Application of Fuzzy Logic on Understanding of Risks in Supply Chain and Supplier Selection

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By

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Certificate of Approval

This is to certify that the thesis entitled **APPLICATION OF FUZZY LOGIC ON UNDERSTANDING OF RISKS IN SUPPLY CHAIN AND SUPPLIER SELECTION** submitted by ***Sri Poorna Chandu Karuturi*** has been carried out under my supervision in partial fulfillment of the requirements for the Degree of ***Master of Technology*** in ***Production Engineering*** at **National Institute of Technology**, **NIT Rourkela**, and this work has not been submitted elsewhere before for any other academic degree/diploma.

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Abstract

The aim of this research is firstly to determine the key risk factors of Supply Chain Management (SCM) and developing an efficient model to assess them. In this work, first the risks involved in SCM has been identified and arranged in a systematic hierarchical structure. Questionnaire surveys have been used for data collection from a managerial decision-making group of a case industry. Next, based on the obtained linguistic data, a fuzzy logic based assessment module has been designed for the evaluation of aggregated SC risks. Finally, various risk factors have been categorized; then ranked using 'fuzzy maximizing and minimizing fuzzy set theory' in order to identify/assess the major risk factors that need to be managed or controlled.

The present trend in the market is no longer the competition among the enterprises but the supply chain. Supplier selection is the most critical decision of the whole procuring department. Selection of supplier is a complicated decision involving many criteria to take into consideration. In later part, this study tries to rank the suppliers centered on different risks and draw a compromise solution. In order to achieve this, understanding risks is of utmost important. In this work, risks associated with the supplier selection have been recognized and analyzed to rank candidate suppliers based on their affinity to risk using fuzzy based VIKOR method. These risks have varied probability of occurrence and impact on the supply chain. Risks have been represented by linguistic variables and then parameterized by Triangular Fuzzy Number (TFN). Fuzzy risk extent has been calculated and thereby Fuzzy Best Value (FBV) and Fuzzy Worst Value (FWV) have been determined. Fuzzy Utility value has been calculated and utilizing this, ranking has been made by closeness to FBV and farness to FWV. Best alternative has been preferred by maximizing utility group and minimizing regret group.

Contents

List of Tables

List of Figures

Chapter 1: Background

1.1. Introduction

1.1.1 Supply Chain Risk

Swiftness in the change/ mutation of manufacturing and marketing techniques led the organizations to think of possible alternatives. With the increase in sophistication in techniques, every organization tries to achieve competitive advantage and gain market share. Under these circumstances, organizations are forced to increase productivity further and further more. This results in production of high quality products or services at economic costs. Under these criteria, achieving profits is a mere possibility. Therefore, the organization has to look for alternative areas to achieve profits and also to increase market share. This led them to focus on concepts of management, related to supply of raw materials, inventory control, production, logistics, distribution and delivery to the customers. Bringing all these under one roof led them towards supply chain. Besides its benefits, comes greater complexity and risks in the supply chain. These risks are inevitable. However, they can be mitigated by supply chain risk identification, evaluation and control. Thus, risk evaluation has become an important part of today's Supply Chain Management (SCM).

Supply chain management involves a set of approaches used to efficiently incorporate suppliers, manufacturers, warehouses and distribution centers so that the product is produced and distributed in the quantity to the right locations and at the right time when there is market demand. For achieving this, there should be co-ordination and communication among all the members of the supply chain network.

Key factors to have an effective SCM are effective flow of information, communication, cooperation and trust among various members of the supply chain. The only goal with the SCM is to respond to uncertainties in customer demand without incurring any additional costs for carrying inventory. SCM has to cope with uncertainties like demand forecast errors, variation in travel times, weather and natural catastrophe, breakdown of machines, war etc., labour conditions, local politics, border issues etc. SCM must try to understand and manage various activities within SC in a systematic manner [Berenji and Anantharaman, 2011].

Supply chain management increases the efficiency of supply chain, along with it added risk. SCM involves an ocean of decisions regarding selection of supplier, logistics, quantity, distributors etc. These decisions are to be made to improve profit and productivity for the organization also contains certain amount of risk. These risks are inevitable and so effort should be made to mitigate them. The main aim of the Supply Chain Risk Management (SCRM) is to check the optimality for both efficiency and underlying risk. Its aim is to subdue risks, so that they don't affect the proper functionality of existing supply chain. It means decreasing the vulnerability of a supply chain, increasing its ability to withstand unexpected adverse issues, improving sustainability or increasing resilience [Norrman and Jansson, 2004].

For in depth understanding of supply chain risks; different risks (risk sources) involved in supply chain as classified by Berenji and Anantharaman (2011) have been reported below. Supply chain risks were classified majorly into six categories viz. *Supply risks*, *Demand risks*, *Operational risks*, *Social/political risks*, *Competitive/economic risks* and *Control & plan risks*.

Supply risks: Any risk that involves the raw materials or semi-finished goods or finished goods that are to supplied to the next level in the supply chain comes under supply risk. The problem may be delay or insufficiency or low quality of raw material. This may result due to many reasons. An exclusive supplier having a problem directly impacts the organization. The risk of bankruptcy may extend from a little disruption to shutdown of company. Keeping track of financial records of critical suppliers and searching for alternative suppliers or providing some aid to them might help. Cargo damages are manageable if the quantity is less and parts are not damaged beyond they can be repaired. But if it is the other way results increase in per part cost as well as insufficiency of parts. Its sub categories include:

1. Materials quality
2. Supplier satiation
3. Global sourcing
4. Exclusive supplier
5. Delivery times
6. Cargo damages
7. Bankruptcy of supplier

Demand risks: the factors that influence the change in demand results in demand risk. Various factors that might affect demand may be sales withdrawal by customers, changes in the market demand either increase or decrease, changes in the product requirement etc. These should be handled very carefully and if not incurs a loss of expenditure through idling of workers and machinery, increase in inventory carrying etc. during decrease in demand and while increase, there occurs an increase in lead time resulting customer dissatisfaction. To mitigate this kind of risks proper alignment of production with demand has to be made. To cope with changes in product requirement, frequent market survey has to be done. Under this sub categories include:

