-term decision criteria by developing fuzzy inference system on each function of SC based on the input value (calculated through phase 1) and decision criteria weights (calculated based on experts opinion through AHP) and the relationship developed in step 6. In phase 3, we will integrate each function of considered SC function on overall SC performance by developing fuzzy inference system. We entered input values (calculated through phase 2) and considered SC functions weights (calculated based on experts opinion through AHP) and the relationship developed in step 6.

Again it is important to provide a brief introduction about Fuzzy Inference System (FIS). Fuzzy logic is a methodology that helps in problem solving and gives a simple way to obtain a definite solution from information which is vague and imprecise. Figure 3.7 mentioned the framework for Fuzzy DM system (FDMS).

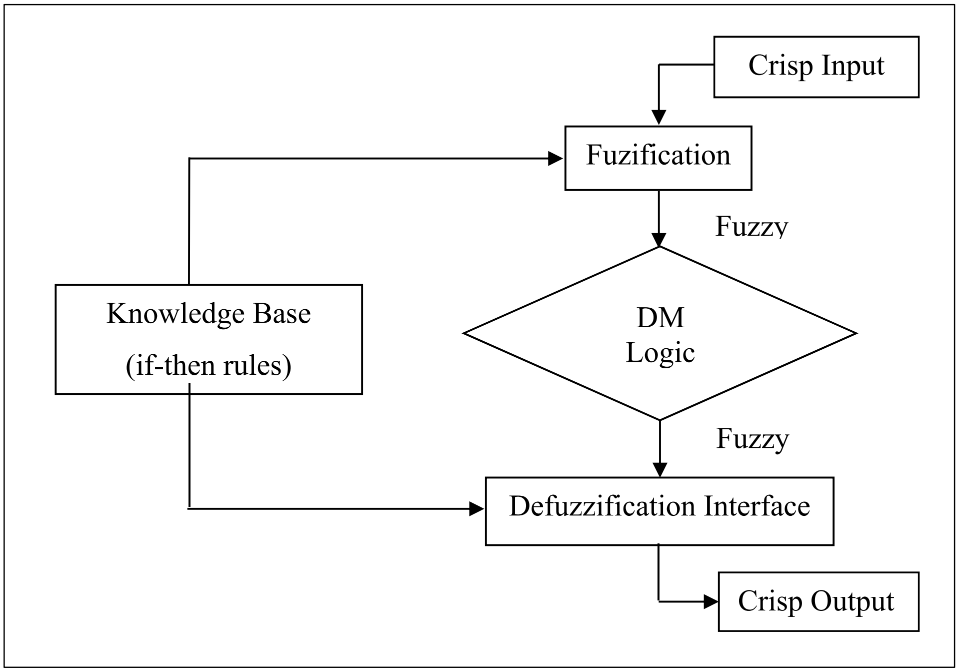

Figure 3.7 FDMS
(Adopted from Dweiri & Kablan, 2006 and Khan et al. 2016)

According to Dweiri and Kablan, (2006) "Fuzzy set theory was first introduced by Zadeh in 1967. He was motivated by observing that human reasoning can utilize concepts and knowledge that don't have well-defined boundaries". According to Yen & Langari (1999), Fuzzy set theory (FST) is a generalization of the ordinary set theory. FDMS is comprised of four main components: a fuzzification interface, a knowledge base, MCDM logic, and a defuzzification interface (Dweiri, 1999; Lee, 1990) as shown in figure 3.7. In essence, a FDMS is a fuzzy expert system (FES). FES is oriented towards numerical processing where conventional expert systems are mainly symbolic reasoning engines (Kandel, 992; Yang et al*.*, 2001; Zadeh, 1983). Figure 3.7 provides a framework for the interrelationships between the components that constitute a FDMS. Dweiri & Kablan, (2006) describe the four components are explained as in the following:

- **"The fuzzification interface:** It evaluates the attributes of the input variables on their membership functions to determine the degree of truth for each rule premise".

- **"The knowledge base:** It comprises experts' knowledge of the application domain and the decision rules that govern the relationships between inputs and outputs. The membership functions of inputs and outputs are designed by experts based on their knowledge of the system and experience".

- **"The decision making logic (DML):** It is similar to simulating human MCDM in inferring fuzzy control actions based on the rules of inference in fuzzy logic. The evaluation of a rule is based on computing the truth value of its premise part and applying it to its conclusion part. This results in assigning one fuzzy subset to each output variable of the rule. In Min Inferencing the entire strength of the rule is considered as the minimum membership value of the input variables' membership values".

- **"The defuzzification interface:** It converts a fuzzy control action (a fuzzy output) into a fuzzy control action (a crisp output). The most commonly used method in defuzzification is the center of area method (COA). The COA method computes the crisp value as the weighted average of a fuzzy set".

For detailed steps and theoretical background of how fuzzy inference system works, readers are advised to read a detailed explanation of fuzzy inference system in annex II.

CHAPTER 4

CASE STUDY OF AN AUTOMOBILE MANUFACTURING COMPANY

The previous chapter discussed and proposed an integrated framework to measure overall SC performance based on hybrid Fuzzy-AHP. This chapter illustrates the use of the proposed knowledge base system (describes in chapter 5) and evaluates overall supply chain performance via a case study in an automovie company.

4.1 Data collection and Initial Settings

Now it is important to implement the proposed KBS in a case company to evaluate overall SC performance. This will illustrate the use of Fuzzy MCDM in evaluating overall SC performance. XYZ Company is located in southern part in a developing country and one of the largest automotive cars manufacturers. It's established in 1989 in technical collaboration with Toyota Tsusho Corporation (TTC), Japan. The manufacturing facility and offices are located on a 105-acre site in the south, while the product is delivered to end customers nationwide through a strong network of 41 independent 3S dealerships spread across the country. They manufacture, imports and distribute passenger cars, SUV's and 4WD and commercial vehicles from Japan and Thailand. It has 2300 plus workforce of team members & management employees. The company won several awards in the past few years such as corporate excellence award and consumer choice award. The management of XYZ Company is interested in building a FDMS that evaluate their overall SC performance. We implement proposed methodology step by step as mentioned in figure 4.1

Step 1: Define major functions of SC cycle

In order to evaluate overall SC performance, we need to define the major functions of SC that we will consider in measuring overall performance. We enquired about the identified functions of considered SC and case company agreed with us that they have same functions of SC as mentioned in figure 3.4. Therefore we decided to consider same SC functions for a case company.

Step 2: Identify short-term and long-term decisions

It is important to find out decisions that are associated with short-term and long-term decision criteria. We decided to consider same identified short-term and long-term decisions and will validate it with company's experts once we will form experts group in step 5 and validate it step 6.

Step 3: Identify short-term and long-term decision criteria for Case Company

In section 3.1, step 3 of previous chapter, we identified short-term and long-term decision criteria which we decided to use in our case company and once we will form experts group in step 5 and validate it in step 6.

Step 4: Expert's group formation

In order to implement a proposed methodology and to evaluate overall SC performance, we need experts who can validate that identified criteria from literature and are relevant to their company, perform the pair-wise comparison on identified short-term and long-term criteria and develop the relationship between short-term and long-term decision criteria (fuzzy knowledge base). Firms often find that there is a lack of operational guidelines on how to develop performance evaluation criteria and constructs (Lapide, 2000). Therefore, a group decision-making process assists in developing Fuzzy-AHP based overall supply chain performance framework across the cross-functional levels. Stakeholders of the automobile manufacturing firm are selected from the following departments: (a) procurement, (b) manufacturing, (c) logistics, (d) warehouse, and (e) operations. Five key persons are selected from each stakeholder for their participation in the interviews. The interviewees from each stakeholder comprise one person from the manager, deputy manager and assistant manager levels, and three key officers.

During company's group MCDM process we found many decision points and variables that require the involvement of all stakeholders. All members of the group have more than 8 years of experience and have at least 3 years with the company. Firstly, we briefed them about the objectives of this exercise (evaluate overall supply chain performance) and explained supply chain performance method which includes the rationale for each construct and their inter-relationship. Secondly, Fuzzy-AHP methods are explained not only how to evaluate overall supply chain performance method is to be undertaken but also allow them to have an idea of the rationale for selection. Next, the participants were asked to perform the pair-wise comparison on Saaty's scale as mentioned in table 3.1 of previous chapter, develop if-then else rules, and define membership functions. The group forms a consensus decision and come up with one value/results under the chairmanship of the operational head of the company. We rectify some queries that were raised by few members by explaining the whole procedure and purpose of this group MCDM.

4.1.1 KBS development

Step 5: Validation of identified short-term and long-term decision criteria in a case company

Once the expert's team was formed, experts were asked to review the identified criteria for short-term and long-term decision criteria as mentioned in Annex I table AI-1 and table AI-2. After thorough discussion among each group, they approved and validated the identified short-term and long-term decisions and decision criteria.

Step 6: Importance weights calculation of short-term & long-term decision criteria, and SC functions using AHP

In order to get importance weight of short-term and long-term decision criteria, we need to perform the pair-wise comparison on Saaty's scale mentioned in table 3.1of privious chapter. Experts were asked to perform a pairwise comparison based on Saaty's scale for short-term and long term decision criteria importance and SC functions. We entered these values in AHP software. Table 4.1 and table 4.2 summarized the importance weights of short-term and long-term decision criteria, and table 4.3 summarizes the importance weights of considered SC functions.

Table 4.1 Importance Weights of Short-term Decision Criteria of Considered SC

Supplier Selection		**Manufacturing**		**Warehousing**		**Logistics**	
Short Term Criteria (c_m)	**Wt. (AHP) w_i**	**Short Term Criteria (c_m)**	**Wt. (AHP) W_i**	**Short Term Criteria (c_m)**	**Wt. (AHP) W_i**	**Short Term Criteria (c_m)**	**Wt. (AHP) W_i**
On time delivery (OTD)	0.324	Productivity (P)	0.248	Order Accuracy (OA)	0.369	Quality of Goods delivered (QGS)	0.351
Price	0.201	Cost/ Operation Hour (C/O Hour)	0.233	Order Fill Rate (OFR)	0.216	Faulty Deliveries (FD)	0.248
Rejection Rate (RR)	0.194	Defect %	0.222	Cost / Order (C/O)	0.134	On Time Delivery (OTD)	0.165
Air / Water / Land Emission (AWLE)	0.142	Air/ Water/ Land Emission (AWLE)	0.130	On Time Delivery (OTD)	0.125	Cost / Unit Delivered (C/U Delivered)	0.109
Lead Time (LT)	0.091	On Time Delivery (OTD)	0.096	Inventory Turn (IT)	0.097	Return Product Cost / Unit (RPC/U)	0.073
Delivery Flexibility (DF)	0.047	% of Reused Material	0.071	Damaged Inventory (DI)	0.057	Air/Water/Land Emission (AWLE)	0.053

Table 4.2 Importance Weights of Long-term Decision Criteria of Considered SC

Supplier Selection		**Manufacturing**		**Warehousing**		**Logistics**	
Long Term Criteria (C_n)	**Wt. (AHP) W_i**	**Long Term Criteria (C_n)**	**Wt. (AHP) W_i**	**Long Term Criteria (C_n)**	**Wt. (AHP)**	**Long Term Criteria (C_n)**	**Wt. (AHP) W_i**
Monetary Value (MV)	0.403	Manufacturing / Inventory Cost (Mfg. / Inv Cost)	0.511	Order Fill Rate (OFR)	0.358	Flexibility (F)	0.068
Supplier Delivery Performance (SDP)	0.187	Environmental Friendly Operation (EFO)	0.247	Inventory Level (IL)	0.317	Delivery Reliability (DR)	0.303
Geographical Location (GL)	0.101	Capacity Utilization (CU)	0.131	Storage Utilization (SU)	0.260	Transportation Cost (TC)	0.377
Environmental Friendly Supplier (EFS)	0.310	OEE	0.111	Inventory Count Accuracy (ICA)	0.064	Environmental Friendly Transportation (EFT)	0.252

Table 4.3 Importance Weight of Considered SC Functions

Supplier Selection	0.230	Manufacturing	0.371	Warehousing	0.111	Logistics	0.288

Step 7: Develop fuzzy if-then rules (knowledge-base)

Experts were asked to develop a fuzzy knowledge base (if-then rules) based on their experience. Experts consulted with each other and gave us the rules. They consider the only horizontal relationship between considered SC functions criteria. A sample of such rules is mentioned in table 4.4 below. Similarly, experts establish rules for short-term and long-term decision criteria and overall SC performance.

Table 4.4 If-Then, Else Rules Examples

	Supplier Delivery Performance			
		Rejection rate Wt.		
		L	M	H
Rejection Rate	L	H	H	M
	M	L	M	L
	H	L	L	L

PS: L = Low ; M = Medium ; H = High

Above mentioned rules can be interpreted as follows:

If rejection rate is “Low” and its weight factor is “low” then supplier delivery performance will be “high.”

If rejection rate is “medium” and its weight factor is “high” then supplier delivery performance will be “low.”

Step 8: Develop framework in Fuzzy Inference System (FIS) using Matlab

In order to develop integrated FIS to evaluate overall SC performance, we need to build inference system in three phases as explained above in step 8 of section 3.3 of chapter 4. An example of FIS is mentioned in figure 4.1. The structure of integrated framework to evaluate overall SC performance in each phase is shown in figure 4.2.

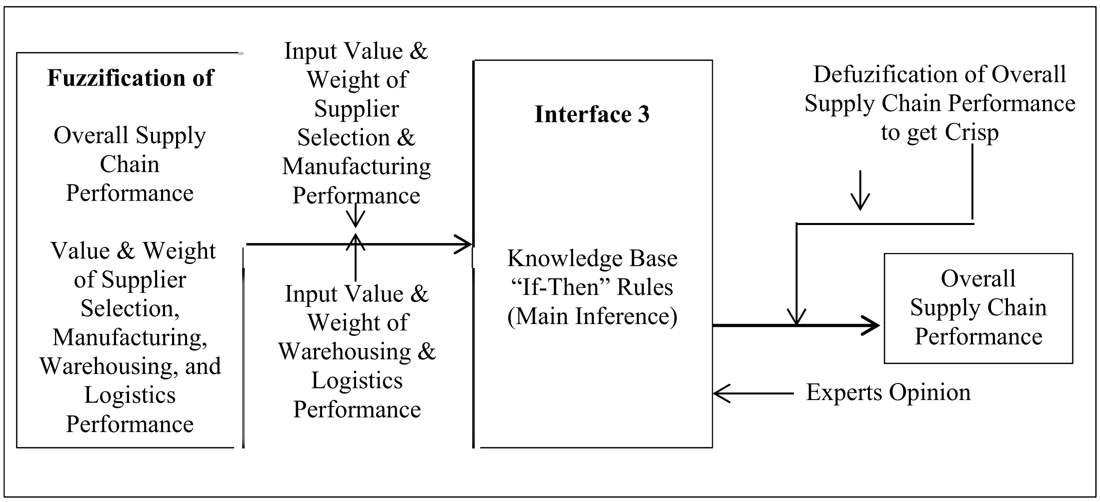

Figure 4.1 FIS of Integrated System to Evaluate Overall SC Performance

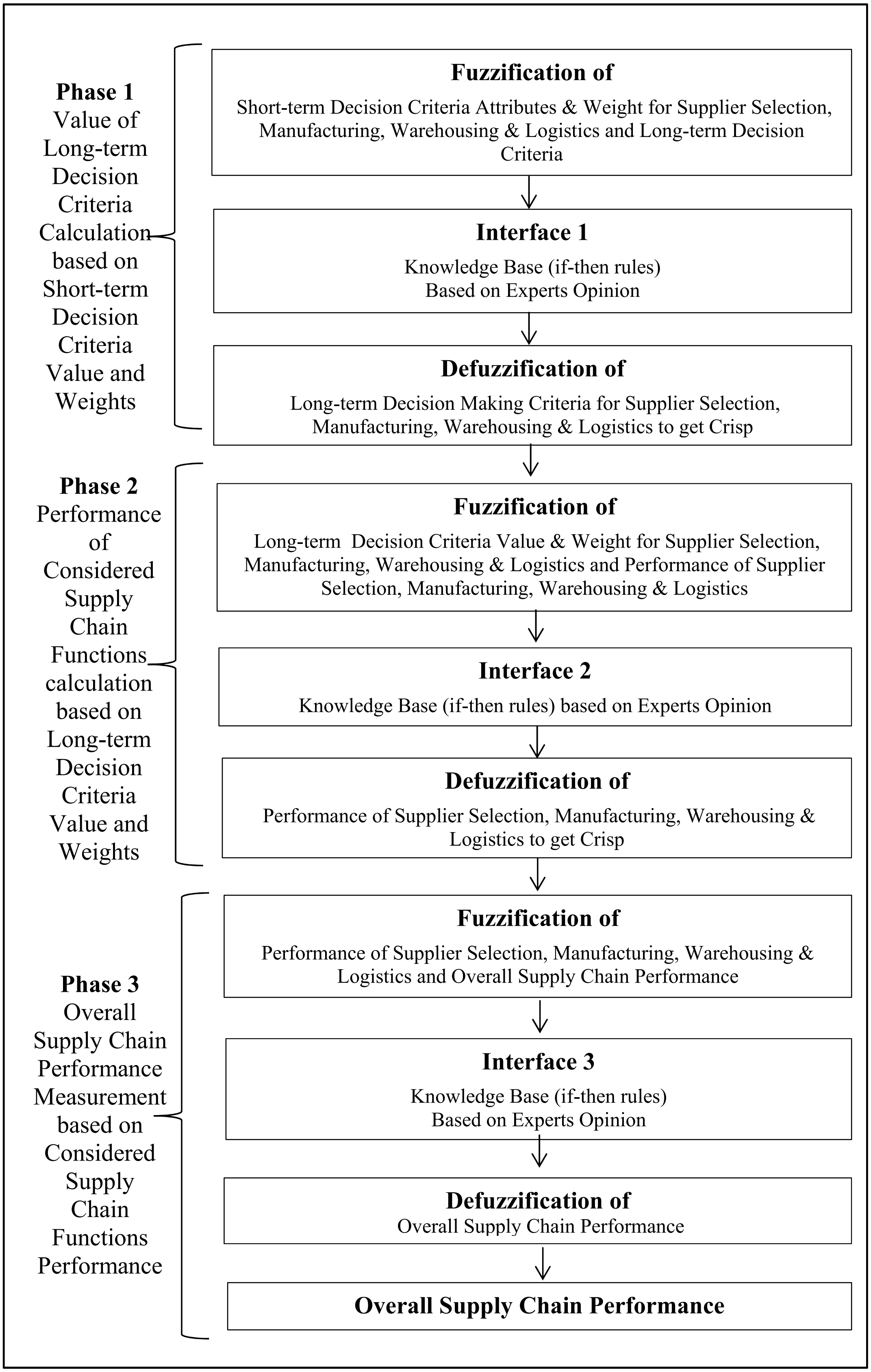

Figure 4.2 Structure of integrated framework to evaluate overall SC performance

4.1.2 Overall SC performance evaluation

Having all necessary inputs for the determination of the overall SC performance, we can at this point build a FDMS for the evaluation of overall SC performance according to the following steps.