1. Sale withdrawal
2. Market demand changes
3. After sale service

4. Changes in product preferences
5. Non-flexibility

Operational risks: The risks associated with planning and manufacturing comes under operational risk. These risks may include human error resulting defective parts, improper planning of production line which might result halt in assembly line. Changes in product design or changes in production technology might need reordering of production line in the workshop or modified machinery needing operating personnel training. Problems with the supplier when the raw material has to be changed and his contract tenure left. Searching for a new supplier or old one being transformed takes time. This produces discontinuities in supply chain. This further can be categorized into:

1. Changes by employer
2. Changing production technology
3. Human error
4. Sharing comments among departments
5. Changes in product design and engineering
6. Operation quality

Social/Political risks: Political risk is the kind of risk occurs when there happens to be changes in political scenario or policies. Shifting of government might result in many changes in taxing policies etc. Globalizations being the trend, political changes around the world that adversely affect, create disruptions in supply chain. Cancelation of export/import licenses lead to excess of goods required for the local market requires idling. Power sanctions might alter according to the availability results breakdown of plant causing disruptions in supply chain. This sub categorized into:

1. Agreement terms and type
2. Losing personnel
3. Grey propaganda in public
4. Socio political lobby
5. Sanctions
6. Controlling export/import
7. Custom delays and damages

Competitive/economic risk: The risk which incurs loss to Supply Chain due to changes in economic factors like exchange rate changes, collapse of stock market or increase in the inflation rate. This risk can be called as external risk. The organization has nothing to do for avoiding these situations. So, it can only be design of Supply Chain so that it can cope with such situations. Its sub categories include:

1. Inflation rate
2. Partners bankruptcy
3. Stock market crash
4. Exchange rate changes
5. Financial crises

Control/Plan risk: The risks associated with changes of managerial decision or crashes in operational schedule planning or failure of control tools/methods comes under this. Flaws in decision making or external agents forcing change yield to modify the production processes or schedules. This causes delays and break in supply chain. Supply chain should be designed to subdue these situations. This again sub categorized as:

1. Information flow and information systems
2. Control tools and methods
3. Crashes and/or changes in planning

1.1.2 Suppliers Selection

Supplier selection is an important decision-making process in supply chain management. Different suppliers have varied 'pros and cons' associated with them. Therefore, selecting an appropriate supplier is always a difficult task. Supplier section has a major impact on proper functioning of supply chain as well as product quality. Selection of right supplier improves the efficiency of supply chain and significantly increases corporate competitiveness. Organizations must be very cautious not only about price and quality of raw material but also about the structure of the organization, production capabilities, reliability, company policy etc. For some cases, it is not only enough to look at supplier conditions but also suppliers' supplier reliability and capability. For the case of Just in Time (JIT) manufacturing, supplier selection is of utmost importance.

Today at an average manufacturer spends approximately half its revenue to purchase goods and services, thus making a company's success reliant on their interactions with suppliers. The role of procurement managers within companies has become particularly important. Supplier selection involves the congregation of decisions made by different organizational levels in the company. Each level or each department may have their own priorities based on their ease of manufacturing. Taking all these into study, one cannot have an optimal solution. So, in selecting an appropriate supplier, one has to consider all these requirements and should take a compromising decision. With much of company's money being spent and increasing dependency on the outsourcing of many critical and complex parts, the role of buyer is not only critical but also challenging. Buyers must define and calculate what will be the best value means for the buying organization, and undertake procurement actions accordingly. To identify the best value, the procurement manager must have a common meeting with technical, operations and legal experts within the company, and should be a professional negotiator and director across many internal and external parties.

Supplier selection is the process by which the buyer identifies, estimates, and deals with suppliers. The challenges mentioned make supplier selection a rich topic for industrial operations and management disciplines.

To cope with the growing competition it isn't enough only to select from the existing or known suppliers but the management should be able to identify new suppliers. New supplier identification is so important that it might a novel production technology or may have structural advantage or low labor cost which ultimately impact the cost of the product and may be able to supply it for cheaper than any other or may be able to deliver with lesser lead time that might allow to maintain minimum inventory which reduces expenses for maintenance as well as money will be put to best use.

Again there involves a key factor for selection of suppler i.e. risk associated with them. Supplier risk is more important than any because it directly affects the buyer in all aspects of production involving that part or operation that has to be done only after the part is assembled. These situations may lead to complete halt of the company incurring huge loss in the form of manufacturing holiday, idling of labor, loss of customer faith etc. Sometimes it can be even worse and might lead to lockup of the factory.

Therefore, supplier selection, evaluation and monitoring are crucial for an industry to survive in long term. Ranking of suppliers becomes complex when suppliers must be evaluated across multiple dimensions/ evaluation indices. For example, if the buyer wishes to evaluate suppliers' bids on the extents of price and lead-time, the buyer must build a trade-off between these two dimensions to determine whether it favors, say, a bid with a high price and less lead time to a bid with a low price and higher lead time. The real challenge of supplier evaluation lies in constructing this tradeoff in a way that perfectly reflects the buyer's preferences (Srividhya and Jayaraman; 2007; Beil, 2010).

1.2. Supply Chain Risk: Prior State of Art

Risks in supply chains represent one of the major business issues today. Since every organization strives for success and uninterrupted operations, efficient supply chain risk management is very crucial (Jereb et al., 2012). The following section provides results of in depth literature review on supply chain risk management and related aspects.

Zsidisin (2003) provided a grounded definition of supply risk. The study focused on the sources of supply risk, emanating from individual supplier factors and market characteristics, and the outcomes of supply risk events, which involved the inability of purchasing firms to meet customer requirements and threats to customer life and safety. Findings from this research provided practitioners and academicians a starting point for understanding supply risk and insights as to how supply risk could negatively affect business operations. Jüttner et al. (2003) clarified the concept of supply chain risk management. The existing literature on supply chain vulnerability and risk management was reviewed and compared with findings from exploratory interviews undertaken to discover practitioners' perceptions of supply chain risk and current supply chain risk management strategies.