Step (a): Figure 4.3 illustrates the intended FDMS for overall SC performance. We have six inputs for supplier selection (short-term decision criteria and their weights), and four output (long-term decision criteria). Similarly, we have six inputs for manufacturing, warehousing, and logistics (short-term decision criteria and their weights) and four output (long-term decision criteria). In order to evaluate overall SC performance by the integrated system as mentioned in figure 4.3, we develop the same FDMS for phase 2 and phase 3. In general, the value of long-term decision criteria of each function of SC is determined from the aggregation of the following three components:

1) The combined impact of short-term decision criteria of supplier selection (price and weight of price) on long-term decision criteria (Monetary value, supplier delivery performance, geographical location and environmental friendly supplier): This combined impact can be evaluated using a set of fuzzy if–then rules. These rules should be usually based on expert’s knowledge and experience in the case company. These rules have been developed for all short-term criteria of supplier selection (rejection rate, on time delivery, lead time, delivery flexibility, air/water/land emission and their associated weights) on long-term decision criteria (Monetary value, supplier delivery performance, geographical location and environmental friendly supplier).

2) The combined impact of long-term decision criteria of supplier selection, manufacturing, warehousing, and logistics (values that we got it from step 1 and their weights) on the performance of supplier selection, manufacturing, warehousing, and logistics. This combined impact can be evaluated using a set of fuzzy if–then rules. These rules should be usually based on expert’s knowledge and experience in the case company. These rules have been developed for all

long-term criteria of SC functions (supplier selection, manufacturing, warehousing, and logistics) performance of considered SC functions.

3) Similarly, the combined impact of performance of considered SC function (supplier selection, manufacturing, warehousing and logistics) on overall performance can be evaluated using a set of fuzzy if–then rules.

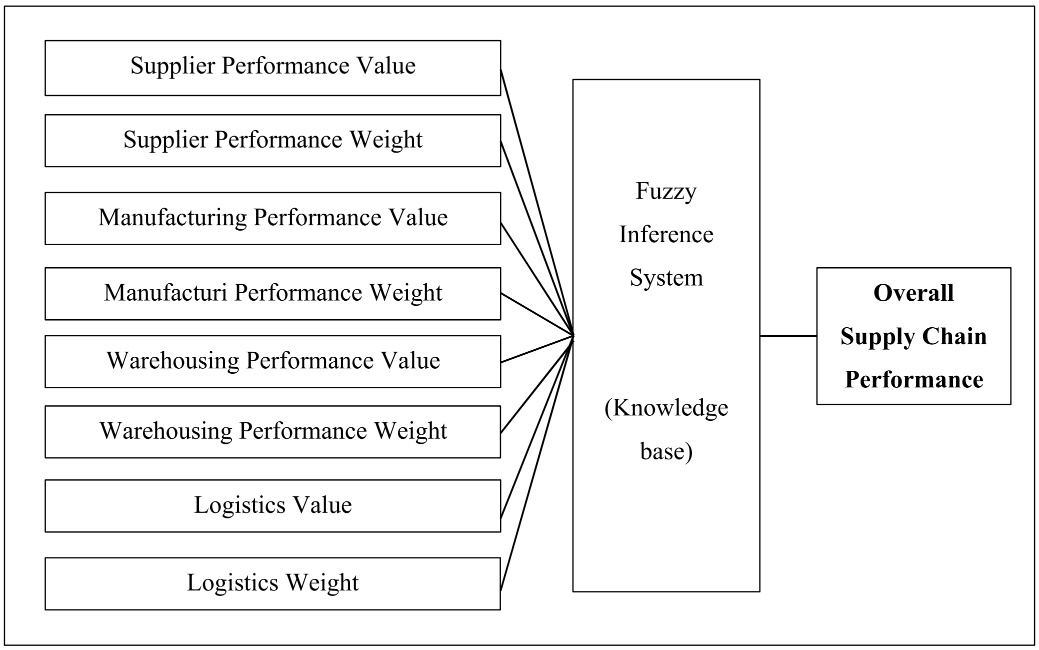

Figure 4.3 Intended FDMS for Overall Performance Evaluation

Step (b): Fuzzify the input variables and the output variable in phase 1, phase 2 and phase 3 as mentioned in figure 4.2 based on experts' knowledge and experience. Dweiri and Kablan, (2006) mentioned that "membership functions, in general, are developed using expert's knowledge and experience. The boundaries and the shape of each subset are usually suggested by experts. We selected to use the following fuzzy subsets to fuzzify the input variables L (Low), M (Medium), and H (High)". In addition, we selected to use trapezoidal membership functions. Similarly, the other input variables and the output variable are fuzzified.

Step (c): Enter if–then decision rules into the software. The used if–then rules in our case study are assumed to be based on heuristic knowledge and experience of the experts.

They are conveniently tabulated in the form of look-up tables as mentioned above in table 4.4. For all three phases, experts were asked to develop rules based on their experience. The total number of rules included in the first phase is 558; in the second phase is 128 and 36 in the third phase. These rules are entered into the software, and they will be accessed and their truth-ness evaluated during the inferencing process. Now the structure of the FDMS is complete because inferencing and defuzzification are built in functions in the software.

Now our FDMS is ready to accept input values. In phase 1, if we feed the system with the input ST criteria attributes and weights of short-term criteria of each function of SC (supplier selection, manufacturing, warehousing, and logistics) as mentioned in table 4.1. FDMS will relate input values to their fuzzy sets, the decision rules are applied, and the fuzzy results of the output variable (long-term decision criteria) in phase one for each function of SC are composed and defuzzified using the center of area (COA) method. The output of each SC function of long-term decision criteria based on input values of short-term decision criteria from case company and weights from AHP. Table 4.5 shows the phase 1 results below:

Table 4.5 Long-term Decision Criteria Values Based on Short-term Decision Criteria (STDC) Values (Attributes) and Weights (Phase 1)

Supplier Selection			Manufacturing			Warehousing			Logistics		
STDC (C_m)	Attribute	Wt. (AHP) (W_i)	STDC (C_m)	Attribute	Wt. (AHP) (W_i)	STDC (C_m)	Attributes	Wt. (AHP) (W_i)	STDC (C_m)	Attributes	Wt. (AHP) (W_i)
OTD	0.90	0.324	P	0.85	0.248	OA	0.95	0.369	QGD	0.93	0.351
Price	75	0.201	C?O Hour	45	0.233	OFR	0.97	0.216	FD	0.89	0.248
RR	0.10	0.194	Defect %	0.07	0.222	C/O	26	0.134	OTD	0.91	0.165
AWLE	60	0.142	AWLE	54	0.130	OTD	0.93	0.125	C/U Delivered	36	0.109
LT	12	0.091	OTD	0.90	0.096	IT	7	0.097	RPC/U	31	0.073
DF	6	0.047	% of Reused Material	0.08	0.071	DI	0.03	0.057	AWLE	60	0.053

Knowledge Base System (Phase 1)

Supplier Selection		Manufacturing		Warehousing		Logistics	
Long Term Decision Criteria (LTDC) (C_n)	Value	Long Term Decision Criteria (C_n)	Value	Long Term Decision Criteria (C_n)	Value	Long Term Decision Criteria (C_n)	Value
MV	0.54	IL	0.311	OFR	0.576	F	0.375
SDP	0.546	EFO	0.302	IL	0.506	DR	0.493
GL	0.357	CU	0.337	SU	0.618	TC	0.658
EFS	0.478	OEE	0.487	ICA	0.569	EFT	0.487

Similarly, table 4.6 shows the performance of each SC functions (supplier, manufacturing, warehousing, and logistics) based on long-term decision criteria value that we got in phase I (as mentioned in table 4.5) and the relative importa nce weights that we got from AHP (as mentioned in table 4.2). FDMS will relate input values to their fuzzy sets, the decision rules are applied, and the fuzzy results of the output variable (performance) in phase two for each function of SC are composed and defuzzified using the COA method.

Table 4.6 Performance of Considered SC Functions Based on Long-term Decision Criteria Values and Weights (Phase 2)

Supplier Selection			Manufacturing			Warehousing			Logistics		
LTDC (C_n)	Value	Wt. (AHP) (W_j)	LTDC (C_n)	Value	Wt. (AHP) (W_j)	LTDC (C_n)	Value	Wt. (AHP) (W_j)	LTDC (C_n)	Value	Wt. (AHP) (W_j)
MV	0.540	0.403	IL	0.311	0.511	OFR	0.576	0.358	F	0.375	0.068
SDP	0.546	0.187	EFO	0.302	0.247	IL	0.506	0.317	DR	0.493	0.303
GL	0.357	0.101	CU	0.337	0.131	SU	0.618	0.260	TC	0.658	0.377
EFS	0.478	0.310	OEE	0.487	0.111	ICA	0.569	0.064	EFT	0.487	0.252

Knowledge Base System (Phase 2)

Supplier Performance	0.664	Mfg. Performance	0.650	Warehousing Performance	0.414	Logistics Performance	0.378

Table 4.7 shows the overall SC performance based on considered SC functions (supplier selection, manufacturing, warehousing, and logistics) performance values that we got in phase 2 (as mentioned in table 4.6) and its importance weights from AHP as mentioned in table 4.3. FDMS will relate input values to their fuzzy sets, the decision rules are applied, and the fuzzy results of the output variable (Overall SC performance) in phase three for the performance of each function of SC are composed and defuzzified using the COA method.

Table 4.7 Considered SC Functions Performance (Phase 3)

Considered SC Functions Performance	Value	Weight (AHP)
Supplier Selection	0.664	0.230
Manufacturing	0.650	0.371
Warehousing	0.414	0.111
Logistics	0.378	0.288

Knowledge Base System (Phase 3)

Overall SC Performance	**0.507**

Based on short-term criteria attributes that we got from a case company information system, we can see that the performance of supplier selection is 66.4%, manufacturing is 65%, warehousing is 41.4%, and logistics is 37.8%. Also note that as per company experts and based on their pair-wise comparison, the importance of supplier selection in evaluating overall supply chain performance in 23% followed by 37.1 % of manufacturing, 11.1% of warehousing and 28.8 % of logistics. These important values totally depend on company's experts and developed KBS. For considered case company, overall supply chain performance of a case company is **50.7%**.

For a better presentation of the results, a SC monitoring dashboard is shown in figure 4.4. The dashboard is useful for both top managers and operational managers (planners) and allows them to see overall performance. Moreover, it will also help decision makers in setting targets and monitor overall SC performance over a period of time.

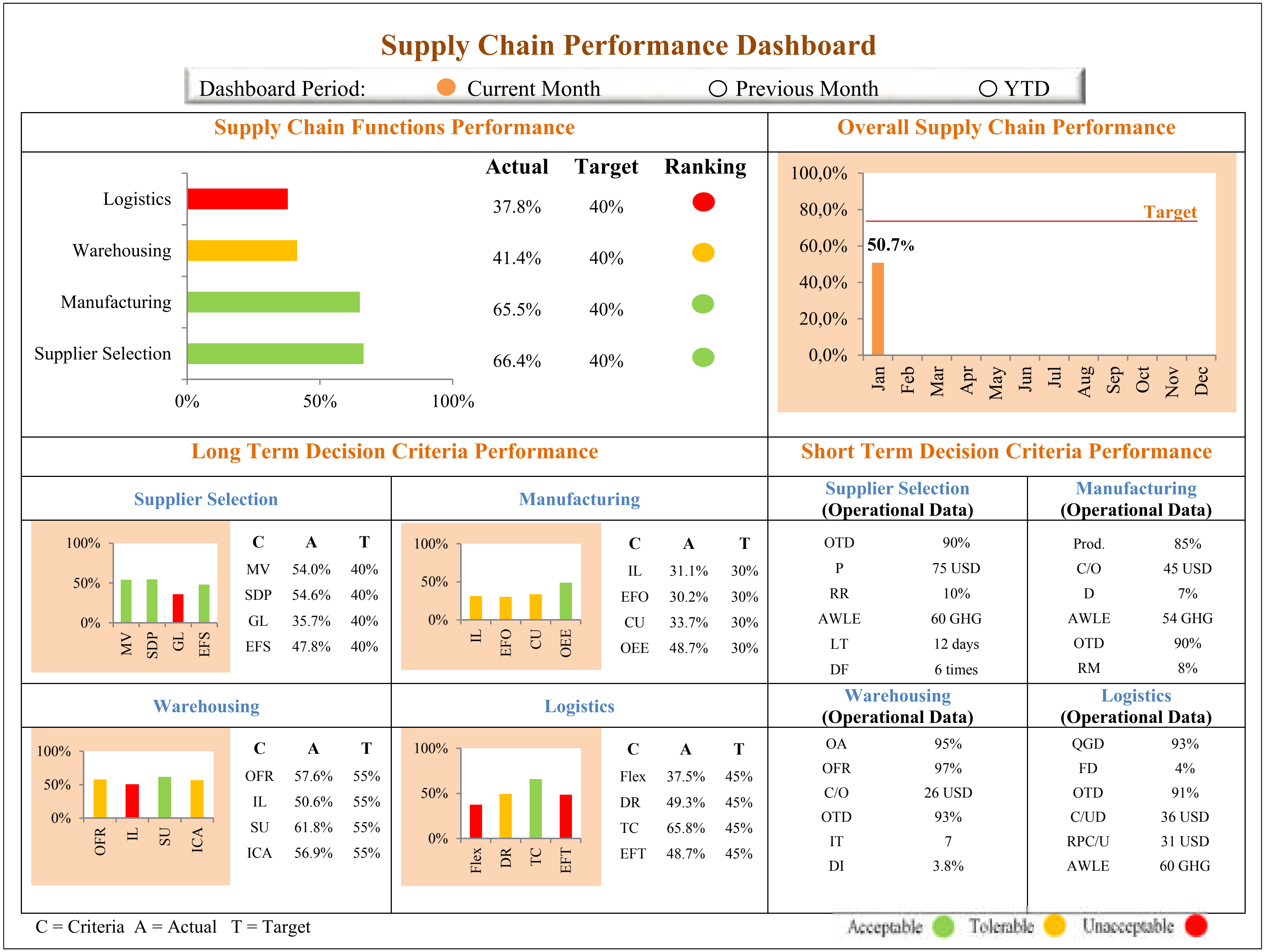

Figure 4.4 Supply chain performance dashboards

4.2 Discussion and practical implications

The proposed methodology is general in nature and can be implemented in different sectors with few modifications such as a change in criteria (short-term and long-term) and weights which reflect the change in supply chain strategies and policies. In the case of an automobile manufacturing company, the identified criteria and SC functions were approved by the case company experts, and we implemented the proposed methodology. There might be a cross functional relation between short-term decision criteria across considered SC functions, and Fuzzy knowledge base will allow decision makers to establish such relation based on their experience.

Decision makers and experts can develop as much relationship as they think are possible and they think it is relevant for their SC. In the case company, experts considered the horizontal relationship between the decision criteria. SC Managers and decision makers' are now able to evaluate precisely the SC performance based on the knowledge system that helps decision makers and SC managers to use efficiently the data from data management systems.

The second purpose of this study was to integrate and evaluate overall SC performance. The proposed methodology is able to integrate considered SC functions and their associated short-term and long-term decision criteria in three (3) different phases as mentioned in figure 4.2. In phase one, we calculated long-term decision criteria value based on short-term decision criteria attributes (that we got it from case company information system) and weights (that we got it from AHP). In the second phase, we calculated the performance of considered SC functions (supplier selection, manufacturing, warehousing, and logistics) based on long-term decision criteria value that we got in phase 1 and weights that we calculated using AHP. In the third phase, overall SC performance was evaluated based on considered SC functions performance that we got in phase 2 and their importance weights using AHP. In this manner, every decisions and decision criteria have a relation to each other and an impact on overall SC performance. The proposed KBS uses experts' knowledge and experience to develop the relationship between decisions and decisions criteria (short term and long term) and their impact on overall SC performance.

The third purpose of this study was to identify underperformed decision criteria at different decision level (long-term or short-term) to improve overall SC performance. After implementation of our proposed knowledge base SC performance evaluation system, we can notice that overall SC performance of case company is 50.7% and needs improvement. Our proposed methodology will help decision makers to find underperformed function; in this case, logistics is the lowest performed function in the entire SC as its value is lowest in all SC function, which is 37.8%. It is also noticed that its importance or relation in measuring overall SC performance is 28.8% which is significant. Therefore, now decision makers have a decision to improve logistic performance in order to improve overall SC performance.

As mentioned previously, we need decisions and decision criteria related to logistics at long-term and short-term level. In this case, we can see that from table 4.6, flexibility (long-term decision criteria) and its associated decision which is fleet variety has low value which is 0.375 and its importance weight is 6.8% followed by environmental friendly transportation value (long-term criteria) and its associated decision which is sustainable transportation is 0.487, and its importance weight is 25.2%. Now here decision maker has a choice to choose either flexibility or environmental friendly transportation decision criteria and decisions which are fleet variety and sustainable transportation to improve overall SC performance.

For example, if want to take a decision at a long-term level to improve logistics performance that will lead to improving overall SC performance, we have to increase fleet variety and select transportation service provider which has a variety of fleet. This will improve flexibility (long-term decision criteria) and improve overall SC performance. This show that our proposed KBS can easily provide the direction of improvements, identify decisions and decisions criteria, and helps decision makers in improving overall SC performance.

Developed overall SC performance evaluation dashboard is practically allowed decision makers and SC managers to view overall SC performance in one shot. Proposed KBS automatically updates the information in the dashboard by integrating new changes in policies and strategies with operational results. In this manner, and in order to improve overall SC performance, decision makers and SC managers' needs to identify which function and which criteria (long-term / short-term) needs extra focus and attention. In this case, the proposed KBS is able to identify underperformed decision criteria (long-term / short-term) easily. This will help them to pay more attention to that specific decision criterion (long-term / short-term) and improve overall SC performance.

4.3 Conclusion

Existing SC performance models are not efficient to align with digitalization and establish a relationship between decisions and decision criteria. Every SC of industry segment is different. Therefore, we need a holistic and integrated knowledge base SC performance evaluation system that evaluates overall SC performance, establish a relationship between decisions (long-term and short-term) and decision criteria of SC functions and allow decision makers to see the impact of their short-term or long-term decisions on overall SC performance.

This thesis developed a knowledge based system that establishes a relationship between short-term and long-term decisions and decisions criteria and evaluates overall SC performance. Proposed KBS can be implemented in an industry and relationship between the decisions and decision criteria can be developed by the experts. This relationship can cascade or across the SC functions as mentioned in figure 3.4. According to the proposed approach, the relationship among decisions and decision criteria and overall SC performance are determined from the integration of the following three impacts:

- The combined impact of short-term decision criteria attributes (from case company) and its importance weights (from AHP) of considered SC functions (supplier selection, manufacturing, warehousing, logistics) on long-term decision criteria of considered SC. (Phase 1)

- The combined impact of long-term decision criteria value (from Phase 1) of considered SC functions and its importance weight factor (from AHP) on the performance of each function of considered SC. (Phase 2)
- The combined impact of considered SC functions performance value (from phase 2) and its importance weight factor (from AHP) on overall SC function.

The proposed integrated KBS for overall SC performance evaluation is illustrated via a case study. A fuzzy MCDM system is designed and implemented using the MATLAB software for overall SC performance evaluation. In addition, the AHP, and Expert Choice (EC) were used for the assessment of the priorities of short-term and long-term decision criteria and functions of considered SC. The development of a fuzzy MCDM system for overall SC performance evaluation is easily implemented using the MATLAB software. MATLAB is a software that operates using “file menu” instead of commands. It allows decision makers to construct membership functions and creates a database of fuzzy “if-then” rules. Moreover, fuzzy inference system (FIS) is a built in options in MATLAB.

Here it is important to mention that proposed KBS extensively depends on decision maker’s knowledge and their experience. Their knowledge and experience are needed in selection and construction of membership functions and fuzzy sub-sets for every input variable and output variables. Also, their knowledge was used in developing fuzzy “if-then” rules to establish a relationship between input variables and output variables. Therefore we will consider our proposed and implemented KBS as Fuzzy MCDM Expert System (FMCDMES). Similar to other expert systems, our proposed KBS is able to store decision maker’s knowledge and their experience and can be updated after several months of implementation. It also helps in building up the organization corporate memory that might be useful for upcoming decision makers and experts.

At last, our proposed system is able to monitor the effect of changing the behavior of customers due to digital transformation of SC. It creates a relationship between each function of SC decisions and decision criteria and SC functions and gives a holistic and integrated approach to evaluate overall SC performance which is lacking in existing SC performance evaluation system.

Our proposed KBS is depended on expert's knowledge and their experience. Therefore it is essential for organizations to update KBS after several months of experience and results.

CHAPTER 5

MULTI-OBJECTIVE SUPPL CHAIN DESIGN MODEL FOR LONG-TERM DECISION-MAKING AND PERFORMANCE EVALUATION

In the previous chapters, we developed and implemented a KBS to evaluate the overall SC performance based on hybrid Fuzzy-AHP model. If the overall supply chain performance is not up to the mark and needs improvement, it is essential for decision makers to incorporate under-performed decision criteria (attribute) during the SC design and operational planning. SC performance heavily depends on how well the design of SC integrates the main criteria used by the SC performance measurement system. In this chapter, we will propose SC design model based on considered SC long term decision criteria (attributes) and get the expected (optimum) values of these criteria (attributes). After that we will evaluate expected (optimum) overall SC performance based on expected (optimum) long term criteria (attributes) values obtained from SC design model. Moreover, we will compare expected (optimum) overall SC performance by considering different scenarios such as efficient SC, flexible SC, and environmental friendly SC.

5.1 Introduction

In order to compete in today's business environment organizations have to deliver product and service to the customers more rapidly as before. SC design has a significant impact on overall SC performance, and well-designed SC will be able to deliver the product more rapidly. Also, it is important for decision makers to see the impact of decisions that they took during SC design on overall SC performance. Each SC function and their associated criteria (attributes) have an impact on overall SC performance. Uncertainty is inherent in any SC and decision makers should consider uncertainty while designing SC. In order to effectively managing SC functions, decision makers' needs to take effective and efficient long-term decisions while considering uncertainty to increase overall SC performance. Therefore, integration of supply chain functions and decisions with the supply chain performance criteria is essential for effective and efficient SCM. As today's business competition is among SCs, instead of individual firms, it is deemed essential to design the appropriate supply chain based on the competitive strategy of the company, which can help sustain competitive advantages for all chain members. Numerous articles for designing SCs in the recent two decades (Gebennini, Gamberini, & Manzini, 2009) have been introduced and demonstrate how sensitive the supply chain design to the criteria and performance used at this phase. SC network design in the broad sense is a strategic decision that must be optimized to manage SC operations efficiently. The decisions of SC system design have an impact on the delivery of different product, the cost of product delivered and lead time. According to Pishvaee & Razmi (2012), SC network design, as the most important strategic decision in SCM, plays a significant role in overall environmental and economic performance of the SC. In general, SC network design includes determining the locations, numbers, and capacities of network facilities and the aggregate material flow between them (Melo et al. 2009).

The connection between the SC design and SCM is essential for efficient operations. Many companies such as Wal-Mart, Dell Computers, etc. are successful companies, and they achieve their success because of their efficient SC design and management of SC activities. From the literature, we can easily find out that many companies such as Webvan and acquisition of Quaker Oats's in 1994 show that weakness and inability of their SC design and ineffective management of SC. Therefore, SC design decisions play a fundamental role in any organizations success or failure. Chopra & Meindl (2016) mentioned that SC design problem has to make different decisions related to the number of facilities and their locations, capacity requirements at each manufacturing sites, distribution network design and supplier selection. For example, Wal-Mart has been a leader in using SC design, and SC efficient operations to achieve success. Wal-Mart developed its SC with clusters of stores around distribution centers to facilitate frequent replenishment at its retail stores in a cost-effective manner. Frequent replenishment allows stores to match supply and demand more efficiently than the competition. The results are impressive. In their 2004 annual report “the company reported a net income of more than $9 billion on revenues of about $250 billion”. These are dramatic results for a company that reached annual sales of only $1 billion in 1980. The growth in sales represents an annual compounded growth rate of 26 percent (Chopra & Meindl, 2016).

In managing SC, many decisions are required related to the flow of information, flow of material, flow of product and flow of money. SC decisions can be divided into two broad categories which are long-term decisions and short-term decisions depending upon the frequency and period. SC design is a long term decision as in designing of SC a company has to decide how to structure the SC over the next several years. It allows that what will be the configuration and different resources will be assigned, and what will be the different process at each stage will perform. An organization must ensure that the SC configuration supports its long-term strategy (goals). "SC design decisions are typically made for the long term (a matter of years) and are very expensive to alter on short notice. Consequently, when companies make these decisions, they must take into account uncertainty in anticipated market conditions over the next few years" (Chopra & Meindl, 2016).

5.2 Motivating Problem

SC long-term decisions have an impact on overall supply chain performance. For example, if the distribution center location is not appropriate, it is quite impossible to deliver the product on time and minimize transportation cost. Similarly, if we will not consider sustainability criteria as primary criteria during supplier selection, it's hard to meet sustainability in SC operations. Therefore, to achieve adequate overall supply chain performance, SC design should incorporate all long-term decision and decisions criteria and linked them with short-term decisions and decision criteria. It is evident from the literature that SC design is one of the essential factors that have an impact on the performance of SC. Decisions such as planned capacity in each facility, contractual terms with suppliers and facilities location are few long term decisions that have to be taken while designing SC (Chopra & Meindl, 2016). If decision makers will not pay attention to these decisions at the design phase, it's hard to achieve high supply chain performance through sophisticated information systems. Therefore In order to improve the performance of SC, it is essential for DM to first design an effective and efficient SC and integrate different functions and activities of SC so that SC surplus will increase and improve overall SC performance. Thus, if the organization wants to improve the supply chain performance, decision makers should focus more on SC design and establish the efficient and effective link between long term decisions criteria (attributes) and SC design through KBS.

Real-world supply chain design problems have inherent uncertainty. The reason for uncertainty can be related to target values of objectives, supply, and demand, unexpected natural disasters, quality of the supplied product, etc. Many authors developed SC design models either by ignoring this uncertainty or use probability concepts to approximate them. However, if there is a lack of evidence available or lack of certainty in evidence, standard probabilistic concepts and methods are not appropriate In such situations, we can specify uncertain parameters with the help of experts experience decisions makers' subjective judgment (Celikbilek, Erenay, & Suer, 2015).

In SC design we have to maximize or minimize different goals which are conflicting in nature and often achievement of all goals is rarely possible. MCDM methods usually deal in the resolution of multiple conflicting goals to achieve a satisfying solution rather than traditional maximization or minimizing multiple objectives. Generalized goal programming has been proven approach to reduce under achievement (negative) and over achievement (positive) deviations from the targeted goals. However, in real life, some or all of multiple objectives are un-quantifiable or imprecise and needs linguistic measurement such as good, very good, etc. To address such situations, it is appropriate to model objective functions and constraints with a certain tolerance limit. To measure accurately multiple goal values of different objectives is difficult because of availability of partial information.

Models available in the literature are not adequate to cater uncertainty which is inherent in SC. Decision makers need to know how well they are performing and how far they are from the optimum (expected) value. Once the proposed KBS, proposed in chapter 3, evaluates the overall SC performance, now we have to compare it with the optimum (expected) overall SC performance. However available decision models are not catering this situation and re-evaluating overall SC performance. To address such situations, it is appropriate to model objective functions and constraints with a certain tolerance limit. To measure accurately multiple goal values of different objectives is difficult because of availability of partial information. Similarly, to incorporate uncertainty which is inherent in SC, it is difficult to approximate inputs. Figure 5.1 below illustrate that once we will evaluate overall SC performance (as mentioned in figure 3.2 and implemented in chapter 4), now in this chapter we propose a decision model to redesign the SC after incorporating underperformed decisions criteria (attributes) and improve overall SC performance by providing a link between SC evaluation and SC decisions (long-term and short-term).

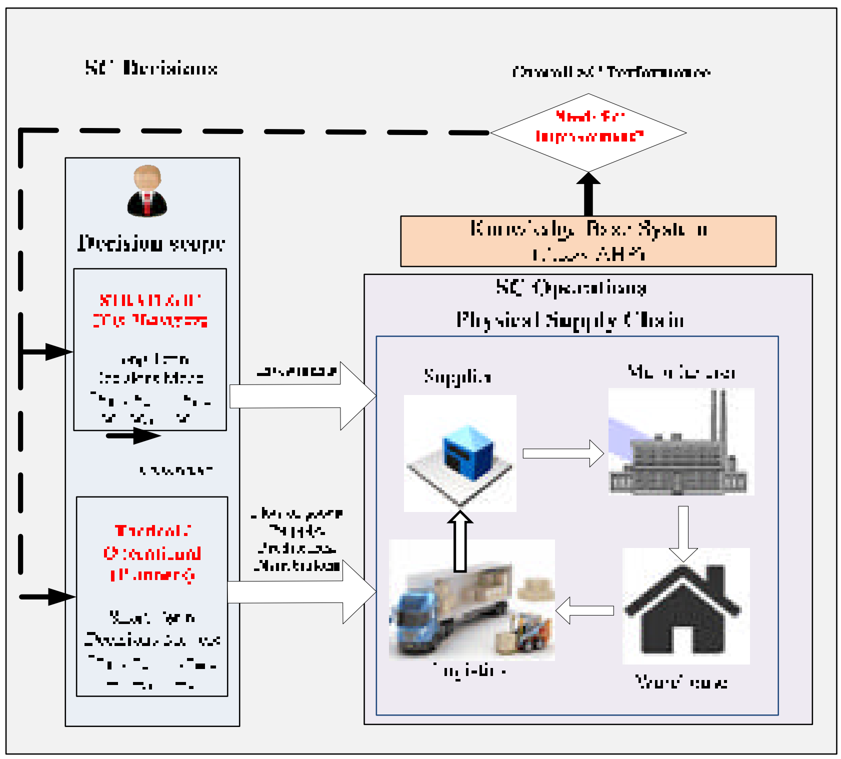

Figure 5.1 Supply chain design framework

5.3 Literature Review

Supply chain (SC) design is usually a quantitative analysis in which stakeholders build working concepts for an actual SC. Such analysis usually helps in supporting long-term decisions. This will help decision makers to focus more on decisions criteria which have an impact on overall SC performance. According to Varsei and Polyakovskiy (2016), SC network design aims to find the best possible SC configuration following the company's competitive strategy and long-term goals. It is concerned with the long-term strategic decisions related to the number, location, and capacity of production plants and distribution centers; the flow of raw material, intermediate and/or finished products throughout SC; and a set of suppliers to select (Chopra & Meindl, 2016). As pointed out in Gebennini et al.(2009); Sabri & Beamon,(2000); Simchi-Levi, Kaminsky, & Simchi-Levi, (2004); and Thanh, Bostel, & Peton, (2008), the SC design's central decisions include supplier selection, facility location and capacities, customer demand allocation, raw material, component and product flows, which are at the strategic level. To cope with these decisions, researchers have proposed a myriad of valuable strategic SC design models (Linda et al. 2016). Many authors used different methodologies in SC design such as nonlinear programming models (Park, Lee, & Sung , 2010); heuristics models (Ahmadi & Azad, 2010; Baumgartner & Thonemann, 2010), and fuzzy theory (Bidhandi et al. 2009; Mahnam et al. 2009).

Chaabane et al. (2011) "considered the design of a forward SC while incorporating the cap-and-trade system and environmental regulatory requirements. Chaabane et al. (2012) extended the work of Ramudhin and Chaabane (2010) by developing a comprehensive multi-objective optimization model for the design of a SC integrating an emissions trading scheme". Similarly Wang et al. (2011) "proposed a multi-objective optimization model for the design of a SC with three echelons (suppliers–facilities–customers) integrating environmental concerns. The impact of facility location and supplier selection on the environment considered the carbon emissions on the different arcs of the SC. An integer variable representing the level of environmental protection in each facility and possibly reflecting the technology selection decision was introduced in their model". Lee et al. (2010) applied mixed integer programming models (MILP) and studied SC network design in which they include location and allocation of facilities and decisions related to routing. Chen and Lee (2004) study multi-echelon SC considering uncertainty in the product price, demand. They applied FMOO method by developing a model based on MILP. Gullien et al. (2005) developed a model to solve stochastic MOP based on MILP with branch and bound technique. Hugo et al. (2005) designed a SC network to help strategic decision-making process of future hydrogen cell SC. They developed and presented a standard and generic MILP model to identify optimal optimization strategies in integrated SC configuration. Altiparmak et al. (2006) developed a model to design plastic products company SC based on MILP and MOO using GA. Chen et al. (2003) and Mitra et al. (2009) developed MILP model using fuzzy and MO to formulate SC. One of the most important classes of multi-criteria decision models that have been used widely is Goal programming (GP) which is capable of solving problems which have conflicting objectives. In last 50 years, there is a lot of development and modifications have been done which makes GP as one of the most preferred MCDA technique. It applied in many areas such as engineering, management, and social sciences. Originally introduced in the 1950s by Charnes et al. (1955) “the popularity and applications of GP have increased immensely due to the mathematical simplicity and modeling elegance. Over the recent decades, algorithmic developments and computational improvements have significantly contributed to the diverse applications and several variants of GP models”. Selim and Ozkarahan (2008) employ a fuzzy goal programming approach to study SC distributor network design model. Ghorbani et al. (2014) propose a FGP approach for a multi-objective model of reverse SC design. Martí et al. (2015) “proposed a SC network design model that simultaneously considers the emissions and costs related to both facility location and transport mode decisions while taking into account the innovative or functional nature of products through the explicit consideration of demand uncertainty and inventory costs”.

Chaabane et al. (2011) “considered two objective functions in their model which are minimizing the total logistics cost and minimizing the total emissions. The carbon emissions were a function of logistics decisions including production facility location, supplier selection, transportation mode, and technology selected”. Chaabane et al. (2012) “developed a model by considering a closed loop SC with suppliers, production facilities, distribution centers, customers, and recycling centers and the aggregate environmental impacts regarding input consumptions and output emissions. The model minimized the total amount of these emissions as well as the total cost. It is assumed that carbon emissions credits might be purchased and sold as long as the company complies with the carbon emissions limit”. Martí et al. (2015) “developed a model that explicitly addressed differences across facility locations regarding costs/emissions of raw materials or components, manufacturing technologies, and labor. Their model emphasized carbon footprint and SC responsiveness trade-offs, and their implications on the SC network design". Wang et al. (2011) proposed a multi-objective optimization model for the design of a SC and the objectives were to minimize the total cost as well as the total carbon emissions in the nodes and arcs of the SC (Nouira et al. 2016). Selim and Ozkarahan (2008) "employ a fuzzy goal programming approach, and the objective is to select the optimum number, location and capacity level of plants and warehouses to deliver products to retailers with least cost to satisfy desired service level." Ghorbani et al. (2014) propose a FGP approach for a multi-objective model of reverse SC design with the objective to minimize recycling cost, the rate of waste generated by recyclers and material recovery to develop responsive and efficient reverse SC. Chen and Lee (2004) developed a model based on FMOO and MILP in which they considered expected profit, expected customer service level, and average safety stock of each entity. Uncertainty in demand was managed by using specified probabilities and fuzzy variables. Altiparmak et al. (2006) considered different objectives in their model which is based on based on MILP and MOO using GA which was the minimization of total SC cost, maximize service level, and maximize capacity utilization.

Below table 5.1 summarizes the literature regarding considered SC functions and model type.

Table 5.1 Different SCND models and considered SC function

S.No.	Authors	SC Function Considered	Objective functions (Criteria)	Model Type
1	Sakawa et al. (2001)	Integrated Logistics and Transportation	- Cost (min)	Fuzzy mathematical programming
2	Dimerli & Yimer (2006)	Integrated Production and Distribution	-Production cost (min) -Logistics cost (min) -Assembly cost (min) -Inventory cost (min)	FMILP
3	Aliev et al. (2007)	Integrated Production and Distribution	- Production cost (min)- - Fill rate (max)	FLP
4	Celikbilek, Erenay, & Suer (2015	Integrated SC	- Satisfaction level(max)	FMILP
5	Selim, Araz, & Ozkarahan, (2008)	Integrated SC	- Total cost (min)	FGP
6	Xu, He, & Gen, (2009)	SCND	- Total cost (min)	FGA
7	Gumus, Guneri, & Keles (2009)	SCND	- Product flow (max)	Neuro Fuzzy and LP
8	Paksoy & Yapici Pehlivan(2012)	SCND	- Total cost (min)	FMOLP
9	Rao, Subbaiah, & Singh, (2013)	SCND	- Total cost (min) -Volume flexibility (max)	FGP
10	Amalnick & Saffar, (2017)	GSCND	Minimize cost of shipment, Purchasing machine	FMOMP
11	Bilgen, (2010)	Integrated production and distribution	- Production cost (min) - Cost of products(min)	FMP
12	Pochampally & Gupta (2012)	SCND	- Select efficient collection center	FLP
13	Ghorbani et al. (2014)	RSCND	- Recycling cost (min), - Material recovery time (min)	FGP
14	Tsai & Hung (2009)	SCD	Profit maximiztion	FGP
15	Balaman et al. (2014)	SCND	Profit, Unused waste	FMOLP
16	Pishvaee & Razmi (2012)	SCD	Enviormental impact (min)	FMOMP

5.3.1 Learning from the literature

In real-world supply chain design problem, because of the conflicting nature of the multiple objectives and the vagueness in information regarding the environmental coefficients, cost, demand variations and related parameters, conventional deterministic methods are unsuitable for yielding an effective solution. Such uncertainties have an impact on overall SC performance. SC design/redesign decisions are long term decisions and once implemented, it is hard to change. By the time design/redesign of SC is in place or implemented, many decision variables such as cost, demand, inventory may change significantly.

In the literature, different kind of decisions models (short term and long term) treated and considered by many authors separately. For example, different facility location decision models were developed with the objective of maximizing order fill rate of retailer and minimization of transportation cost. Some location decision models also focused on the number of distribution center with an objective of minimizing operating shipping cost and location cost. Literature is rich in different kind of decision models that were developed to design SC. Although literature highlights the importance of SC design concerning overall SC performance. Most of the models developed for SC design did not consider the impact of their design on overall SC performance. For example, every SC design model optimizes certain objective function such as minimization of cost or maximization of SC surplus / profit. However, in reality, it is not mandatory that minimization of the cost will give the optimum overall SC performance. Therefore it is essential for decision makers to design their SC and compare their optimum criteria values with overall SC performance. Previously developed models are not adequate enough to provide a connection of SC design models with overall SC performance. This connection is important for decision makers to make appropriate SC design decisions and select a strategy that maximizes the overall SC performance and in line with goals and objectives of the organization:

a) How to improve overall SC performance?

b) How to establish a link between decisions and decisions criteria (attribute) to redesign SC?

Above mentioned question motivated us to develop a decision model for SC design by considering multi-objective to optimize long-term decision criteria. Developed model will give the expected (optimum) value of considered objective functions (long-term decision criteria) and help us to evaluate overall SC performance based on KBS developed in chapter 3. This way we can compare overall SC performance with the expected (optimum) SC performance and set goals and target to achieve the desired performance.

5.4 Multi-objective model for supply chain design

5.4.1 Problem description and assumptions

To redesign SC, we will consider the same functions of SC as mentioned in figure 3.4 and mentioned in figure 5.2 below.