Hallikasa et al. (2004) focused on risk management in supplier networks. The primary aim was to illustrate challenges that network co-operation brings to risk management. The paper outlined the general structure of the risk management process and presented methods for risk management in a complex network environment. The results indicated that risk management was an important development target in the studied supplier networks. When the dependency between companies increased, they became more exposed to the risks of other companies. The presented processes facilitated understanding and managing of uncertainties and risks in supplier networks. Norrman and Jansson (2004) reported that supply chain risk management (SCRM) was of growing importance, as the vulnerability of supply chains increased. The main thrust of this article was to describe how Ericsson, after a fire at a sub-supplier, with a huge impact on Ericsson, had implemented a new organization, and new processes and tools for SCRM. The approach described here tried to analyze, assess and manage risk sources along the supply chain, partly by working close with suppliers but also by placing formal requirements on them. This explorative study also indicated that insurance companies might be a driving force for improved SCRM. The article concluded with a discussion of risk related to traditional logistics concepts (time, cost, quality, agility and leanness) by arguing that supply chain risks should also be put into the trade-off analysis when evaluating new logistics solutions-not with the purpose to minimize risks, however, but to find the efficient level of risk and prevention.

Kleindorfer and Saad (2005) reported two broad categories of risk affecting supply chain design and management: (1) risks arising from the problems of coordinating supply and demand, and

(2) risks arising from disruptions to normal activities. This paper was concerned with the second category of risks, which might arise from natural disasters, from strikes and economic disruptions, and from acts of purposeful agents, including terrorists. The paper provided a conceptual framework that reflected the joint activities of risk assessment and risk mitigation that were fundamental to disruption risk management in supply chains.

Faisal et al. (2006) presented an approach to effective supply chain risk mitigation by understanding the dynamics between various enablers that helped to mitigate risk in a supply chain. Using interpretive structural modeling, the research presented a hierarchy-based model and the mutual relationships among the enablers of risk mitigation. Gaudenzi and Borghesi (2006) provided a method to evaluate supply chain risks that stand in the way of the supply chain objectives. An analytical hierarchy process model was proposed to identify supply chain risk factors with a view to improving the objective of customer value. The two phases of the method were the prioritization of supply chain objectives; and the selection of risk indicators. Wu et al. (2006) aimed to reinforce inbound supply chain risk management by proposing an integrated methodology to classify, manage and assess inbound supply risks. Inbound supply risk factors were identified through both an extensive literature review as well as a series of industry interviews. A hierarchical risk factor classification structure was created with an analytical hierarchy processing (AHP) method to rank risk factor for suppliers. Tang (2006) reviewed various quantitative models for managing supply chain risks. A unified framework was developed for classifying SCRM articles. This review could serve as a practical guide for some researchers to navigate through the sea of research articles in this important area. By highlighting the gap between theory and practice, the study might motivate researchers to develop new models for mitigating supply chain disruptions.

Kumar and Viswanadham (2007) suggested the framework of a Decision Support System (DSS) adopting Case-Based Reasoning approach; which could support decision makers in preventive as well as interceptive construction supply chain risk management. Badr and Stephan (2007) proposed a framework to bridge the gap between security concerns and risk management in a supply chain; typically, the Supply Chain Operations Reference (SCOR) model. The framework extended risk management with security awareness by proposing roles for each process in SCOR. Its underlying approach focused on the types of threats in SCOR implementation projects and applied empirical benchmarks to measure risks in processes with respect to the security-oriented framework.

Liu and Wang (2008) assumed that supply chain risk evaluation is a multi-criteria decision making problem under fuzzy environments. To tackle the problem, this paper firstly identified and discussed some of the important and critical decision criteria and constructed the evaluation indicator framework. This paper presented a modified grey relational analysis method based on the concepts of ideal and anti-ideal points. Iranmanesh et al. (2008) explored fuzzy analytical hierarchy process (FAHP) as a means of risk evaluation methodology to prioritize and organize risk factors faced in IT projects. A real case of IT projects, a project of design and implementation of an integrated information system in a vehicle producing company in Iran was studied. Related risk factors were identified and then expert qualitative judgments about these factors were acquired. Translating these judgments to fuzzy numbers and using them as an input to FAHP, risk factors were then ranked and prioritized by FAHP in order to make project managers aware of more important risks and enable them to adopt suitable measures to deal with these highly devastative risks.

Russell and Smith (2009) provided a literature review on reversing supply chain outsourcing and framed the sourcing decision in terms of multiple options, including multi- sourcing, near sourcing, and in-sourcing. A decision tree model was presented to aid the decision maker in evaluating the expected value of various sourcing decisions when risks and returns were explicitly considered. Trends and conditions that influenced the outsourcing decision were also discussed. Trkman and McCormack (2009) presented preliminary research concepts regarding a new approach to the identification and prediction of supply risk. This approach to the assessment and classification of suppliers was based on supplier's attributes, performances and supply chain characteristics, while it was also modified by factors in the supplier's specific environment. The challenges posed to supply chains due to a turbulent environment (both from within the industry and external influences) were examined. A new method for the assessment and classification of suppliers based on their characteristics, performances and the environment of the industry in which they operate was presented. Pujawan and Geraldin (2009) provided a framework to proactively manage SC risks. The framework would enable the company to select a set of risk agents to be treated and then to prioritize the proactive actions, in order to reduce the aggregated impacts of the risk events induced by those risk agents. A framework called house of risk (HOR) was developed, which combined the basic ideas of two well-known tools: the house of quality of the quality function deployment and the failure mode and effect analysis. The framework consisted of two deployment stages. HOR1 was used to rank each risk agent based on their aggregated risk potentials. HOR2 was intended to prioritize the proactive actions that the company should pursue to maximize the cost-effectiveness of the effort in dealing with the selected risk agents in HOR1.

Moeinzadeh and Hajfathaliha (2010) aimed to reinforce SC risk management by proposing an integrated approach. SC risks were identified and a risk index classification structure was created. Then, the authors developed a SC risk assessment approach based on the analytic network process (ANP) and the VIKOR methods under the fuzzy environment where the vagueness and subjectivity were handled with linguistic terms parameterized by triangular fuzzy numbers. By using FANP, risks weights were calculated and then inserted to the FVIKOR to rank the SC members and find the most risky partner. Tuncel and Alpan (2010) aimed to show how a timed Petri nets framework could be used to model and analyze a supply chain (SC) network which was subject to various risks. The method was illustrated by an industrial case study. We first investigated the disruption factors of the SC network by a failure mode, effects and criticality analysis (FMECA) technique. The authors then integrated the risk management procedures into design, planning, and performance evaluation process of supply chain networks through Petri net (PN) based simulation. The developed PN model provided an efficient environment for defining uncertainties in the system and evaluating the added value of the risk mitigation actions. The findings of the case study showed that the system performance could be improved using risk management actions and the overall system costs could be reduced by mitigation scenarios.