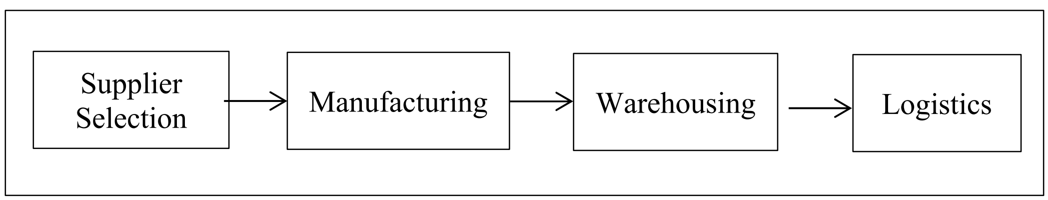

Figure 5.2 Considered SC functions for designing / redesigning

We will develop a model to redesign SC by considered lon-term decisions criteria (attribute) to improve overall SC performance. SC structure has an impact on overall SC performance and decision makers needs to design an efficient SC with only one objective which minimizes system wide cost (maximize profit). Some major long term SC decisions that are essential for SC design are (1) Outsourcing decisions, (2) production and warehouse location decisions, (3) warehouse and production facility capacity decisions, (4) logistics service provider selection, and (5) location of distribution center decisions. Let's consider the vector $X = (x_1, x_2, x_3 \ldots, x_k)$ as the long term decisions made by top managers to design the SC based on the strategy characterized by some specific long-term criteria $[C_1, C_2, C_3, \ldots, C_n]$ and their respective weights $(W_1, W_2, \ldots, W_3, \ldots, W_n)$. The group of decision makers defines these criteria.

Table 5.2 shows some examples of decision criteria (attributes), and the relevant decisions that influence might influence the criteria. For each criterion, let's consider f_i the objective function that measures the decision criteria, C_i and that has an impact on the overall SC performance.

Table 5.2 Performance attributes, their related decision variables, and corresponding indicators to measure these criteria

SC Function	**Decision Criteria (attributes)** $C_1, C_2., C_3, ... C_n$	**Decision(s) affected by criteria F(X)= ($x_1, x_2, x_3, … x_k$)**	**Measurement**
Supplier selection (SS)	Monetary value (MV)	- Quantity of raw materials to be purchased -Supplier selection	Cost of purchased raw materials
	Supplier delivery performance (SDP)	- Flow of raw materials -Amount of back orders at plants	Ratio of purchased orders delivered on-time and in full (without back order) to plants' demands
	Geographical Location Cost (GLC)	Supplier selection	Cost of establishing a business with suppliers
	Environmental Friendly Supplier (EFS)	- Quantity of raw materials to be purchased - Supplier selection	GHG associated with purchasing raw materials
Manufacturing (Mfg.)	Manufacturing/ Inventory cost	- Quantity of production - Plant and technology selection	Cost of producing products + Cost of establishing a plant with technology
	Overall Equipment Efficiency (OEE)	- Quantity of good products - Technology selection at plants	Ratio of good products quantity to products demand
	Capacity Utilization (CU)	- Quantity of production - Plant and technology selection	Ratio of production quantity to production capacity
	Environmental Friendly Operations (EFO)	- Quantity of production - Technology selection at plants	GHG associated with manufacturing activities

Table 5.2 Performance attributes, their related decision variables, and corresponding indicators to measure these criteria (continued)

Warehousing (WH)	Storage Utilization (SU)	Inventory level at Plants, DCs, and retailers	Ratio of raw materials/products at storage to storage capacity
	Inventory Count Accuracy (ICA)	Inventory level at DCs	
	Order Fulfillment (OF)	Flow of products to DCs	Ratio of products at DCs to products demand
	Inventory Level / Cost (ILC)	Inventory level at Plants, DCs, and retailers	Cost of holding products at storages
Logistics (L)	Flexibility (F)	Transportation mode selection	Ratio of available transportation capacity to total transportation capacity
	Delivery Reliability (DR)	- Flow of products to retailers - Amount of back orders at retailers	Ratio of products delivered on-time and in full (without back order) at retailers to products demand
	Transportation Cost (TC)	- Flow of raw materials and end products between nodes -Transportation mode selection	Cost of transporting raw materials/products between nodes
	Environmental Friendly Transportation (EFT)	- Flow of raw materials and end products between nodes -Transportation mode selection	GHG associated with transporting raw materials/products between nodes

5.4.2 Multi-objective supply chain design model

Table 5.2 shows some examples of decision criteria (attributes), and the relevant decisions that influence might influence the criteria. For each criterion, let's consider f_i the objective function that measures the decision criteria, C_i and that has an impact on the overall SC performance.

$$\begin{aligned} &\min/\max(\mathrm{F(X)}) \\ &\mathrm{s.t}\ \ \mathrm{G(X)} <= 0 \end{aligned} \tag{5.1}$$

Where $X \in R^n$ is the vector of decisions variables and $F(X) = (f_1(X), f_2(X),..., f_n(X))$ is the vector function to be maximized or minimized, and $G(\mathrm{x}) = (g_1(X), \mathrm{g}_2(X),..., \mathrm{g}_j(X))$ is the vector of the different design and logical constraints.

5.5 Solution Methodology

In SC network design, it is difficult for decision makers to quantify SC performance and decisions. For example, after evaluation of overall SC performance, decision makers are not sure about their performance such as is it good, or average or bad. They need an expected (optimum) overall performance to compare with. Similarly, the variables and performance criteria are also linguistic. For example, customer satisfaction level, therefore it is essential for decision makers to convert this linguistic information into nonlinguistic information. To do so, we will use fuzzy concept here and transform the multi-objective FGP model to a mixed integer linear programming model.

5.5.1 Defining the membership function

There are many possible forms for a membership function to represent in fuzzy objective function such as linear, exponential, and hyperbolic piece-wise linear (Peidro & Vasant, 2009). The most feasible for constructing a membership function to solve fuzzy mathematical programming problems is a linear form because linear membership function is to generate equivalent, efficient and computationally linear model (Bellman & Zadeh, 1970).

To solve this problem, the multi-objective FGP model needs to be transformed to a mixed-integer linear programming model. To this aim, firstly we need to define a membership function to represent the fuzzy objective functions. In this work, we used linear membership function for formulating the objective functions. The membership function can be constructed for each objective as follows (Peidro, Díaz-Madroñero, & Mula, 2009).

$$\mu_m = \begin{cases} 1 & z_m < z_m^l \\ \dfrac{z_m^u - z_m}{z_m^u - z_m^l} & z_m^l < z_m < z_m^u \\ 0 & z_m > z_m^u \end{cases} \tag{5.2}$$

$$\mu_M = \begin{cases} 1 & z_M > z_M^u \\ \dfrac{z_M - z_M^l}{z_M^u - z_M^l} & z_M^l < z_M < z_M^u \\ 0 & z_M < z_M^l \end{cases} \tag{5.3}$$

Where μ_m is the membership function for a minimization objective z_m and μ_M is the membership function for a maximization objective z_M. Besides, $z^l{}_m$, $z^l{}_M$ and $z^u{}_m$, $z^u{}_M$ are lower and upper bounds of objective functions. For our model, we replace z_m or z_M by f_i depending on the optimization objective if it is for maximization or for minimization. The estimation of the lower and upper values can be obtained from payoff table. Moreover, the weighted additive approach introduced by Selimi et al. (2008) and Diaz-Madronero and Peidro can be used to transform the FGP to a MILP model. As mentioned in table 5.1, we have different attributes (criteria) for each function of SC, and we have different objectives to improve overall SC performance. To formulate such kind of problem in which we have different objectives and goals, different weights of different attributes, and different degree of satisfaction, Selim et al. (2008), proposed to use Tiwari, Dharmar, & Rao (1987) weighted additive approach which is defined as follows:

$$
\begin{aligned}
&\max \sum_{k=1}^{n} W_k . \mu_k(\mathrm{X}) \\
&\mathrm{s.t} \\
&0 \le \mu_k(\mathrm{X}) \le 1 \\
&\mathrm{G(X)} <= 0 \\
&X \ge 0
\end{aligned}
\tag{5.4}
$$

In this approach, W_k and μ_k represent the weights and the satisfaction degree of the k^{th} goal and objective respectively. This will allow the decision makers (experts) in considered SC functions to assign different weights to the individual goals or objectives or attributes and fuzzy membership function will reflect their relative importance levels. Five steps are important to follow to solve the problem. Firstly, optimize each criterion individually; secondly, create payoff table to find a range of objective function, thirdly, develop membership function of each objective function between (0,1); fourthly, convert mathematical formulation to FGP model; and finally, solve the model with expert's importance weights of each objective function. This model also considered all the constraints mentioned in annex III.

5.6 Experimental study

5.6.1 Data description

This section illustrates an implementation of the mathematical formulation in a real-life Frozen Food Supply Chain Network operating in Canada (Geramianfar et al. 2016). Two plants are available. The first one is located in the province of Quebec. The second plant, which is the greenest one due to recent investments in new machines, is located in Ontario. Manufacturing plants supply six (6) customer areas in six different regions: Canada East, Canada West, US East, US West, US South and US North. Figure 5.3 shows the percentage of mass sold in different regions. Product delivery from manufacturing plants to retailers can be carried out either directly or indirectly through thirty established distribution centers, controlled by third-party logistics (3PLs) companies. All food products are kept in freezing storage at all locations of the distribution stage. The available transport options (Full truckload and less than truckload) may be different from one direction to the next. The third-party logistics companies establish emissions rates and transportation costs for each direction and transportation type. The planning horizon at PDC is considered to be one year, broken down into twelve one-month periods. Due to of the huge amount of data involved, we are unable to cover all of it in this paper. Therefore, samples of some parameters are reported in Annex III. Figure 5.4 shows the percentage mass of products sold in different regions and aggregated demand of retailers for all product families is also illustrated in figure 5.5. Distribution centers and retailers data can be found in Annex III.

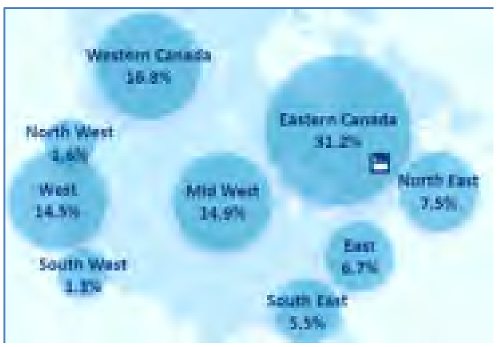

Figure 5.3: % mass of products sold in different region

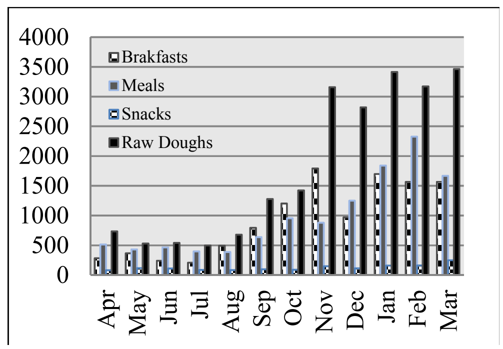

Figure 5.4: Aggregated demand (pallets)

5.6.2 Implementation of the model in a case problem

The mathematical formulation is implemented in GAMS 24.7.1, and solved using CPLEX solver. With four product families (P=4), two manufacturing plants (I=2), thirty distribution centers (J=30), five hundred and ninety-four retailers (K=594) and twelve time periods (T=12), the proposed MILP model has approximately 1,348,473 variables and 580,447 constraints. Problem decisions can directly or indirectly influence SC criteria defined in table 5.1. For the sake of this study, only those criteria related to the case study are selected as shown in Figure 5.5 .

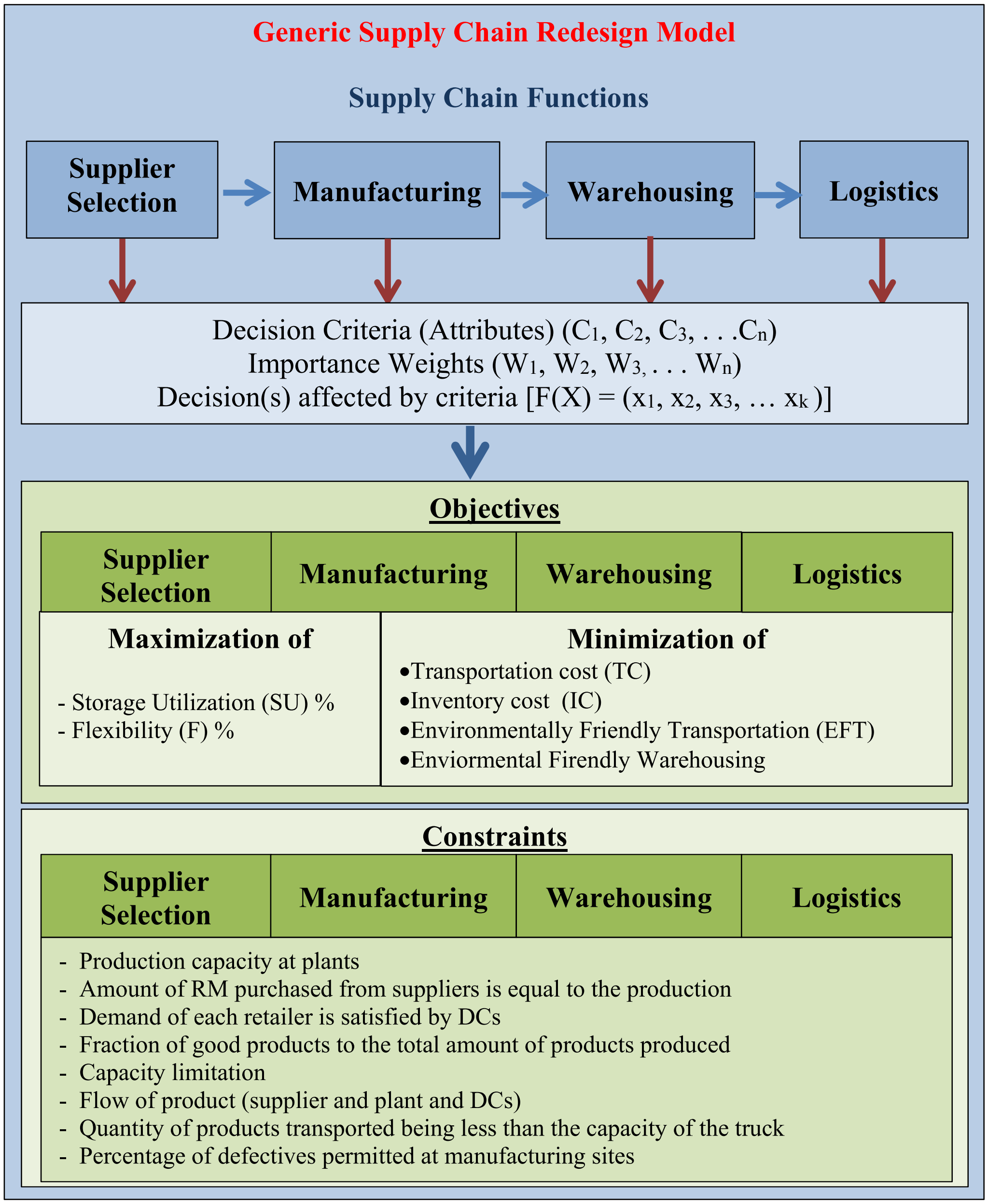

Figure 5.5 Generic SC redesign model

Since the traditional way to design the supply chain is based on cost, we run first the model to evaluate the supply chain performance (scenario 0) for each criterion. Table 5.3 below shows the upper and lower bound of objectives and their % chance with total cost minimization To obtain the nadir values (optimum) and generate the range of criteria, payoff table is also illustrated in table 5.4. Payoff table is created by solving each criterion individual and substituting the values of decision variables in objective functions accordingly.

Table 5.3 Upper and lower bound of objective function with total cost minimization

Criteria number	Objective	Upper / Lower Bond	Total Cost optimization	% Change
1	Transportation cost (TC) $	11,224,669	11,549,000	+2.81%
2	Inventory cost (IC) $	623,411	792,000	+21.00%
3	Storage Utilization (SU) %	58	51	-12.07%
4	Flexibility (F) (%)	20	5	-75.00%
5	Environmentally Friendly Transportation (EFT) (tCo_2)	4,87	3174	+86.00%
6	Environmentally Friendly Warehousing (EFW) (tCo_2)	16	586	-97.00%

Table 5.4 Pay off Table

	TC*	IC*	SU*	F*	EFT*	EFW*
TC (1000$)	11,224 *	83,995	85,072	86,562	80,075	83,222
IC (1000$)	3,922	623*	1,627	4,098	3,673	2,421
SU (%)	18	52	58 *	18	17	51
F (%)	4.7	13	12.8	20 *	10	11
EFT (tCo_2)	2,916	3,300	3,613	2,975	487*	3,305
EFW (tCo_2)	162	135	157	189	132	16*

* Optimum Value

5.6.3 Supply chain design scenario and performance analysis

The proposed model has significant managerial implications, and decision makers can consider different scenarios to get optimum values of considered multiple objective functions. We consider five (5) different scenarios which are as follows.

Scenario 1: Equally important weights (Equ.W)

In this scenario, we will consider equal importance weights of all objective function criteria which are inventory cost (IC), transportation cost (TC), storage utilization (SU), flexibility (F), tons of Co_2 emission at WH and tons of Co_2 emission during transportation.

Scenario 2: Environmental friendly SCD (Env.D)

In this scenario, we will give more weights to the objective function criteria that are related to the environment. We will give 0.60 (0.30 each for tons of Co_2 emission at WH and tons of Co_2 emission during transportation) and rest of the importance weight of the criteria are equally divided which is 0.1 each for inventory cost (IC), transportation cost (TC), storage utilization (SU), flexibility (F).

Scenario 3: Economical SCD (Eco.)

In this scenario, we will give more weights to the objective function criteria that are related to cost. We will give 0.60 (0.30 each inventory cost (IC), transportation cost (TC),) and rest of the importance weight of the criteria are equally divided which is 0.1 each for storage utilization (SU), flexibility (F), tons of Co_2 emission at WH, and tons of Co_2 emission during transportation.

Scenario 4: Flexible SCD (Flex.)

In this scenario, we will give more weights to the objective function criteria that are related to flexibility which is 0.50. Rest of the importance weight of the criteria are equally divided which are 0.1 each for storage utilization (SU), inventory cost (IC), transportation cost (TC), tons of Co2 emission at WH, and tons of Co2 emission during transportation.

Scenario 5: Efficient SCD (Eff.)

In this scenario, we will give more weights to the objective function criteria that are related to efficiency and utilization (SU) which is 0.50. Rest of the importance weight of the criteria are equally divided which are 0.1 each for flexibility (F), inventory cost (IC), transportation cost (TC), tons of Co2 emission at WH, and tons of Co2 emission during transportation.

Now we will consider the following scenario:

a) Comparison of inventory cost effect on each scenario (1 to 5) as mentioned above and compare it with the optimum value of inventory cost

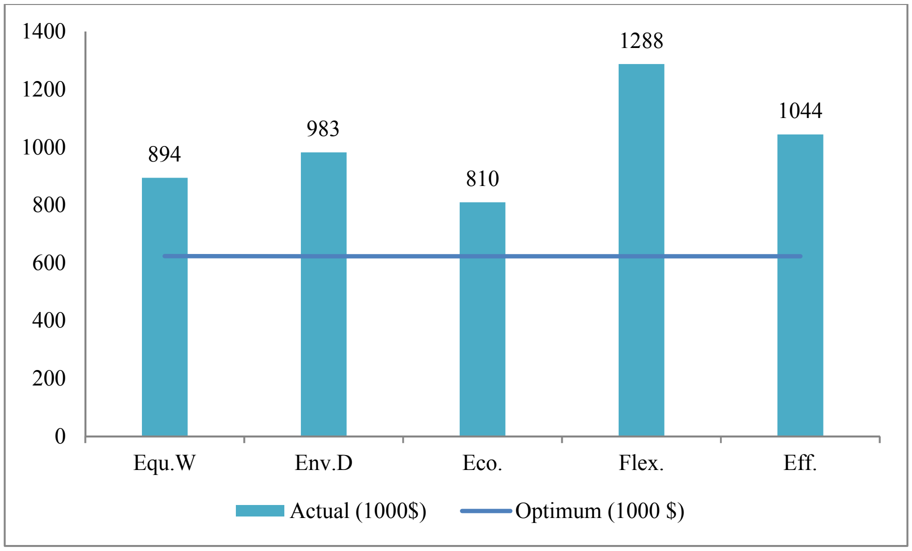

Figure 5.6 Effect of inventory cost on different scenarios (1 to 5)

In figure 5.6, we compared optimum inventory cost with each scenario. It can be noticed that inventory cost in scenario 3 (Eco.) is close (30%) to the optimum inventory cost. It is because, in scenario 3, we optimize cost. Similarly, the highest deviation occurs in scenario 4 (flexible) and the deviation is 107% from the optimum inventory cost. This is because, in this scenario, we gave more weights to flexibility and as we know to increase flexibility, we need more inventory to be more flexible and fulfill customer demand. This information is important in the context of overall SC performance. Decision makers need to know the impact of inventory cost on each strategy (scenario 1 to 5) and select the best strategy which has minimum effect on inventory cost and maximize overall SC performance.

b) Comparison of transportation cost effect on each scenario (1 to 5) as mentioned above and compare it with the optimum value of transportation cost.

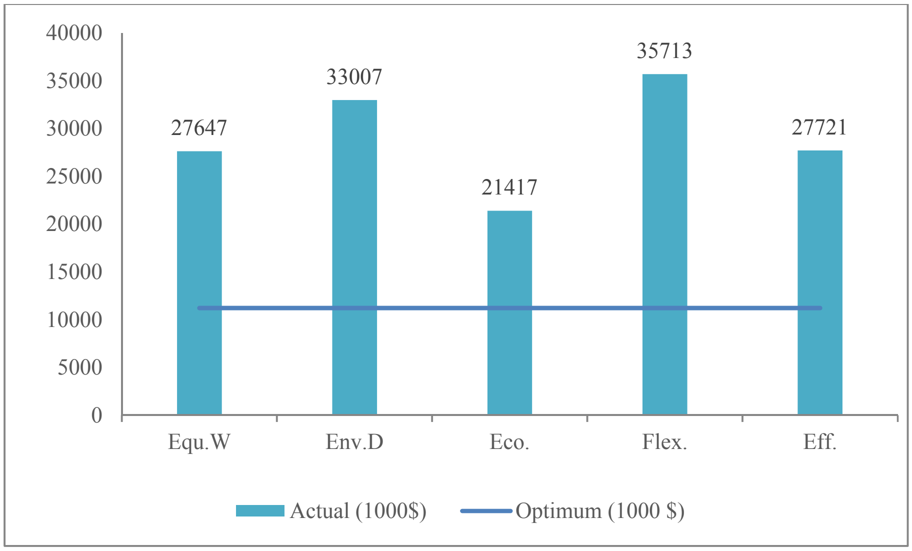

Figure 5.7 Effect of transportation cost on different scenarios (1 to 5)

In above-mentioned figure 5.7, we compared optimum transportation cost with each scenario. It can be noticed that transportation cost deviation in scenario 3 (eco.) is 91% which is the minimum deviation as compared to the other scenario. It is because in scenario 3 we optimize total cost in designing SC. Similarly, the highest deviation occurs in scenario 4 (flex.) and the deviation is 218% from the optimum transportation cost. This is because in scenario 4 we gave more weights to flexibility and as we know to increase flexibility, we will have more half load truck, and partial load delivers to be more flexible and deliver products on time. Overall SC performance depends on minimization of total SC cost. Here in all strategies (scenario 1 to scenario 5), it can be noticed that overall SC performance will be more if we go with the economical design SC.

c) Comparison of storage location effect on each scenario (1 to 5) as mentioned above and compares it with the optimum value of storage utilization.

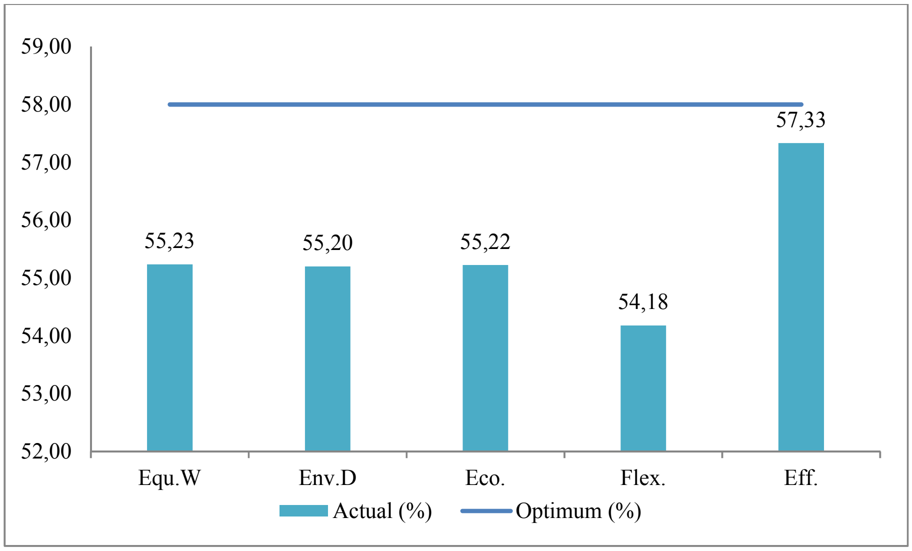

Figure 5.8 Effect of storage utilization on different scenarios (1 to 5)

In above-mentioned figure 5.8, we compared optimum storage utilization with each scenario. It can be noticed that storage utilization average deviation in all scenario is minimum and reduced by 4.4%. The minimum deviation is reduced by 1.2% in scenario 5 (flex.), and maximum reduction in storage utilization is 6.6% in scenario 4 (eco.). Effective storage utilization maximizes the overall SC performance. Figure 5.8 above shows the effect of storage utilization on different strategies and compare it with the optimum value. This will help decision makers to choose the right strategy to maximize storage utilization and overall SC performance.

d) Comparison of environmentally friendly transportation effect on each scenario (1 to 5) as mentioned above and compares it with the optimum value of environmentally friendly transportation.

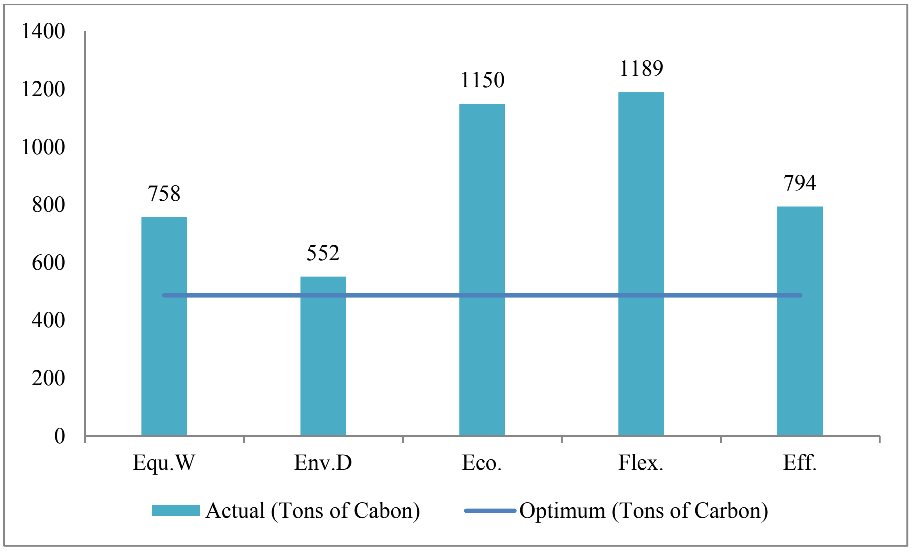

Figure 5.9 Effect of environmentally friendly transportation On different scenarios (1 to 5)

In above-mentioned figure 5.9, we compared environmental friendly transportation with each scenario. It can be noticed that environmentally friendly transportation deviation in scenario 2 (eco.) is 13% which is the minimum deviation as compared to the other scenario. It is due to the fact that in scenario 2, we gave more weights to the environmentally friendly transportation function criteria as we wanted to design environmental friendly SC. Similarly, the highest deviation occurs in scenario 4 (flex.) and the deviation is 114% from the optimum environmental friendly transportation. This is due to the fact that in scenario 4, we gave more weights to flexibility and as we know in order to increase flexibility, we will have more half load truck, and partial load delivers to be more flexible and deliver products on time. This will result in minimizing overall SC performance.

e) Comparison of environmental friendly warehouse effect on each scenario (1 to 5) as mentioned above and compares it with the optimum value of environmental friendly warehouse.

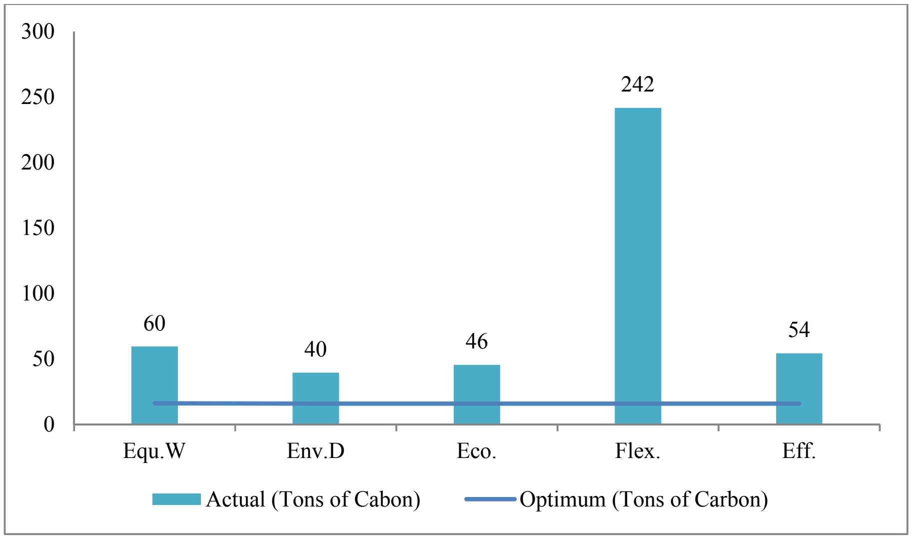

Figure 5.10 Effect of environmental friendly warehouse on different scenarios (1 to 5)

As mentioned in figure 5.10 we can notice that the average difference is huge (451%) in all scenarios with a minimum of 147.3% in scenario 2 (env) and significant difference in scenario 4 (flex). The reason behind it is that in all scenarios we are either minimizing cost or maximizing utilization or flexibility. This lead to generate more Co_2 emission because of increased storage in warehouses and effects overall SC performance.

f) Comparison of flexibility effect on each scenario (1 to 5) as mentioned above and compares it with the optimum value of environmental friendly warehouse.

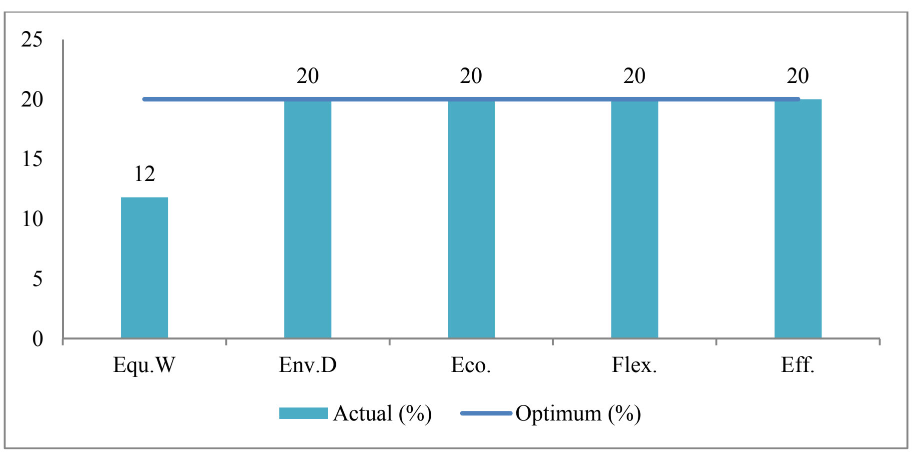

Figure 5.11 Effect of flexibility on different scenarios (1 to 5)

As mentioned in above figure 5.11 we can notice that there is no difference occurs in all scenarios except scenario 1 (equ.W) which is reduced by 41%. This is because of the fact that in all scenarios with optimizes utilization and cost objective functions except in scenario 2 (env.D) in which we designed SC by optimizing sustainability criteria. This is because we increase sustainability compromise with flexibility in operations to main standard Co_2 emission.

5.6.4 Overall SC performance evaluation

Now after getting the optimum values of considered long-term decision criteria (attribute) in the design phase, we will develop the phase II of KBS as per the steps mentioned in figure 4.2 as the case company considered in SCD is different. We will put expected (optimum) values in KBS and get the performance of considered SC functions. Since we considered only six (6) long-term decision criteria (attributes) in SCD, we will put other criteria (that not considered) weights equal to “zero” in previously developed KBS and evaluated the SC functions performance. Once we have a SC functions performance, we will follow the same steps of phase III as mentioned in figure 4.2. Figure 5.12 shows the intended FDMS for overall SC performance evaluation.

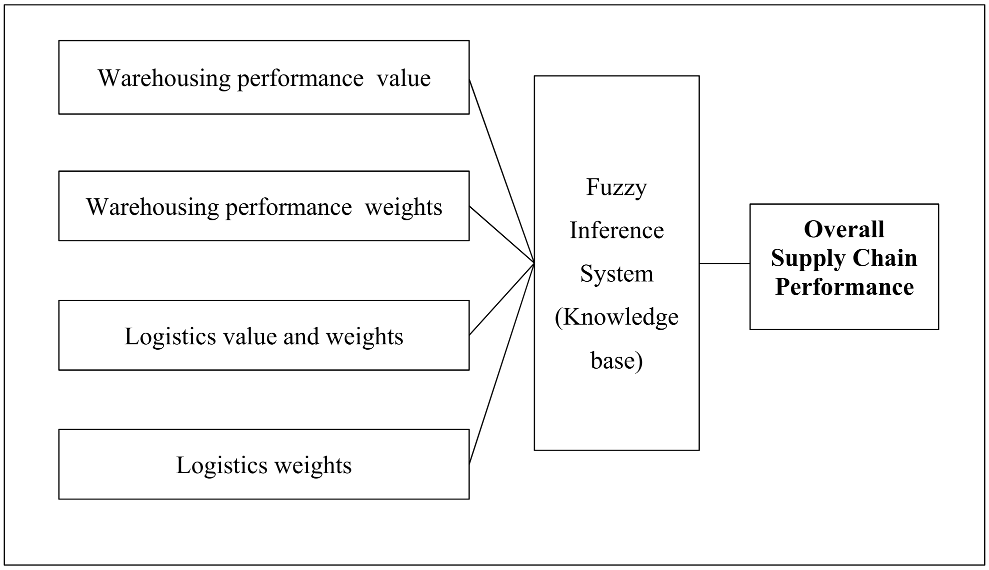

Figure 5.12 Intended FDMS for overall performance evaluation

Table 5.5 shows the performance of considered SC functions based on expected (optimum) values of considered objective functions (long-term decision criteria) and its weights. Here please note that due to unavailability of data we only considered six (6) objective functions (long-term decision criteria) in evaluating considered SC function by normalizing the weights of decision criteria (attribute). Expected values of considered objective functions values are the expected (optimum) values of traditional SCD which is the minimization of total cost.

Table 5.5 Performance of considered SC functions based on expected (optimum) values of considered objective functions (long-term decision criteria) (Phase 2)

Warehousing			**Logistics**		
Long Term Criteria (C_n)	**Value**	**Normalized Wt. (W_i)**	**Long Term Criteria (C_n)**	**Value**	**Normalized Wt. (W_i)**
IC	0.97	0.495	F	0.026	0.097
SU	0.83	0.405	TC	0.96	0.541
EFW	0.57	0.099	EFT	0.2	0.361

↓

Knowledge Base System (Phase 2)

↓

Warehousing Performance	**0.632**	**Logistics Performance**	**0.448**

Table 5.6 shows the considered SC functions in a case study. FDMS will relate input values to their fuzzy sets, the decision rules are applied, and the fuzzy results of the output variable (considered SC functions) in phase two for the performance of each function of SC are composed and defuzzified using the COA method.

Table 5.6 Considered SC Functions Performance (Phase 3)

Considered SC Functions Performance	**Value**	**Normalized Wt. (W_i)**
Warehousing	0.632	0.278
Logistics	0.448	0.721

↓

Knowledge Base System (Phase 3)

↓

Overall SC Performance	**0.492**

Here it is important to mention that in overall SC performance evaluation of considered SC functions in SCD, we considered the same weights (after normalization) and got the approval of case company decision makers and membership functions as developed in initial KBS for evaluation of initial SC performance. Moreover, we will follow the same steps as mentioned in figure 4.2 in chapter 4 for phase II and phase III. Evaluation of overall SC performance is based on the optimum long-term decision criteria (attribute) value that we got from the SC design model. Same steps and same KBS will be used to evaluate overall SC performance of all considered scenarios (1 to 5) and mentioned in figure 5.13.

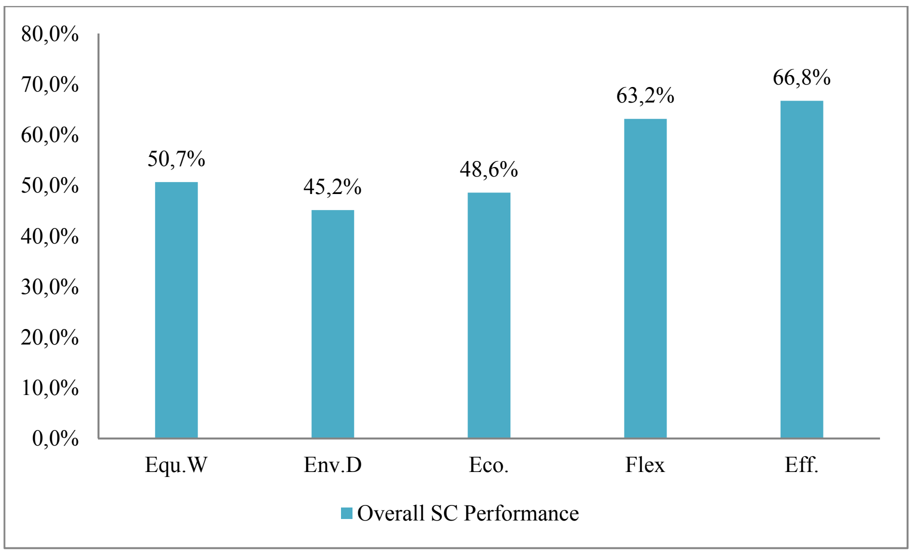

Figure 5.13 Overall performance evaluation of different scenarios

Above mentioned figure 5.13 shows that the maximum overall SC performance is in scenario 5 (eff.) and lowest SC performance is in scenario 2 (Env.D). It is because of the reason that if the strategy to focus more on environmental SC, it will affect overall SC performance as we have to spend more on environmental operations that minimize SC surplus. Similarly, efficient SC scenario has a maximum SC performance as SCD gives more importance to improve the efficiency of SC. SC is to deliver the right product to the right customer at the right time in an efficient and cost effective way. This shows in efficient SC scenario as well. Even though the efficient scenario is not giving us maximum expected (optimum) value summation of considered objective functions (criteria) but due to the decision makers' strategy, developed KBS gives maximum overall SC performance in efficient SC scenario. Current trends in business which increases complexity in SC design and management, we need efficient SC to cope up with these complexities. Therefore maximum expected (optimum) objective function value is not the only criteria to maximize overall SC performance.