Berenji□ et al. (2011) studied to identify and assessing the risk in supply chain using Fuzzy Analytic Network Process (for allocating weights to risk factors) and Fuzzy TOPSIS (for ranking the supply chain members). Ebrat and Ghodsi (2011) aimed at determining the key risk factors of construction projects in Iran and developing an intelligent system to assess them. In this research, first the risks involved in construction projects were identified and arranged in a systematic hierarchical structure. Next, based on the obtained data a network was based on the adaptive fuzzy system was designed for the evaluation of project risks. The results showed that the ANFIS models were more promising in the assessment of construction projects risks. Azari et al. (2011) used the fuzzy TOPSIS method, and provided a rational and systematic process for developing the best model under each of the selection criteria. Decision criteria were obtained from the nominal group technique (NGT). The proposed method could discriminate successfully and clearly among risk assessment methods. Shemshadi et al. (2011) investigated a new novel approach for this problem based on ANP and fuzzy TOPSIS methods while it took into account the risk factor solely regarding the decision maker's venture strategy. In addition to an ANP model that determined the effects of decision criteria, in the said approach, a set of five risk categories was deployed to affect the decision maker's choice by normalizing the weights of risk criteria. Ravasizadeh et al. (2011) proposed a model integrated fuzzy Delphi, fuzzy AHP and VIKOR under fuzzy environment methods towards identifying and evaluating E-Supply Chain Risks. The authors contributed E-supply chain risk by identifying thirteen critical criteria for evaluating suppliers' risk. The findings showed that four criteria; the extent of acceptable information, interrelationship risk, lack of honesty in relationships and product quality and safety were the most important for evaluating suppliers' risk. Pfoh et al. (2011) reported the potentiality of structural analysis for supply chain risks. It demonstrated how interpretive structural modeling (ISM) supported risk managers in identifying and understanding interdependencies among supply chain risks on different levels (e.g. 3PL, first-tier supplier, focal company, etc.).

Danaa et al. (2011) presented a model of risk control in equipment manufacturing supply chain. The authors provided a solution methodology using unascertained mathematics and fuzzy theory to measure risk in electronic manufacturing supply chain; the model combined the unascertained theory with fuzzy method. The authors constructed the model considering the occurrence probability and the loss magnitude of risk simultaneously in single model using risk utility function. In this model, the unascertained mathematical was applied to measure occurrence probability of electronic manufacturing supply chain risk, and the fuzzy theory was utilized to solve loss magnitude caused by electronic manufacturing supply chain risk, then the whole risk of electronic manufacturing supply chain was given according to the mean of risk by the utility function of the risk probability and the risk loss. A key process involved in supply chains is a priori evaluation of potential partners, not only in terms of expected cost (which includes exchange rate risk), but also in terms of other risks. These risks can include product failure, producing company failure (such as bankruptcy), and even political risk. Olson and Wu (2011) aimed to compare tools to aid supply chain organizations in measuring, evaluating, and assessing risk in this environment. The authors demonstrated the use of DEA, followed by a DEA simulation model and also a Monte Carlo simulation using a risk-adjusted cost concept. Once non-dominated partners were identified by DEA, simulation analysis was applied to compare expected performance of vendors, and the range of expected outcomes could be identified, aiding supply chain core organizations to better select producing partners. Thun and Hoenig (2011) reported the empirical analysis of supply chain risk management practices based on a survey with various manufacturing plants conducted in the German automotive industry. After investigating the vulnerability of supply chains in general and examining key drivers of supply chain risks, the paper identified supply chain risks by analyzing their ***likelihood to occur*** and their ***potential impact*** on the supply chain. The results were visualized in the probability-impact-matrix distinguishing between internal and external supply chain risks.

Shameli-Sendi et al. (2012) presented a practical model for information security risk assessment. This model was based on multi-criteria decision-making and used fuzzy logic. Hu (2012) integrated fuzzy inference methodology with failure modes effects analysis (FMEA) to develop a two stage risk assessment model. The first stage systematically identified potential risks in DC, employing the FMEA method. The second stage evaluated risk by using a risk inference expert system, developed in this study, to obtain the risk priority number (RPN). The RPN of a given failure mode was evaluated using three indexes: degree of severity, frequency of occurrence, and chance of detection. Chen (2012) explained the financial innovation service product-fundamental mode of supply chain finance, and explored the risk of supply chain finance. Fuzzy ordinal regression support vector machine was used to analysis the risk of supply chain finance by the index system of risk assessment.

Vosooghi (2012) identified main risks related to crude oil supply chain and implements fuzzy analytic hierarchy process (FAHP) for weighing them. The results showed that the most important risk area was the regulatory and environmental risks and that the transference and cooperation policy was rated as the best response strategy. The paper provided a comprehensive framework of risks that need to be considered in crude oil supply chain risk management (SCRM) context; and it illustrated that how various risks and risk management strategies could be assessed through the FAHP approach to aid managers in their decision making processes. Cunbin and Peng (2012) proposed a new modeling method based on trapezoidal fuzzy number FAHP to solve the problem of risk element transmission in enterprise project evaluation chain. The authors firstly put forward enterprise project chain risk element transmission and constructed enterprise project chain risk element transmission tetrahedron model and then proposed the theory of enterprise project evaluation chain risk element transmission based on trapezoidal fuzzy number FAHP.

Vilkon and Hallikas (2012) presented concepts and findings concerning the identification and analysis of risks in multimodal supply chains. This research approach was holistic, and incorporated perspectives from different parts of the chain. The multimodal maritime supply chain in focus runs from the Gulf of Finland to the Finnish mainland. The authors mapped the process and the structure, and presented a framework for categorizing the risks in terms of their driver factors in order to assess the overall impact on the performance of the supply chain. Finally, the authors analyzed the risk impacts in terms of delays in the chain by means of Monte-Carlo-based simulation. Ohmori and Yoshimoto (2012) discussed how to manage supply-chain disruption risks from natural disasters or other low-likelihood-high-impact risk drivers. In this paper, the authors described a framework for assessing how much individual mitigation strategies had the impact on the entire supply-chain protection against disruption, using network reliability. The authors proposed three categories of risk-mitigation approaches: Stability, Absorb, and Alternative. With a clear understanding of relations between these mitigation strategies and the entire supply-chain risks, mangers could select effective risk-reduction approaches to their supply-chain.