Our proposed SC design model is linked with overall SC performance and provides decision makers a basis and direction of improvement. We design SC by considering long-term decisions criteria (attributes) and obtained expected (optimum) values of these criteria by developed SC design model. These expected (optimum) values can be used to compare it with the values that were obtained based on short term criteria operational data (actual values) in the previous chapter. This will provide the direction of improvement in overall SC performance by showing the difference between actual and expected (optimum) long-term decision criteria (attributes) values. We considered different scenarios by changing importance weights and evaluated overall SC performance of each scenario. This shows that our proposed methodology is able to provide a link between different SC designs with overall SC performance. This will allow decision makers to choose the best design among the different scenarios by knowing each design overall SC performance. This shows that there is a link between SC design and overall SC performance.

5.7 Conclusion

SC design is a strategic decision and decisions associated with design have a long term impact on overall SC performance. In this chapter, we proposed a model in which decision makers can see the impact of their decisions on different objective functions. FGP based model is designed to capture uncertainty as we have no exact information about some decisions and their impact. Fuzzy modeling approach provides an appropriate framework to describe and treat fuzziness in an efficient manner. Above mentioned SC design model and previously developed KBS (in chapter 3) gives the expected (optimum) overall SC performance and allow us to see how our current overall SC performance is based on long-term (strategic) criteria (attributes) values and allow decision makers to compare current performance with the optimum one. It can also be used for benchmarking and provide improvement directions.

In this chapter, we proposed a general model by considering most appropriate decisions criteria (attributes) from literature and aligned with the overall SC performance evaluation system. First, we developed a general SC design model by considering all long-term decision criteria (attributes) that we used in evaluating overall SC performance based on FAHP KBS. A case from a frozen food company was considered because of availability of data. However model that we used to generate some results, we considered six (6) objective functions (long-term decision criteria) that were related to our case study and used in chapter 4. Once we got the expected (optimum) values of considered objective functions, we evaluated overall SC performance based on same KBS with same steps as mentioned in phase II and phase III in chapter 3. However, due to unavailability of data, we did not consider all long-term decision criteria (attributes) in SC design model, therefore, we normalize weights accordingly. The proposed model allows decision makers to compare their SC performance with the expected (optimum) performance. This will also allow decision makers to improve overall performance. In the end, we evaluate overall SC performance of all considered scenario and allow decision makers to choose the best strategy (from scenario 1 to scenario 5) based on maximum overall SC performance.

The purpose of connecting SC design model with the overall SC performance is to allow decision makers to select the best SC design that gives you maximum overall SC performance. It also allows decision makers to use the same criteria (attribute) in measuring overall SC performance that was used in SC design. If criteria for overall SC performance evaluation are not as same as considered in SC design phase, then it will be quite impossible to improve and achieve desired SC performance. For example, if during SC design phase if we will not focus on selecting environmental friendly suppliers then at the operational level, our performance in GHG emission will be high and that will reflect in overall SC performance. Therefore it is essential to consider all decision criteria (attribute) at SC design that will be used in overall SC performance evaluation.

What you cannot measure, you cannot manage. Therefore, it is essential for decision makers to evaluate the SC performance for a different SC design strategy.

CONCLUSION

The aim of this chapter is to presents the overall conclusions, as well as the contributions to research and knowledge that this work has provided. Finally, the chapter provides some thoughts on future work, based on the research conducted in this thesis.

Overall conclusion

Managing SC and delivering the right product to the right customer at the right time in addition to maximizing SC cost surplus is a challenging task. Organizations are finding new ways of managing their SC effectively and efficiently. It is essential for organizations to integrate different SC functions such as supplier selection, manufacturing, warehousing, and logistics in order to minimize inherent “wastes” and non-value added activities such as repeating of data entry, and duplication of activities at different functions of SC. In digital SC performance model, Web 2.0 technologies help organizations to trace every transaction. Tagging technologies such as RFID, barcode provide real time data feed for physical movement at any stage of operation. If we combine this operational data with financial and non-financial information along with data from external sources (supplier inventory status, order in-transit) will help decision makers to take better decisions in order to improve overall SC performance as compared to reporting techniques which are often used today. An integrated SC performance model supports flexibility in SC decisions (short-term or long-term) since information and relationship between SC functions are no longer independent. This integration allows decision makers to take a closer look at SC function performance and increase the visibility of their decisions effect on overall SC performance.

However, finding of this thesis show that existing SC performance models are not efficient to align with digitalization and establish a relationship between SC functions and decision criteria. The inadequate balance between financial and non-financial measurement exits in current SC performance management system. In addition to that existing SC performance management systems are not sufficient enough to establish a connection between short term and long term MCDM of SC network and they have a deficiency in integrating SC functions and highlighting underperformed function of SC network.

It is evident from the literature that over the last decade, a large number of research papers, certified courses, professional development programs and scientific conferences have addressed SCM, thereby attesting to its significance and importance. SCM is an MCDM problem because, throughout its process, different criteria related to each SC activity and their associated sub-criterion must be considered. Often, these criteria are conflicting in nature; for their part, MCDM methods have also attracted significant attention among researchers and practitioners in the field of SCM.

Our proposed KBS measured overall SC performance that illustrated via a case study. A fuzzy MCDM system is designed and implemented using the MATLAB software for overall SC performance evaluation. Moreover, the AHP and Expert Choice (EC) was used for the evaluation of the priorities of short-term and long-term decision criteria and functions of considered SC. The development of a fuzzy MCDM system for overall SC performance evaluation is easily implemented using the "MATLAB software." MATLAB is "menu-driven" software that allows the implementation of fuzzy constructs like "membership functions" and the creation of a database of "decision rules." In addition, fuzzy inferencing and defuzzification are built in functions in MATLAB. The software is easy to use and is user friendly.

The implemented FDMS relied heavily on "expert's knowledge and experience". Expert's knowledge and experience were needed in the determination of "fuzzy subsets and membership functions" for each input and output variable and in the determination of "if–then rules" that govern the relationships between "inputs and the output." Hence, the implemented FDMS might be considered as a Fuzzy MCDM Expert System (FDMES). The proposed FDMS like any other "expert system" can help preserve the knowledge of experts in any organization, i.e., it builds up the corporate memory of the firm.

At last, our proposed system is able to absorb the effect of changing the behavior of customers due to digital transformation of SC. It creates a relationship between each function of SC decisions and decision criteria and SC functions and gives a holistic and integrated approach to evaluate overall SC performance which is lacking in existing SC performance evaluation system. Once the overall SC performance has been evaluated and underperformed criteria were identified, our proposed SC design model will incorporate underperformed criteria and redesign SC to improve overall SC performance. Therefore, we believe that our proposed methodology and its successful implementation answer all research questions and achieve objectives that were set in the introduction chapter.

The main contributions and scientific novelty of this research study are as follows:

- Provided a systematic literature review on the application of the MCDM methods and its combination with other methods at different levels of SCM decisions

SCM is a MCDM problem because, in the entire SC network, we must consider different criteria related to each sub-criterion of the SC cycle. In order to manage the entire SC, we must identify the relationship of each criterion, which has an effect on the performance of the SC. Based on the indicators identified, we then take decisions. This shows that decision-making is critical in managing the SC cycle and SCM is a MCDM problem. This thesis looks at various MCDM methods applied for decision-making in SCM at the strategic, tactical and operational levels and analyses the reasons behind their adoption. This thesis showed that Fuzzy and its integration with other MCDM have effectively and efficiently be applied at every level of the SC decision-making process as well as in considered SC functions. This is because of the fact that due to digitalization and after introduction Internet of Things (IoT), the perspective of SC has been totally changed.

- Review, limitations, and categorization of exiting SC performance measurement models

Over the last decade, advancement in information technology forced organizations to deliver product in effective and efficient manner. Performance measures are important for the effectiveness of SC. In order to cope up with ever rising customers' demand and fulfil their requirement increased the importance of supply chain performance and its measurement systems. Many researchers and practitioner came up with a system to measure supply chain performance. Moreover, many researchers published review papers in the area of supply chain performance measurement to highlights its importance and significance in organizations performance. However, most of the PMSs are specific in nature and not providing holistic supply chain performance measurement. Therefore, this thesis reviews all existing SC PMSs (SCPMS), identify limitations, and categorized them into different MCDM levels (long-term and short-term), functions/perspective considered, financial / non-financial, and integrates SC functions, and identify the future directions of SC PMS that must be align with future needs and give holistic view of overall SC.

- KBS for overall SC performance evaluation

Due to globalization and digitalization, logistics and SCM are playing a central role in the fulfillment of customers demand. Based on real time information, fast decisions are important in order to deliver product more rapidly. Thus, performance measurement is critical to the success of the SC. Performance measures are important to evaluate the effect of different decisions and the effectiveness of the SC. In order to improve a system, we need to measure its current performance. This thesis identified the need for integrated performance measurement system to measure overall SC performance considering the limitations of existing performance measures and digitalization. We proposed a hybrid Fuzzy-AHP framework that integrates and establishes a relationship between main functions of SC functions and decision criteria and proposed a methodology to measure overall SC performance.

- SC design model to provide link between decisions and decision criteria (attributes)

Nowadays competitions among organizations and customers' expectations have been increased significantly. In order to meet customer expectations and deliver product at the right time to the right customer in right quantity is become challenging due to uncertainty which is inherent in SC functions. Organizations success depends on how they integrate their SC functions with decisions and its associated decision criteria.

We developed general SC design model to get the expected (optimum) values of considered objective functions. Based on these expected (optimum) values we evaluated overall SC performance. This provides the link between decisions and decision criteria and direction of improvement and allows decision makers to seelct the best strategy to get maximum overall SC performance.

Managerial implications

This thesis has following managerial implication:

- This thesis is useful for academic researchers, decision makers, and experts to whom it will provide a better understanding of the application of MCDM methods in SCM, at various levels of the decision-making process, and establish guidelines for selecting an appropriate MCDM method for SC activities at different levels of decision-making.

- The proposed KBS in this thesis assists organizations / decision makers in evaluating their overall SC performance and identifying under-performed SC function.

- Our proposed KBS for overall SC performance evaluation can help SC managers and decision makers as an indicator to measure their internal SC objectives. They can also use our proposed KBS to benchmark their SC performance.

- Managers and decision maker needs to know what criteria should be focused more in SC design phase to improve supply chain performance and what is the link between SC design and supply chain performance. Our proposed SC design model helps managers in comparing their actual performance on long-term decisions and overall SC performance with the expected (optimum) performance. This will allow them to set their targets and gives directions for improvements.

Limitation

The results and conclusions of this work are not possible without following limitations:

- Our selection of MCDM method (Fuzzy-AHP) in developing KBS is based on systematic literature review results in chapter one (1).
- We considered four (4) essential functions of SC in developing KBS and overall SC performance evaluation.
- In developing Fuzzy Inference Systems (FIS), the range of membership functions and in developing if-then else rules we relied on case company experts.
- Proposed KBS is implemented in an automotive case company for overall SC performance evaluation.
- SC design model did not include uncertainties in considered SC parameters. Moreover, due to lack of data, we did not implement SC design model in the same case company (automotive) as mentioned in chapter 4.

Future work

Our proposed KBS is based on experts' opinion and their pair-wise comparison. In developing the KBS, experts defined long-term and short-term decisions and criteria (attributes) weights and their importance weights. Our KBS is relying only on case company experts. In future, we can develop and conduct a survey for getting the importance weights and defining membership function by collecting surveys from many experts and not just from one company.

Fuzzy membership functions convert linguistic information into crisps value which is the unique feature of fuzzy inference system. This can be done through different shapes of the membership function. The proposed KBS used mamdani fuzzy inference system in which experts define membership functions limits and its shape. In future, once we have enough data we can use Sagino fuzzy inference system in which membership functions and rules can be developed using the data.

The proposed SC design model proposed general formulation by considering all long-term criteria (attributes). However, we run the model by considering only a few objective functions (criteria) and re-evaluated overall SC function. In future, we can run the model by considering all the long-term criteria (attributes) and re-evaluate overall SC performance of the same case company as mentioned in chapter 4.

In developing SC design model, we did not include uncertainties in different parameters (long-term decision criteria). In future, we will develop a model in which we will incorporate uncertainty in the objective function and get the expected (optimum) values of all considered long-term decision criteria (attribute).

RECOMMENDATIONS

Based on our proposed knowledge base system and developed SC design decision model, it is recommended that:

- The company can evaluate their SC performance over the period of 4-6 months and maintain dashboard as mentioned in chapter 4.

- Once they have enough information over the period of 4 to 6 months and if their SC performance in not up to the mark, they can measure expected (optimum) value of long-term decision criteria (attributes) using developed SC design decision model as mentioned in chapter 5.

- Once they have expected (optimum) value of long-term decision criteria (attributes), they can re-evaluate their SC performance using phase II and phase III of same KBS that was developed in chapter 3.

- Re-evaluated SC performance can be compared with the current overall SC performance in order to compare and improve overall SC performance and made strategies to achieve the expected (optimum) performance.

- This is a continuous process of evaluation and improvement and company will improve their SC performance after few cycle of evaluation.

ANNEX I

Table AI-1 Short - term decision criteria

SC Function	Decisions Drivers	Decision Criteria	Reference
Supplier Selection	Cost	Price	Kaplan & Norton (1992) Lambert & Pohlen (2001) Shepherd & Günter (2011)
	Supplier Delivery Performance	Rejection rate	Kaplan & Norton (1992)
		On time delivery	Gaudenzi & Borghesi (2006) Gunasekaran et al. (2004) Supply Chain Council (2012)
		Lead time	Otto & Kotzab (2003) Bhagwat & Sharma (2007) Gaudenzi & Borghesi (2006)
		Delivery Flexibility	Otto & Kotzab (2003) Bhagwat & Sharma (2007) Gaudenzi & Borghesi (2006) Shepherd & Günter (2011)
	Supplier Sustainability	Air/Water/Land Emission	Agarwal et al. (2011) Agarwal & Vijayvargy (2012)
Manufacturing	Meeting Production Target	On time delivery/cycle time	Otto & Kotzab (2003) Gunasekaran et al. (2004)
	Quality of Manufactured Product	% defect	Gunasekaran et al. (2004) Gaudenzi & Borghesi (2006) Bhagwat & Sharma (2007)
	Cost	Cost / operation hour	Beamon (1999) Gunasekaran et al. (2004) Gunasekaran et al. (2001) Shepherd & Günter (2011)
	Effective Utilization of Resources	Productivity	Gunasekaran et al. (2004)
	Sustainable Operations	Air/water/land emission or Solid/ Hazardous/water waste	Azzone & Noci (1998) Agarwal et al. (2011) Agarwal & Vijayvargy (2012)
		% of crushed material	Gunasekaran et al. (2001) Hu & Hsu (2010) Rao & Holt (2005)
Warehousing	Cost	Cost / order	Gunasekaran et al. (2004) Gunasekaran et al. (2001) Otto & Kotzab (2003) Shepherd & Günter (2011)
	Material Handling	Damaged Inventory	Supply Chain Council (2012) Gunasekaran et al. (2004)
	Delivery Performance	On time delivery	Gunasekaran et al. (2004) Gaudenzi & Borghesi (2006) Shepherd & Günter (2011)
		Order fill rate	Gunasekaran et al. (2004) Supply Chain Council (2012) Gaudenzi & Borghesi (2006)
		Order accuracy	Bhagwat & Sharma (2007) Kaplan & Norton (1992)
	Inventory Management	Inventory Turn	Beamon (1999)

Table AI-1 Short - term decision criteria (continued)

Logistics	Performance of Goods Delivered	Quality of Goods Delivered	Gunasekaran et al. (2004)
		Faulty Deliveries	Gunasekaran et al. (2004) Gunasekaran et al. (2001) Gaudenzi & Borghesi (2006)
		On time Delivery	Gunasekaran et al. (2004) Gaudenzi & Borghesi (2006) Shepherd & Günter (2011)
	Operation Cost	Cost / unit delivered	Gaudenzi & Borghesi (2006) Shepherd & Günter (2011)
	Sustainability Cost	Cost / unit delivered of RL	Diabat & Govindan (2011) Mondragon et al. (2011)
	Sustainable Transportation	Air/water/land emission or Solid/ Hazardous/ water waste	Azzone & Noci (1998) Agarwal et al. (2011) Agarwal & Vijayvargy (2012)

Table AI-2 Long-term decision criteria

SC Function	**Decisions drivers**	**Decision Criteria**	**References**
Supplier Selection	Cost	Monetary Value	Gunasekaran et al. (2004) Gunasekaran et al. (2001)
	Supplier Performance Management	Supplier delivery performance	Gunasekaran et al. (2004) Gunasekaran et al. (2001)
	Sourcing	Geographical Location	Mondragon et al. (2011b)
	Sustainable Supplier	Environmental Friendly Supplier	Hu & Hsu (2010)
Manufacturing	Maintenance Management	OEE	Mondragon et al. (2011b)
	Improving Machine Uptime	Capacity Utilization	Otto & Kotzab (2003) Gunasekaran et al. (2004) Gunasekaran et al. (2001)
	Inventory Policies	Inventory	Gunasekaran et al. (2004) Gunasekaran et al. (2001)
	Sustainable Manufacturing	Environmental Friendly Operations	Hu & Hsu (2010) Gunasekaran et al. (2004)
Warehousing	Size, Design, ASRS of Warehouse	Storage utilization	Otto & Kotzab (2003) Gunasekaran et al. (2004) Gunasekaran et al. (2001)
	Inventory Management Systems	Inventory count accuracy	Gunasekaran et al. (2004) Gunasekaran et al. (2001)
	Order Management System	Order fulfillment	Bhagwat & Sharma (2007) Gaudenzi & Borghesi (2006)
	Finished Product Inventory Policy	Inventory Level	Supply Chain Council (2012) Gunasekaran et al. (2004)

Table AI-2 Long-term decision criteria (continued)

Logistics	Fleet Variety	Flexibility	Gunasekaran et al. (2004) Gunasekaran et al. (2001) Shepherd & Günter (2011)
	Transportation Quality	Delivery Reliability	Gunasekaran et al. (2004) Gunasekaran et al. (2001)
	Long-Term Contract with Logistics Service Provider	Transportation cost	Gunasekaran et al. (2004) Gunasekaran et al. (2001)
	Sustainable Transportation	Environmental friendly transportation	Hu & Hsu (2010)

Table AI-3 Level of DM and timeline

Level of DM	**Considered DM Level**	**Description of Decisions**	**Type of Decision Made**
Strategic	Long-term Decision Making	The strategic level includes decisions that have a long-lasting effect on the firm	This includes decisions related to warehouse location, capacity of warehouse and distribution centers, manufacturing decisions such as automated or manual, supply chain network design
Tactical			
Operational	Short-Term Decision Making	The operational level includes decisions which are usually day-to-day, such as loading/unloading, daily production plan, etc.	These include decisions related to satisfying daily and weekly forecasting, settling damages or losses with suppliers, vendors, and clients, and monitoring logistics activities for contract and order fulfillment.