1.3. Suppliers Selection: Prior State of Art

Supplier selection is the process by which firms identify, evaluate, and contract with suppliers. The supplier selection process deploys a tremendous amount of a firm's financial resources. In return, firms expect significant benefits from contracting with suppliers offering high value (Beil, 2009). Supplier selection is the process by which the buyer identifies, evaluates, and contracts with suppliers. The challenges mentioned above make supplier selection a fertile topic for operations and management science disciplines. There is also a growing audience for such research, as the importance of fostering talent by employing buyers with analytical expertise, general management backgrounds, and deep knowledge in a particular purchasing category becomes widespread (Reinecke et al. 2007).

Hallikas et al. (2004) provided the general structure of risk management methods in a complex network environment. This study helped to understand the risk of other companies thus facilitate in choosing the right supplier.

Chen et al. (2006) applied a hierarchy multiple criteria decision-making (MCDM) model based on fuzzy-sets theory to deal with the supplier selection problems in the supply chain system. According to the concept of the TOPSIS, a closeness coefficient was defined to determine the ranking order of all suppliers by calculating the distances to the both fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solution (FNIS) simultaneously. Finally, an example was shown to highlight the procedure of the proposed method.

Chan and Kumar (2007) discussed some critical decision-making criteria along with the risk factors for development of an effective structure for selection of appropriate supplier. Fuzzy extended Analytic Hierarchy Process (FAHP) was used to handle the different criteria of suppliers' selection like cost, service, quality, and risk profile of the supplier.

Levary (2008) used analytical hierarchy process to evaluate and rank potential suppliers. Ranking was done among the potential foreign customers based on several criteria of supply chain reliability including potential risk of the supplier. Trkman and McCormack (2009) presented concepts based on suppliers' attributes, performances and supply chain characteristics which also depended on the supplier's specific environment in which they were supposed to operate, for the assessment and classification of suppliers.

Guo et al. (2009) introduced a potential support vector machine technology combined with decision tree to address issues on supplier selection including feature selection, multiclass classification etc. Ravindran et al. (2010) presented a risk classification and quantification method for optimizing supplier section. Risk quantification involves separation of risk into 'value at risk' (VaR) and 'miss the target' (MtT). Extreme value theory was proposed to quantify VaR type and Taguchi's loss functions for MtT type risks. These were used as objectives in the multi-criteria models and solved for supplier selection.

Keskin et al. (2010) applied Fuzzy Adaptive Resonance Theory (ART)'s classification ability to the supplier evaluation and selection area. The proposed selection method, using Fuzzy ART not only selected the most appropriate supplier(s) and also clustered all of the vendors according to chosen criteria. To explain the Fuzzy ART method a real-life supplier selection problem was solved and suppliers were categorized according to their similarities. The obtained results showed that the proposed method was well suited as a decision-making tool for supplier evaluation and selection problem.

Shemshadi et al. (2011) proposed a hybrid model based on ANP and fuzzy TOPSIS for improving the solution for the supplier selection problem. This method utilized ANP to determine weights and risk impact and final solution based on TOPSIS method.

1.4. Problem Statement

In the present context, supply chain risk evaluation is seemed to be a Multi-Criteria Decision Making (MCDM) problem under complexity and vagueness. To tackle the problem, this study explores fuzzy evaluation of the decision criteria (measures and metrics/dimension of risk or different risk sources) and constructs the evaluation indicator framework to measure aggregated risk involved with organizations and their supply chains. In this method, the risk related information has been partially known (incomplete, inconsistent and imprecise) and the vagueness and subjectivity have been handled with linguistic terms parameterized by trapezoidal fuzzy numbers. A fuzzy-based risk assessment module has been developed in this reporting.

Suppliers' risk is one of the crucial components in supply chain risks. Appropriate suppliers selection decision-making can mitigate such risks. The objective of supplier selection is to reduce purchasing risk, maximize overall value to the purchaser and build a long term, reliable relationship between buyers and suppliers.

Many methods have been proposed and used for supplier evaluation and selection; most of them try to rank the suppliers from the best to the worst and to choose the appropriate supplier(s). Supplier evaluation and selection is a complex and typical multi criteria decision-making problem. Because of human judgment needs in many area of supplier selection such as preferences on alternatives or on the attributes of suppliers or the class number and borders supplier selection becomes more difficult and risky (Keskin et al., 2010).

In order to facilitate suppliers' selection decision-making considering suppliers' risk, the study proposes application of VIKOR method in fuzzy environment. Numerical illustration demonstrates application feasibility of the said approach towards effective suppliers' selection.

The objectives of this research are two-fold:

1. To develop an efficient supply chain risk assessment module in fuzzy context.
2. To develop an efficient decision support system using fuzzy logic and VIKOR concept towards appropriate suppliers' selection and to cope up with suppliers' risk.

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Chapter 2: Fuzzy Preliminaries

2.1 Fuzzy Set Theory

To deal with vagueness in human thought, Lotfi A. Zadeh (1965) first introduced the fuzzy set theory, which has the capability to represent/manipulate data and information possessing based on non statistical uncertainties. Moreover fuzzy set theory has been designed to mathematically represent uncertainty and vagueness and to provide formalized tools for dealing with the imprecision inherent to decision making problems. Some basic definitions of fuzzy sets, fuzzy numbers and linguistic variables are reviewed from Zadeh (1965; 1975), Buckley (1985), Negi (1989), Kaufmann and Gupta (1991).The basic definitions and notations below will be used throughout this thesis until otherwise stated.

2.1.1 Definitions of fuzzy sets:

Definition 1. A fuzzy set $\tilde{A}$ in a universe of discourse X is characterized by a membership function $\mu_{\tilde{A}}(x)$ which associates with each element x in X a real number in the interval $[0,1]$. The function value $\mu_{\tilde{A}}(x)$ is termed the grade of membership of x in $\tilde{A}$ (Kaufmann and Gupta, 1991).

Definition 2. A fuzzy set $\tilde{A}$ in a universe of discourse X is convex if and only if

$$\mu_{\tilde{A}}(\lambda x_1 + (1-\lambda)x_2) \geq \min\left(\mu_{\tilde{A}}(x_1), \mu_{\tilde{A}}(x_2)\right) \qquad (2.1)$$

For all x_1, x_2 in X and all $\lambda \in [0,1]$, where min denotes the minimum operator (Klir and Yuan, 1995).

Definition 3. The height of a fuzzy set is the largest membership grade attained by any element in that set. A fuzzy set $\tilde{A}$ in the universe of discourse X is called normalized when the height of $\tilde{A}$ is equal to 1 (Klir and Yuan, 1995).

2.1.2 Definitions of fuzzy numbers:

Definition 1. A fuzzy number is a fuzzy subset in the universe of discourse X that is both convex and normal. Fig. 2.1 shows a fuzzy number $\tilde{n}$ in the universe of discourse X that conforms to this definition (Kaufmann and Gupta, 1991).

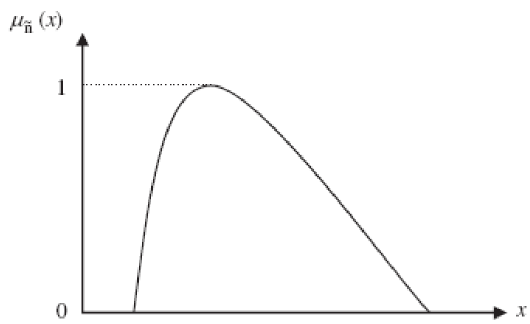

Fig. 2.1. A fuzzy number $\tilde{n}$

Definition 2. The α -cut of fuzzy number $\tilde{n}$ is defined as:

$$\tilde{n}^{\alpha} = \{x_i : \mu_{\tilde{n}}(x_i) \geq \alpha, x_i \in X\}, \qquad (2.2)$$

Here $\alpha \in [0,1]$.

The symbol $\tilde{n}^{\alpha}$ represents a non-empty bounded interval contained in X , which can be denoted by $\tilde{n}^{\alpha} = [n_l^{\alpha}, n_u^{\alpha}]$, n_l^{α} and n_u^{α} are the lower and upper bounds of the closed interval, respectively (Kaufmann and Gupta, 1991; Zimmermann, 1991). For a fuzzy number $\tilde{n}$, if $n_l^{\alpha} > 0$ and $n_u^{\alpha} \leq 1$ for all $\alpha \in [0,1]$, then $\tilde{n}$ is called a standardized (normalized) positive fuzzy number (Negi, 1989).

Definition 3. Suppose, a positive triangular fuzzy number (PTFN) is $\tilde{A}$ and that can be defined as (a,b,c) shown in Fig. 2.2. The membership function $\mu_{\tilde{n}}(x)$ is defined as:

$$\mu_{\tilde{A}}(x)=\begin{cases}(x-a)/(b-a), & if\ a\le x\le b,\\ (c-x)/(c-b), & if\ b\le x\le c,\\ 0, & otherwise,\end{cases} \tag{2.3}$$

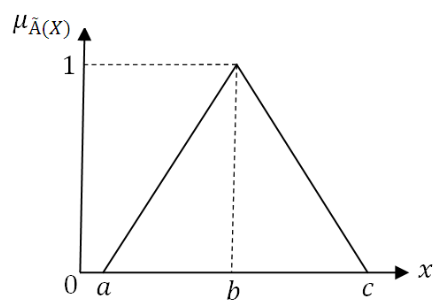

Fig. 2.2 A triangular fuzzy number $\tilde{A}$

Based on extension principle, the fuzzy sum $\oplus$ and fuzzy subtraction Θ of any two triangular fuzzy numbers are also triangular fuzzy numbers; but the multiplication $\otimes$ of any two triangular fuzzy numbers is only approximate triangular fuzzy number (Zadeh, 1975). Let's have a two positive triangular fuzzy numbers, such as $\tilde{A}_1=(a_{1,}\ b_1,c_1)$, and $\tilde{A}_2=(a_2,b_2,c_2)$, and a positive real number $r=(r,r,r)$, some algebraic operations can be expressed as follows:

$$\tilde{A}_1\oplus\tilde{A}_2=(a_1+a_2,b_1+b_2,c_1+c_2) \tag{2.4}$$

$$\tilde{A}_1\,\Theta\,\tilde{A}_2=(a_1-a_2,b_1-b_2,c_1-c_2) \tag{2.5}$$

$$\tilde{A}_1\otimes\tilde{A}_2=(a_1a_2,b_1b_2,c_1c_2) \tag{2.6}$$

$$r\otimes\tilde{A}_1=(ra_1,rb_1,rc_1) \tag{2.7}$$

$$\tilde{A}_1\,\varnothing\,\tilde{A}_2=(a_1/c_2,b_1/b_2,c_1/a_2) \tag{2.8}$$

The operations of $\vee$ (max) and $\wedge$ (min) are defined as:

$$\tilde{A}_1(\vee)\tilde{A}_2=(a_1\vee a_2,b_1\vee b_2,c_1\vee c_2) \tag{2.9}$$

$$\tilde{A}_1(\wedge)\tilde{A}_2 = (a_1 \wedge a_2, b_1 \wedge b_2, c_1 \wedge c_2) \quad (2.10)$$

Here, $r > 0$, and $a_1, b_1, c_1 > 0$,

Also the crisp value of triangular fuzzy number set $\tilde{A}_1$ can be determined by defuzzification which locates the Best Non-fuzzy Performance (BNP) value. Thus, the BNP values of fuzzy number are calculated by using the center of area (COA) method as follows: (Moeinzadeh and Hajfathaliha, 2010)

$$\text{BNP}_i = \frac{[(c-a)+(b-a)]}{3} + a, \qquad \forall_i, \quad (2.11)$$

Definition 4. A matrix $\tilde{\mathbf{D}}$ is called a fuzzy matrix if at least one element is a fuzzy number (Buckley, 1985).

2.1.3 Linguistic variable:

Definition 1.A linguistic variable is the variable whose values are not expressed in numbers but words or sentences in a natural or artificial language, i.e., in terms of linguistic (Zadeh, 1975).The concept of a linguistic variable is very useful in dealing with situations, which are too complex or not well defined to be reasonably described in conventional quantitative expressions (Zimmermann, 1991). For example, 'weight' is a linguistic variable whose values are 'very low', 'low', 'medium', 'high', 'very high', etc. Fuzzy numbers can also represent these linguistic values.