ANNEX II

This overview is adopted from Mendel, (1995)

"A fuzzy logic system (FLS) can be defined as the nonlinear mapping of an input data set to a scalar output data. A FLS consists of four main parts: fuzzifier, rules, inference engine, and defuzzifier". These components and the general architecture of a FLS is shown in Figure AII-1.

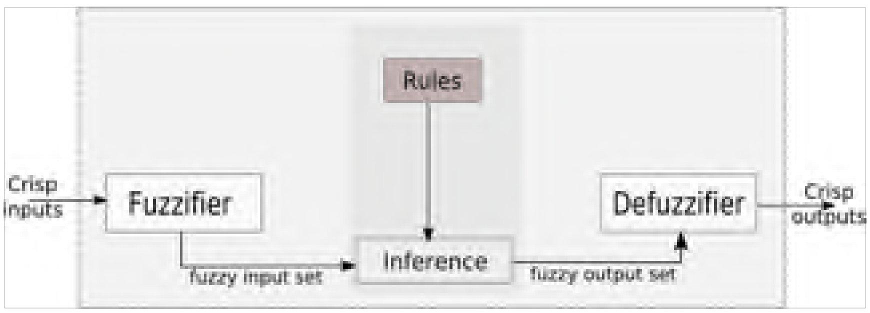

Figure AII- 1: A Fuzzy Logic System
Addopted from Mendel, (1995)

"The process of fuzzy logic is explained in Algorithm AII-1: Firstly, a crisp set of input data are gathered and converted to a fuzzy set using fuzzy linguistic variables, fuzzy linguistic terms and membership functions. This step is known as fuzzification. Afterwards, an inference is made based on a set of rules". Lastly, the resulting fuzzy output is mapped to a crisp output using the membership functions, in the defuzzification step.

"In order to exemplify the usage of a FLS, consider an air conditioner system controlled by a FLS (figure AII - 2). The system adjusts the temperature of the room according to the current temperature of the room and the target value. The fuzzy engine periodically compares the room temperature and the target temperature, and produces a command to heat or cool the room".

Algorithm AII-1: Fuzzy logic algorithm
Addopted from Mendel, (1995)

1	Define the linguistic variables and terms (initialization)
2	Construct the membership functions (initialization)
3	Construct the rule base (initialization)
4	Convert crisp input data to fuzzy values using the membership functions (fuzzification)
5	Evaluate the rules in the rule base (inference)
6	Combine the results of each rule (inference)
7	Convert the output data to non-fuzzy values (defuzzification)

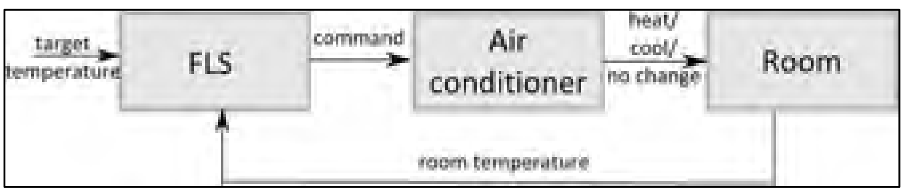

Figure AII- 2: A Simple FLS to Control an Air Conditioner
Addopted from Mendel, (1995)

Linguistic variables

“Linguistic variables are the input or output variables of the system whose values are words or sentences from a natural language, instead of numerical values”. A linguistic variable is generally decomposed into a set of linguistic terms.

Membership functions

“Membership functions are used in the fuzzification and defuzzification steps of a FLS, to map the non-fuzzy input values to fuzzy linguistic terms and vice versa”.

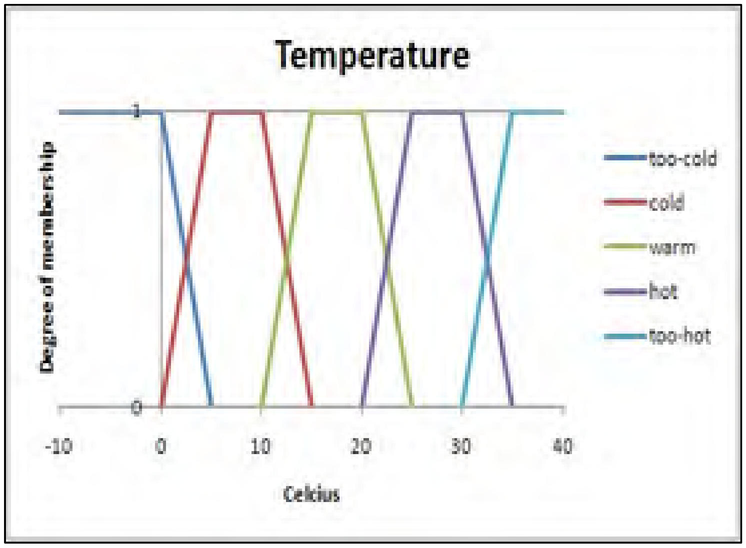

Figure AII- 3: Membership Functions for
T(temperature) = {too-cold, cold, warm, hot, too-hot}
Addopted from Mendel, (1995)

"There are different forms of membership functions such as triangular, trapezoidal, piecewise linear, Gaussian, or singleton (figure AII- 4). The most common types of membership functions are triangular, trapezoidal, and Gaussian shapes. The type of the membership function can be context dependent and it is gen- erally chosen arbitrarily according to the user experience".

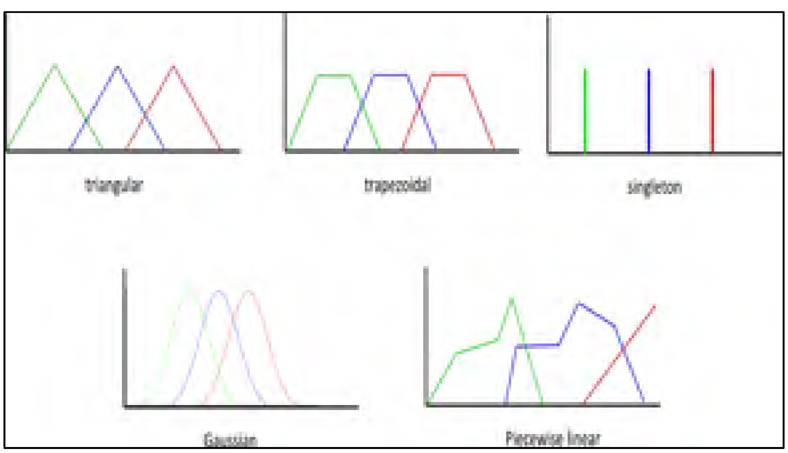

Figure AII - 4: Different Types of Membership Functions.

Fuzzy rules

"In a FLS, a rule base is constructed to control the output variable. A fuzzy rule is a simple IF-THEN rule with a condition and a conclusion. In table AII- 1, sample fuzzy rules for the air conditioner system in figure AII - 2 are listed. Table AII - 2 shows the matrix representation of the fuzzy rules for the said FLS. Row captions in the matrix contain the values that current room temperature can take, column captions contain the values for target temperature, and each cell is the resulting command when the input variables take the values in that row and column. For instance, the cell (3, 4) in the matrix can be read as follows: If the temperature is cold and the target is warm then the command is heat".

Table AII - 1: Sample fuzzy rules for air conditioner system
Addopted from Mendel, (1995)

S.No.	Fuzzy rules
1	IF (temperature is cold OR too-cold) AND (target is warm) THEN command is heat
2	IF (temperature is hot OR too-hot) AND (target is warm) THEN command is cool
3	IF (temperature is warm) AND (target is warm) THEN command is no-change

Table AII - 2: Fuzzy matrix example
Addopted from Mendel, (1995)

Temperature/target	Too-cold	Cold	Warm	Hot	Too-hot
too-cold	no-change	heat	heat	heat	heat
cold	cool	no-change	heat	heat	heat
warm	cool	cool	no-change	heat	heat
hot	cool	cool	cool	no-change	heat
too-hot	cool	cool	cool	cool	no-change

Fuzzy set operations

"The evaluations of the fuzzy rules and the combination of the results of the individual rules are performed using fuzzy set operations. The operations on fuzzy sets are different than the operations on non-fuzzy sets. Let μA and μB are the membership functions for fuzzy sets A and B. Table AII - 3 contains possible fuzzy operations for OR and AND operators on these sets, comparatively. The mostly- used operations for OR and AND operators are max and min, respectively. For complement (NOT) operation, Eq. AII-1 is used for fuzzy sets".

$$\mu A\ (x) = 1 - \mu A\ (x) \qquad \text{(AII - 1)}$$

Table AII - 3: Fuzzy set operator
Addopted from Mendel, (1995)

temperature/target	too-cold	cold	warm	hot	too-hot
too-cold	no-change	heat	heat	heat	heat
cold	cool	no-change	heat	heat	heat
warm	cool	cool	no-change	heat	heat
hot	cool	cool	cool	no-change	heat
too-hot	cool	cool	cool	cool	no-change

"After evaluating the result of each rule, these results should be combined to obtain a final result. This process is called inference. The results of individual rules can be combined in different ways. Table AII - 4 contains possible accumulation methods that are used to combine the results of individual rules. The maximum algorithm is generally used for accumulation".

Table AII - 4: Accumulation methods
Addopted from Mendel, (1995)

Operation	Formula
Maximum	$Max\{\mu_A(x), \mu_B(x)\}$
Bounded sum	$Min\{1, \mu_A(x) + \mu_B(x)\}$
Normalized sum	$\frac{\mu_A(x)+\mu_B(x)}{Max\{1, Max\{\mu_A(x'), \mu_B(x')\}\}}$

Defuzzifications

"After the inference step, the overall result is a fuzzy value. This result should be defuzzified to obtain a final crisp output. This is the purpose of the defuzzifier component of a FLS. Defuzzification is performed according to the membership function of the output variable. For instance, assume that we have the result in Figure AII - 5 at the end of the inference. In this figure, the shaded areas all belong to the fuzzy result. The purpose is to obtain a crisp value, represented by a dot in the figure, from this fuzzy result".

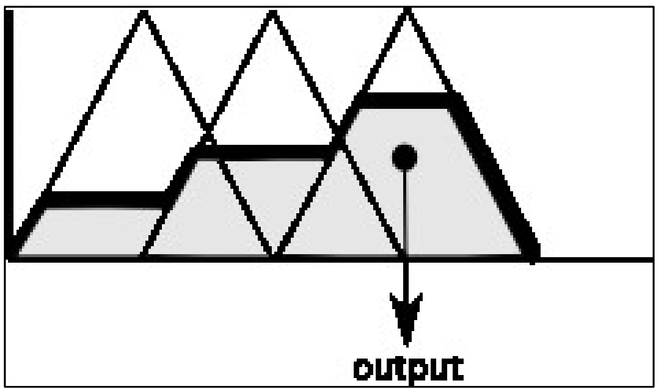

Figure AII - 5: Defuzzification step of a FLS
Addopted from Mendel, (1995)

"There are different algorithms for defuzzification too. The mostly used algorithms are listed in table AII – 5".

Table AII - 5: Defuzzification algorithms
Addopted from Mendel, (1995)

Operation	Formula
Center of Gravity	$U = \frac{\int_{min}^{max} u\,\mu(u)\,du}{\int_{min}^{max} \mu(u)\,du}$
Center of Gravity for Singletons	$\frac{\sum_{i=1}^{p}[u_i\,\mu_i]}{\sum_{i=1}^{p}[\mu_i]}$
Left Most Maximum	$U = inf(u'),\ \mu(u') = sup(\mu(u))$
Right Most Maximum	$U = sup(u'),\ \mu(u') = sup(\mu(u))$

The meanings of the variables used in Table AII - 5 are explained in table AII - 6.

Table AII -6: The variables in table AII – 5
Addopted from Mendel, (1995)

Varaibles	**Meaning**
U	Result of defuzzification
u	Output variable
p	Number of singletons
μ	Membership function after accumulation
i	Index
min	Lower limit for defuzzification
max	Upper limit for defuzzification
sup	Largest value
inf	Smallest value

ANNEX III

Decision making model considering long-term decision criteria (attributes)

Set and Indices

In this study following set and indices are used:

r	set of raw materials: $r \in \{1,2,...,R\}$
p	set of products : $p \in \{1,2,...,P\}$
h	set of manufacturing technology: $h \in \{1,2,...,H\}$
m	set of transportation modes: $m \in \{1,2,...,M\}$
s	set of suppliers: $s \in \{1,2,...,S\}$
i	set of manufacturing sites: $i \in \{1,2,...,I\}$
j	set of distribution centers: $j \in \{1,2,...,J\}$
k	set of retailers: $k \in \{1,2,...,K\}$
t	set of time-periods: $t \in \{1,2,...,T\}$
e_j	Set of energy mix at DC j: $e_j \in \{1,2,...,E_j\}$
e_k	Set of energy mix at retailer k: $e_k \in \{1,2,...,E_k\}$

Parameters

The mathematical model requires the following parameters:

FC_s	fixed cost of establishing a business with supplier s
FC_j	fixed cost of establishing a business with DC j
FC_{ih}	fixed establishing cost of plant i with technology h
PC_{rst}	purchasing cost of raw material r from supplier s during time period t
MC_{piht}	manufacturing cost of product p at plant i with technology h during time period t
TC_{simt}	per unit transportation cost of transportation mode m from supplier s to plant i during time period t

TC_{ijmt}	per unit transportation cost of transportation mode m from plant i to DC j during time period t
TC_{jkmt}	per unit transportation cost of transportation mode m from DC j to retailer k during time period t
BC_{pkt}	per unit backorder cost of product p at retailer k during time period t
BC_{rit}	per unit backorder cost of raw material r at plant i during time period t
HC_{pit}	per unit holding cost for product p at plant i from period t to period $t+1$
HC_{rit}	per unit holding cost for raw material r at plant i from period t to period $t+1$
HC_{pjt}	per unit holding cost for product p at DC j from period t to period $t+1$
HC_{pkt}	per unit holding cost for product p at retailer k from period t to period $t+1$
Dem_{pkt}	demand of retailer k for product p during time period t
$TCap_{simt}$	capacity of transportation mode m between supplier s and plant i during time period t
$TCap_{ijmt}$	capacity of transportation mode m between plant i and DC j during time period t
$TCap_{jkmt}$	capacity of transportation mode m between DC j and retailer k during time period t
$MCap_{piht}$	manufacturing capacity of plant i with technology h for product p during time period t
$SCap_{rst}$	reserved capacity of supplier s for raw material r during time period t
$WCap_{rit}$	warehousing capacity of plant i for raw material r during time period t
$WCap_{pit}$	warehousing capacity of plant i for product p during time period t
$WCap_{pjt}$	warehousing capacity of DC j for product p during time period t
$WCap_{pkt}$	warehousing capacity of retailer k for product p during time period t
LT_{jkp}	delivery lead time for product p from DC j to retailer k
Dis_{si}	distance between supplier s and plant I [*in km*]
Dis_{ij}	distance between plant i and DC j [*in km*]
Dis_{jk}	distance between DC j and retailer k [*in km*]
Max_{pkt}	maximum permitted backorders for product p at retailer k during time period t
α_{piht}	Percentage of waste for product p manufactured at plant i with technology h during time period t

R_{rp} unit requirement for raw material r to manufacture one unit of product p

ρ coefficient for transformation between planning horizon and lead time unit

EIS_{rs} per unit environmental impacts associated with raw material r at supplier s

EIM_{pih} per unit environmental impacts of producing product p at plant i with technology h[kg CO2e]

EIT_{sim} per unit environmental impacts of transportation using transportation mode m from supplier s to plant i [kg CO2e/(t km)]

EIT_{ijm} per unit environmental impacts of transportation using transportation mode m from plant i to DC j [kg CO2e/(t km)]

EIT_{jkm} per unit environmental impacts of transportation using transportation mode m from DC j to retailer k [kg CO2e/(t km)]

EM_{ej} percentage share of energy source e in energy mix of the region where DC j is located ($\sum_{e_j=1}^{E_j} EM_{ej} = 1 \quad \forall j$)

ER_j energy requirement for storing one unit of product at DC j [kWh/ period]

EF_{ej} GHG emission factor for energy source ej [kg CO2e/kWh]

EM_{ek} percentage share of energy source e in energy mix of the region where retailer k is located ($\sum_{e_k=1}^{E_k} EM_{ek} = 1 \quad \forall k$)

ER_k energy requirement for storing one unit of product at retailer k [kWh/ period]

EF_{ek} GHG emission factor for energy source e_k [kg CO2e/kWh]

Decision Variables

This will include continuous, binary variables:

- ***Continuous variables***

p_{rst}**:** Amount of raw material r to be purchased from supplier s

q_{piht}: Amount of product p manufactured at plant i with technology h during time period t

g_{pit}**:** Amount of good product p manufactured at plant i during time period t

x_{rsimt}: Flow of raw material r from supplier s to plant i using transportation mode m during time period t

x_{pijmt}: Flow of product p from plant i to DC j using transportation mode m during time period t

x_{pjkmt}: Flow of product p from DC j to retailer k using transportation mode m during time period t

ip_{rit}: Inventory level of raw material r at plant i at the end of period t

ip_{pit}: Inventory level of product p at plant i at the end of period t

id_{pjt}: Inventory level of product p at DC j during time period t

b_{pkt}: Amount of product p backordered at retailer k during time period t

b_{rit}: Amount of raw material r backordered at plant i during time period t

s_{pkt}: Amount of surplus for product p delivered at retailer k during time period t

- ***Binary variables***

y_{rs}: 1 if raw material r provided by supplier s, 0 otherwise

z_{ih}: 1 if plant i with technology h is opened, 0 otherwise

u_j: 1 if DC j is selected, 0 otherwise

w_{pkt}: 1 if there is a surplus for product p at retailer k during time period t, 0 if there are backorders for product p at retailer k during time period t

l_{simt}: 1 if transportation mode m is selected between supplier s and plant i during time period t, 0 otherwise

l_{ijmt}: 1 if transportation mode m is selected between plant i and DC j during time period t, 0 otherwise

l_{jkmt}: 1 if transportation mode m is selected between DC j and retailer k during time period t, 0 otherwise.

Assumptions

The following assumptions are considered in developing the model:

a) The demand of retailers, price of raw materials, cost and other considered parameters are known a priori.
b) The demand of retailers must be satisfied.
c) The capacity of suppliers, plants, DCs and retailers are limited.
d) Flow between facilities of the same echelon is not allowed.

e) The products cannot be sent directly from plants to retailers.
f) Only good products would be shipped to DCs (e.g. 100 percent inspection at plants).