2.1.4 The concept of generalized trapezoidal fuzzy numbers

By the definition given by (Chen, 1985), a generalized trapezoidal fuzzy number can be defined as $\tilde{A} = (a_1, a_2, a_3, a_4; w_{\tilde{A}})$, as shown in Fig. 2.3.

and the membership function $\mu_{\tilde{A}}(x): R \to [0,1]$ is defined as follows:

$$
\mu_{\tilde{A}}(x)=\begin{cases} \dfrac{x-a_1}{a_2-a_1}\times w_{\tilde{A}}, & x\in(a_1,a_2) \\ w_{\tilde{A}}, & x\in(a_2,a_3) \\ \dfrac{x-a_4}{a_3-a_4}\times w_{\tilde{A}}, & x\in(a_3,a_4) \\ 0, & x\in(-\infty,a_1)\cup(a_4,\infty) \end{cases} \tag{2.12}
$$

Here, $a_1 \le a_2 \le a_3 \le a_4$ and $w_{\tilde{A}} \in [0,1]$

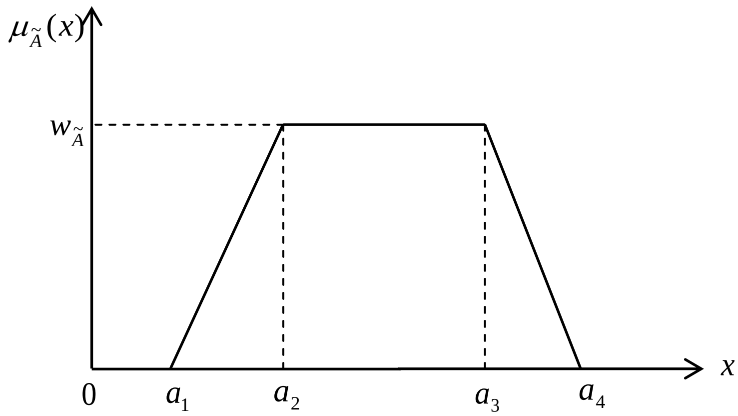

Fig. 2.3 Trapezoidal fuzzy number $\tilde{A}$

The elements of the generalized trapezoidal fuzzy numbers $x \in R$ are real numbers, and its membership function $\mu_{\tilde{A}}(x)$ is the regularly and continuous convex function, it shows that the membership degree to the fuzzy sets. If $-1 \le a_1 \le a_2 \le a_3 \le a_4 \le 1$, then $\tilde{A}$ is called the normalized trapezoidal fuzzy number. Especially, if $w_{\tilde{A}} = 1$, then $\tilde{A}$ is called trapezoidal fuzzy number (a_1, a_2, a_3, a_4); if $a_1 < a_2 = a_3 < a_4$, then $\tilde{A}$ is reduced to a triangular fuzzy number. If $a_1 = a_2 = a_3 = a_4$, then $\tilde{A}$ is reduced to a real number.

Suppose that $\tilde{a} = (a_1, a_2, a_3, a_4; w_{\tilde{a}})$ and $\tilde{b} = (b_1, b_2, b_3, b_4; w_{\tilde{b}})$ are two generalized trapezoidal fuzzy numbers, then the operational rules of the generalized trapezoidal fuzzy numbers $\tilde{a}$ and $\tilde{b}$ are shown as follows (Chen and Chen, 2009):

$$\tilde{a} \oplus \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{a}}) \oplus (b_1, b_2, b_3, b_4; w_{\tilde{b}}) =$$

$$(a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4; \min(w_{\tilde{a}}, w_{\tilde{b}})) \quad (2.13)$$

$$\tilde{a} - \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{a}}) - (b_1, b_2, b_3, b_4; w_{\tilde{b}}) =$$

$$(a_1 - b_4, a_2 - b_3, a_3 - b_2, a_4 - b_1; \min(w_{\tilde{a}}, w_{\tilde{b}})) \quad (2.14)$$

$$\tilde{a} \otimes \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{a}}) \otimes (b_1, b_2, b_3, b_4; w_{\tilde{b}}) =$$

$$(a, b, c, d; \min(w_{\tilde{a}}, w_{\tilde{b}})) \quad (2.15)$$

Here,

$$a = \min(a_1 \times b_1, a_1 \times b_4, a_4 \times b_1, a_4 \times b_4)$$

$$b = \min(a_2 \times b_2, a_2 \times b_3, a_3 \times b_2, a_3 \times b_3)$$

$$c = \max(a_2 \times b_2, a_2 \times b_3, a_3 \times b_2, a_3 \times b_3)$$

$$d = \max(a_1 \times b_1, a_1 \times b_4, a_4 \times b_1, a_4 \times b_4)$$

If $a_1, a_2, a_3, a_4, b_1, b_2, b_3, b_4$ are real numbers, then

$$\tilde{a} \otimes \tilde{b} = (a1 \times b1, a2 \times b2, a3 \times b3, a4 \times b4; \min(w_{\tilde{a}}, w_{\tilde{b}}))$$

$$\tilde{a} / \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{a}}) / (b_1, b_2, b_3, b_4; w_{\tilde{b}})$$

$$= (a_1 / b_4, a_2 / b_3, a_3 / b_2, a_4 / b_1; \min(w_{\tilde{a}}, w_{\tilde{b}})) \quad (2.16)$$

Chen and Chen (2003) proposed the concept of COG point of generalized trapezoidal fuzzy numbers, and suppose that the COG point of the generalized trapezoidal fuzzy number $\tilde{a} = (a_1, a_2, a_3, a_4; w_{\tilde{a}})$ is $(x_{\tilde{a}}, y_{\tilde{a}})$, then:

$$y_{\tilde{a}} = \begin{cases} \dfrac{w_{\tilde{a}} \times \left(\dfrac{a_3 - a_2}{a_4 - a_1} + 2 \right)}{6}, & if\ a_1 \neq a_4 \\ \dfrac{w_{\tilde{a}}}{2}, & if\ a_1 = a_4 \end{cases} \tag{2.17}$$

$$x_{\tilde{a}} = \frac{y_{\tilde{a}} \times (a_2 + a_3) + (a_1 + a_4) \times (w_{\tilde{a}} - y_{\tilde{a}})}{2 \times w_{\tilde{a}}} \tag{2.18}$$

2.2 Ranking of Fuzzy Numbers

The ranking methodology adapted here has been described as follows (Chou et al., 2011). Considering n normal fuzzy numbers $A_i, (i = 1,2,...,n)$, each with a trapezoidal membership function $f_{A_i}(x)$. The revised method performs pair-wise comparisons on the n fuzzy numbers. For each pair of fuzzy numbers, say A_1 and A_2, the pair-wise comparison is preceded as follows.