Objective Function

As mentioned earlier, the proposed model consists of three objective functions. We start the mathematical formulation by introducing the cost objective:

- **Economic Objective**

The cost objective is mainly evaluated by procurement, manufacturing, transportation and warehousing costs. This objective function minimizes the total fixed and variables costs of the network. The economic objective consists of following sub-functions:

- **Procurement function**

This function includes the variable cost of purchasing raw material from suppliers which are introduced as a monetary value in table 1.3 and backorder cost at manufacturing sites.

$$MV = \sum_{t=1}^{T}\sum_{r=1}^{R}\sum_{s=1}^{S} PC_{rst}\, p_{rst} + \sum_{t=1}^{T}\sum_{r=1}^{R}\sum_{i=1}^{I} BC_{rit}\, b_{rit} \qquad \text{(AIII-1)}$$

- **Geographical location cost**

This function addresses the fixed cost of establishing a business with suppliers.

$$GLC = \sum_{s=1}^{S}\sum_{r=1}^{R} FC_{s}\, y_{rs} \qquad \text{(AIII-2)}$$

- **Manufacturing cost function**

This function is the fixed cost of establishing plants with manufacturing technologies, production and backorder costs. Since products are clustered into families by manufacturing technologies, it is possible to have a plant with more than one technology. The equation (3) represents the fixed and variable manufacturing cost at plants.

$$MC = \sum_{i=1}^{I}\sum_{h=1}^{H} FC_{ih} z_{ih} + \sum_{t=1}^{T}\sum_{p=1}^{P}\sum_{h=1}^{H}\sum_{i=1}^{I} MC_{piht} q_{piht} + \sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{p=1}^{P} BC_{pkt} b_{pkt} \qquad \text{(AIII-3)}$$

- **Plants Inventory cost function**

This function calculates the inventory costs at manufacturing sites.

$$IC = \sum_{t=1}^{T}\sum_{r=1}^{R}\sum_{i=1}^{I} HC_{rit} ip_{rit} + \sum_{t=1}^{T}\sum_{p=1}^{P}\sum_{i=1}^{I} HC_{pit} ip_{pit} \qquad \text{(AIII-4)}$$

- **Transportation cost function**

This function represents the cost associated with transportation activities. These three terms are the variable transportation cost of raw materials and products carried out using various modes of transportation.

$$TC = \sum_{t=1}^{T}\sum_{r=1}^{R}\sum_{s=1}^{S}\sum_{i=1}^{I}\sum_{m=1}^{M} TC_{simt} x_{rsimt} + \sum_{t=1}^{T}\sum_{p=1}^{P}\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{m=1}^{M} TC_{ijmt} x_{pijmt} + \sum_{t=1}^{T}\sum_{p=1}^{P}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{m=1}^{M} TC_{jkmt} x_{pjkmt} \qquad \text{(AIII-5)}$$

- **Inventory cost function**

The first term in this function is the fixed cost of establishing a business with DCs. The next two summations represent the variable costs of holding raw materials and products at plants, distribution centers, and retailers, respectively.

$$ILC = \sum_{j=1}^{J} FC_{j} u_{j} + \sum_{t=1}^{T}\sum_{p=1}^{P}\sum_{j=1}^{J} HC_{pjt} id_{pjt} + \sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{p=1}^{P} HC_{pkt} s_{pkt} \qquad \text{(AIII-6)}$$

- **Utilization objective**

The second objective function aims to maximize the utilization of the network. This objective consists of following sub-functions:

- **Supplier delivery performance function**

The first term of this function represents the delivery performance of suppliers which is defined as the ratio of the amount of purchase orders fulfilled by suppliers without backorder to the total amount of required raw materials at manufacturing sites. In fact, this term is the fraction of in full and on-time delivery of raw materials by suppliers during the planning horizon.

$$SDP = \left[\frac{\sum_{t=1}^{T}\sum_{r=1}^{R}\sum_{i=1}^{I}\sum_{s=1}^{S}\sum_{m=1}^{M} x_{rsimt} - \sum_{t=1}^{T}\sum_{r=1}^{R}\sum_{i=1}^{I} b_{rit}}{\sum_{t=1}^{T}\sum_{r=1}^{R}\sum_{p=1}^{P}\left(\sum_{k=1}^{K} Dem_{pkt} R_{rp}\right)} \right] \tag{AIII-7}$$

- **Overall equipment effectiveness Function**

The overall equipment effectiveness (OEE) is also addressed in the second summation which reports the overall utilization of manufacturing operations at plants. In this work, OEE is measured by dividing the quantity of good products (e.g. production quantity minus waste) at manufacturing sites by the total amount of products which are planned to produce (the total demand).

$$OEE = \left[\frac{\sum_{t=1}^{T}\sum_{p=1}^{P}\sum_{i=1}^{I} g_{pit}}{\sum_{t=1}^{T}\sum_{p=1}^{P}\sum_{k=1}^{K} Dem_{pkt}} \right] \tag{AIII-8}$$

- **Manufacturing capacity utilization function**

The capacity utilization at manufacturing sites is calculated by dividing the total production quantity by the total production capacity of plants.

$$CU = \left[\frac{\sum_{t=1}^{T} \sum_{p=1}^{P} \sum_{m=1}^{M} \sum_{i=1}^{I} q_{pimt}}{\sum_{t=1}^{T} \sum_{p=1}^{P} \sum_{m=1}^{M} \sum_{i=1}^{I} MCap_{pimt}} \right] \qquad \text{(AIII-9)}$$

- **Storage utilization function**

In order to measure how well the storage capacities at plants, DCs and retailers are being utilized, the ratio of the amount of products and raw materials stored to the maximum capacity of storages is calculated.

$$SU = \left[\frac{\sum_{t=1}^{T} \sum_{r=1}^{R} \sum_{i=1}^{I} ip_{rit}}{\sum_{t=1}^{T} \sum_{r=1}^{R} \sum_{i=1}^{I} WCap_{rit}} \right] + \left[\frac{\sum_{t=1}^{T} \sum_{p=1}^{P} \sum_{i=1}^{I} ip_{pit}}{\sum_{t=1}^{T} \sum_{p=1}^{P} \sum_{i=1}^{I} WCap_{pit}} \right] + \left[\frac{\sum_{t=1}^{T} \sum_{p=1}^{P} \sum_{j=1}^{J} id_{pjt}}{\sum_{t=1}^{T} \sum_{p=1}^{P} \sum_{j=1}^{J} WCap_{pjt}} \right] + \left[\frac{\sum_{t=1}^{T} \sum_{p=1}^{P} \sum_{k=1}^{K} s_{pkt}}{\sum_{t=1}^{T} \sum_{p=1}^{P} \sum_{k=1}^{K} WCap_{pkt}} \right] \qquad \text{(AIII-10)}$$

- **Delivery reliability function**

Delivery reliability is also the fraction of on-time and in full delivery shipments of products to retailers. This is calculated as the ratio of the amount of product delivered at retailers without backorder to the total demand of product at retailers per period.

$$DR = \left[\frac{\sum_{t=1}^{T} \sum_{p=1}^{P} \sum_{j=1}^{J} \sum_{k=1}^{K} x_{pjkt} - \sum_{t=1}^{T} \sum_{p=1}^{P} \sum_{i=1}^{I} b_{pkt}}{\sum_{t=1}^{T} \sum_{p=1}^{P} \sum_{k=1}^{K} Dem_{pkt}} \right] \qquad \text{(AIII-11)}$$

- **Transportation flexibility function**

The function represents the number and type (capacity) of fleet available for delivery. The function is calculated as the ratio of available transportation capacity using selected transportation modes to the total transportation capacity.

$$F = \left[\frac{\sum_{t=1}^{T} \sum_{s=1}^{S} \sum_{i=1}^{I} \sum_{m=1}^{M} TCap_{simt} l_{simt}}{\sum_{t=1}^{T} \sum_{s=1}^{S} \sum_{i=1}^{I} \sum_{m=1}^{M} TCap_{simt}} \right] + \left[\frac{\sum_{t=1}^{T} \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{m=1}^{M} TCap_{ijmt} l_{ijmt}}{\sum_{t=1}^{T} \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{m=1}^{M} TCap_{ijmt}} \right] + \left[\frac{\sum_{t=1}^{T} \sum_{j=1}^{I} \sum_{k=1}^{K} \sum_{m=1}^{M} TCap_{jkmt} l_{jkmt}}{\sum_{t=1}^{T} \sum_{j=1}^{J} \sum_{k=1}^{K} \sum_{m=1}^{M} TCap_{jkmt}} \right] \tag{AIII-12}$$

- **Environmental Objective**

The third objective function aims to minimize environmental impacts of SC network which contains following sub-functions:

- **Environmentally friendly supplier function**

This function represents the environmental impacts associated with purchasing raw materials from suppliers. Indeed, green procurement is necessary for a company in determining the suitability of a supplier in the sustainable SC.

$$EFS = \sum_{t=1}^{T} \sum_{r=1}^{R} \sum_{s=1}^{S} EIS_{rs} p_{rst} \tag{AIII-13}$$

- **Environmentally friendly operations function**

GHG emissions emitted due to manufacture products at plants are calculated in this function.

$$EFO = \sum_{t=1}^{T} \sum_{p=1}^{P} \sum_{h=1}^{H} \sum_{i=1}^{I} EIM_{pih} q_{piht} \tag{AIII-14}$$

- **Environmentally friendly transportation function**

To calculate the environmental impacts of transportation activities, the distance-based method is used. In fact, the estimated distance would be converted to CO_2 emission by multiplying the distance travelled data by the distance-based emission factor.

$$EFT = \sum_{t=1}^{T}\sum_{s=1}^{S}\sum_{i=1}^{I}\sum_{m=1}^{M}\sum_{r=1}^{R} EFT_{sim} Dis_{si} x_{rsimt} + \sum_{t=1}^{T}\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{m=1}^{M}\sum_{p=1}^{P} EFT_{ijm} Dis_{ij} x_{pijmt}$$
$$+ \sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{K=1}^{K}\sum_{m=1}^{M}\sum_{p=1}^{P} EFT_{jkm} Dis_{jk} x_{pjkmt} \quad \text{(AIII-15)}$$

- **Environmentally friendly warehousing function**

Distribution centres and retailers in various regions might use different energy mix producing dissimilar amount of GHG emissions. Energy mix is referred to the range of energy sources of a region. For instance, Ontario electricity generation is from a mix of energy sources – nuclear, hydro, gas, coal, wind and others. However, to calculate the environmental impacts associated with storages, per unit energy requirement at storages are multiplied by the GHG emission produced from the corresponding energy sources.

$$EFW = \sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{p=1}^{P}\left[\sum_{e_j}^{E_j} EM_{e_j} EF_{e_j}\right] ER_j ID_{pjt} + \sum_{t=1}^{T}\sum_{k=1}^{k}\sum_{p=1}^{P}\left[\sum_{e_k}^{E_k} EM_{e_k} EF_{e_k}\right] ER_k S_{pkt} \quad \text{(AIII-16)}$$

The model also includes constraints (AIII-17) to (AIII-39)

Constraints

$$\sum_{p=1}^{P}\sum_{m=1}^{M}\sum_{i=1}^{I} R_{rp} q_{pimt} = \sum_{s=1}^{S} p_{rst} \quad \forall r,t \quad \text{(AIII-17)}$$

$$p_{rst} \le SCap_{rst} y_{rs} \quad \forall r,s,t \quad \text{(AIII-18)}$$

$$q_{pimt} \le MCap_{pimt} z_{im} \quad \forall p,i,m,t \quad \text{(AIII-19)}$$

$$g_{pit} = (1 - \sum_{m=1}^{M} \alpha_{pimt}) \sum_{m=1}^{M} q_{pimt} \quad \forall p,i,t \quad \text{(AIII-20)}$$

$$\sum_{i=1}^{I}\sum_{t=1}^{T} g_{pit} = \sum_{k=1}^{K}\sum_{t=1}^{T} Dem_{pkt} \quad \forall p \quad \text{(AIII-21)}$$

$$\sum_{j=1}^{J}\sum_{t=1}^{T} x_{pjkt} = \sum_{t=1}^{T} Dem_{pkt} \quad \forall k,p \quad \text{(AIII-22)}$$

$$\sum_{i=1}^{I} x_{rsit} \le \sum_{\tau=1}^{t} p_{rs\tau} - \sum_{i=1}^{I}\sum_{\tau=1}^{t-1} x_{rsi\tau} \quad \forall s,r,t \quad \text{(AIII-23)}$$

$$\sum_{j=1}^{J} x_{pijt} \leq \sum_{\tau=1}^{t} g_{pit} - \sum_{j=1}^{J}\sum_{\tau=1}^{t-1} x_{pij\tau} \quad \forall p,i,t \tag{AIII-24}$$

$$\sum_{i=1}^{I}\sum_{\tau=1}^{t} x_{pij\tau} \geq \sum_{k=1}^{K}\sum_{\tau=1}^{t} x_{pjk\tau} \quad \forall j,p,t \tag{AIII-25}$$

$$\sum_{i=1}^{I}\sum_{t=1}^{T} x_{pijt} = \sum_{k=1}^{K}\sum_{t=1}^{T} x_{pjkt} \quad \forall j,p \tag{AIII-26}$$

$$\sum_{\tau=1}^{t}\sum_{s=1}^{S} x_{rist} - \sum_{\tau=1}^{t}\sum_{p=1}^{P}\sum_{m=1}^{M} R_{rp} q_{pimt} \leq WCap_{rit} \quad \forall r,i,t \tag{AIII-27}$$

$$\sum_{\tau=1}^{t} g_{pi\tau} - \sum_{j=1}^{J}\sum_{\tau=1}^{t} x_{pij\tau} \leq WCap_{pit} \quad \forall i,p,t \tag{AIII-28}$$

$$\sum_{i=1}^{I}\sum_{\tau=1}^{t} x_{pij\tau} - \sum_{k=1}^{K}\sum_{\tau=1}^{t} x_{pjk\tau} \leq WCap_{pjt} u_j \quad \forall j,p,t \tag{AIII-29}$$

$$\sum_{j=1}^{J}\sum_{\tau=1}^{t} x_{pjk\tau} - \sum_{\tau=1}^{t} Dem_{pk\tau} = s_{pkt} - b_{pkt} \quad \forall k,p,t \tag{AIII-30}$$

$$\sum_{r=1}^{R} x_{rsit} = n_{sit} TCap_{sit} + ltl_{sit} \quad \forall s,i,t \tag{AIII-31}$$

$$\sum_{p=1}^{P} x_{pijt} = n_{ijt} TCap_{ijt} + ltl_{ijt} \quad \forall i,j,t \tag{AIII-32}$$

$$\sum_{p=1}^{P} x_{pjkt} = n_{jkt} TCap_{jkt} + ltl_{jkt} \quad \forall j,k,t \tag{AIII-33}$$

$$s_{pkt} \leq WCap_{pkt} w_{pkt} \quad \forall k,p,t \tag{AIII-34}$$

$$b_{pkt} \leq Max_{pkt}(1 - w_{pkt}) \quad \forall k,p,t \tag{AIII-35}$$

$$\alpha_{pimt} \leq Max_{pimt} \tag{AIII-36}$$

$$x_{pjkt} = 0 \quad \forall p,j,k,t \mid \{t.\rho + LT_{jkp} > T.\rho\} \tag{AIII-37}$$

$$p_{rst}, q_{pimt}, g_{pit}, \alpha_{pimt}, x_{rsit}, x_{pijt}, x_{pjkt}, ltl_{sit}, ltl_{ijt}, ltl_{jkt}, b_{pkt}, s_{pkt}, n_{sit}, n_{ijt}, n_{jkt} \geq 0 \tag{AIII-39}$$

$$y_{rs} \in \{0,1\}\ ,\ z_{im} \in \{0,1\}\ ,\ u_j \in \{0,1\}\ ,\ w_{pkt} \in \{0,1\} \tag{AIII-39}$$

- Constraint (AIII-17) ensures that the amount of required raw materials purchased from suppliers is equal to the production quantity at plants.
- Constraint (AIII-18) represents that the number of purchased raw material must be less than the capacity of the supplier.
- Constraint (AIII-19) states the maximum production capacity at plants with selected technology.
- Constraint (AIII-20) is the fraction of good products to the total amount of products produced at plants.
- Constraint (AIII-21) guarantee that the quantity of good products is equal to the product demands at retailers during the planning horizon.
- Constraint (AIII-22) ensures that the demand of each retailer is satisfied by DCs.
- Flow conservations at suppliers, plants, and DCs is also stated in constraints (AIII-23), (AIII-24) and (AIII-25), respectively.
- Constraint (AIII-26) guarantees that there would be no inventory at DCs at the end of the planning horizon.
- Constraint (AIII-27) to (AIII-29) represents the capacity limitation for storages at plants and DCs.
- Constraint (AIII-30) should be satisfied to compute the amount of products delivered in advance or backordered at retailers.
- Constraints (AIII-31) – (AIII-33) ensure that flows between suppliers, plants and DCs consist of full and less than full load truck trips.
- Constraints (AIII-34) and (AIII-35) limit the number of products that can be delivered in advance or backordered at retailers.
- Constraint (AIII-36) represents the maximum percentage of defectives permitted at manufacturing sites.
- Constraint (AIII-37) ensures that there would be no shipment to retailers after the planning horizon.
- Eventually, constraints (AIII-38) and (AIII-39) define the variables' categories.

In this problem we will use Tiwari et al (1987) weighted average approachUsing this approach, the problem can be formulated as follows:

$$\left.\begin{array}{ll} \textit{Maximize} & w_1\mu_{MV} + w_2\mu_{SDP} + w_3\mu_{GLC} + w_4\mu_{EFS} + w_5\mu_{MC} + w_6\mu_{OEE} + w_7\mu_{CU} + \\ & w_8\mu_{IC} + w_9\mu_{EFO} + w_{10}\mu_{SU} + w_{11}\mu_{OF} + w_{12}\mu_{ILC} + w_{13}\mu_{EFW} + w_{14}\mu_F + \\ & w_{15}\mu_{DR} + w_{16}\mu_{TC} + w_{17}\mu_{EFT} \\ \textit{subject to} & \mu_{MV}, \mu_{SDP}, \mu_{GLC}, \mu_{EFS}, \mu_{MC}, \mu_{OEE}, \mu_{CU}, \mu_{IC}, \mu_{EFO}, \mu_{SU}, \mu_{OF}, \mu_{ILC}, \mu_{EFW}, \\ & \mu_F, \mu_{DR}, \mu_{TC}, \mu_{EFT} \in [0,1] \end{array}\right\} \qquad)$$

Moreover, w_1, w_2,…, w_{17} denote the weights of corresponding objective functions. It is clear that determination of weights requires expert's opinion.

Table AIII-1 Distribution center data

Data	Details	Description	Sources
Transportation between plants and DCs	- There are thirty potential 3PLs across united-states and Canada. - Percent of the mass of products sold to: **USA: 52%** **Canada: 48%** ✓ East: 12.95% ✓ Eastern: 65% ✓ Mid-West: 28.64% ✓ Western: 35% ✓ North East: 14.34% ✓ North West: 3.11% ✓ South East: 10.60% ✓ South West: 2.41% ✓ West: 27.95%		Collected data
	The average distance between plants and DCs:		Google Maps. com
	Transportation between plants and DCs is done by freezer 53' truck with an average load of 16 tonnes.	Assumption	
	Emission factor for transportation: 1.29 kg CO_2 eq./km	Assumption	GFCCC (2015)
Freezing storage	Average energy consumed for storage: 40 kWh/m3/year	Assumption	Duiven (2002)
in DCs	Average product volume: 2.8 L		Collected data

Table AIII-2 Retailers data

Data	Details	Description	Sources
Demand	- Total demand for product families is as follows: ▪ Breakfast: 11177/pallet ▪ Meals: 11750/pallet ▪ Snacks: 1500/pallet ▪ Raw doughs: 21702/pallet - Total mass of products sold: 13,758 tones		Collecte d data
Transportation between DCs and retail stores	Average distance between DCs and retail stores: 720 km		
	Transportation between DCs and retailers is done by 53' freezer truck with an average load of 16 tons.	Assumption	
	Emission factor for transportation: 1.29 kg CO2 eq./km	Assumption	GFCCC (2015)
Freezing storage in retail stores	Average energy consumed for storage: 2,700 kWh/m3/year	Assumption	IEA, 2012
	Average product volume: 2.8 L ▪ Based on the main seller's average volumes		Collecte d data

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