The maximizing set M and minimizing set G with membership function f_M is given as,

$$f_M(x) = \begin{cases} \left[(x - x_{\min}) \big/ (x_{\max} - x_{\min}) \right]^k, & x_{\min} \leq x \leq x_{\max} \\ 0, & Otherwise. \end{cases} \tag{2.19}$$

The minimizing set G is a fuzzy subset with membership function f_G is given as,

$$f_G(x) = \begin{cases} \left[(x_{\max} - x) \big/ (x_{\max} - x_{\min}) \right]^k, & x_{\min} \le x \le x_{\max} \\ 0, & Otherwise. \end{cases} \quad (2.20)$$

Here $x_{\min} = Inf\ S, x_{\max} = Sup\, S, S = U_{i=1}^{n} S_i, S_i = \{x / f_{A_i}(x) \succ 0\}$, and k is set to be 1. The revised ranking method defines the right utility values of each alternative A_i as:

$$u_{M_{i1}}(i) = \sup_x \left(f_M(x) \wedge f_{A_i^R}(x) \right), \ i = 1,2; \quad (2.21)$$

$$u_{G_{i2}}(i) = \sup_x \left(f_G(x) \wedge f_{A_i^R}(x) \right), \ i = 1,2. \quad (2.22)$$

The let utility values of each alternative A_i as:

$$u_{G_{i1}}(i) = \sup_x \left(f_G(x) \wedge f_{A_i^L}(x) \right), \ i = 1,2; \quad (2.23)$$

$$u_{M_{i2}}(i) = \sup_x \left(f_M(x) \wedge f_{A_i^L}(x) \right), \ i = 1,2. \quad (2.24)$$

The revised ranking method defines the total utility value of each fuzzy number A_i with index of optimism α as:

$$U_T^{\alpha}(i) = \frac{1}{2} \left[\alpha \{ u_{M_{i1}}(i) + 1 - u_{G_{i2}}(i) \} + (1 - \alpha) \{ u_{M_{i2}}(i) + 1 - u_{G_{i1}}(i) \} \right], \ i = 1,2. \quad (2.25)$$

The index of optimism (α) represents the degree of optimism of a decision-maker (Kim and Park, 1990; Liou and Wang, 1992; Wang and Luo, 2009). A larger α indicates a higher degree of optimism. More specifically, when $\alpha = 0$, the total utility value $u_T^0(A_i)$ representing a pessimistic decision-maker's viewpoint is equal to the total left utility value of A_i. Conversely, for an optimistic decision-maker, i.e. $\alpha = 1$, the total utility value $u_T^1(A_i)$ is equal to the total right utility value of A_i. For a moderate (neutral) decision-maker, with $\alpha = 0.5$, the total utility value of each fuzzy number A_i become

$$U_T^{1/2}(i) = \frac{1}{2}\left[\frac{1}{2}\{u_{M_{i1}}(i) + 1 - u_{G_{i2}}(i)\} + \frac{1}{2}\{u_{M_{i2}}(i) + 1 - u_{G_{i1}}(i)\}\right],\ i = 1,2. \tag{2.26}$$

The greater the $u_T^{\alpha}(A_i)$, the bigger the fuzzy number A_i and the higher it's ranking order.

As described by (Chou et al., 2011), if A_i is a normal trapezoidal fuzzy number, i.e. $A_i = (a_i, b_i, c_i, d_i; 1)$, the total utility value of each fuzzy number A_i can be written as:

$$u_T^{\alpha}(i) = \frac{1}{2}\left(\begin{array}{l}\alpha\left[\dfrac{d_i - x_{\min}}{d_i - c_i + x_{\max} - x_{\min}} + \dfrac{c_i - x_{\min}}{c_i - d_i + x_{\max} - x_{\min}}\right] + \\ (1-\alpha)\left[\dfrac{a_i - x_{\min}}{a_i - b_i + x_{\max} - x_{\min}} + \dfrac{b_i - x_{\min}}{b_i - a_i + x_{\max} - x_{\min}}\right]\end{array}\right) \tag{2.27}$$

2.3 VIKOR Method

There are numerous methods that aid managers in making decisions in conflicting situations where the decision has to be taken by considering various possibilities all having their 'pros and cons'. Of all, Multi-Criteria Decision Making (MCDM) methods are most popular among the organizational decision-making situations. Tong et al. (2007) gave comparative disadvantages of other methods over MCDM methods as:

- Many methods disregard variation in quality losses for multiple responses.
- Solution obtained from methods is calculated by individually optimizing each variable. Problems arise where the situation of variables having different direction of optimality.

- Some methods require very strong mathematical and statistical background.
- Not every situation can have optimality when using the conventional methods.

Even MCDM techniques are complex requiring both engineers and managers to take part in the decision-making. Engineers evaluate the situation having multi-criteria and alternatives mathematically. Now, it is the manager's part to consider the alternatives provided in the order of preference and chose the feasible alternative.

Human interpretation in situation of low and high is not sudden but of slow transition. This creates some vagueness and ambiguity in the information and each alternative may have its own advantages and drawbacks. Classical MCDM technique cannot handle these situations with indefinite information. To deal with such situations Zadeh (1965; 1975; 1976) proposed that key elements in human thinking are not numbers but of fuzzy sets. Fuzzy set theory a powerful tool to deal with these fuzzy and inexplicit data than the conventional mathematics.

The **VlsekriterijumskaOptimizacija I KompromisnoResenje** (i.e. **VIKOR**) was developed by (Opricovic, 1998; Opricovic and Tzeng, 2002) for optimization of complex problems with conflicting and non-commensurable criteria striving for compromise ranking order. This method introduces ranking index based on particular measure of closeness to the ideal solution (Opricovic and Tzeng, 2004). The multi-criteria measure for compromise ranking is developed from the L_p-*metric* used as an aggregating function in a compromise programming method (Yu, 1973; Zeleny, 1982).

$$L_{Pi} = \left\{ \sum_{j=1}^{n} \left[w_j \left(f_j^* - f_{ij} \right) / \left(f_j^* - f_j^- \right)^P \right] \right\}^{1/P} \qquad (2.28)$$

Here, $1 \le P \le \infty; j = 1,...,n,$ with respect to criteria and the variable $i = 1,...,m,$ represent the number of alternatives such as $A_{1,} A_{2,} .....A_m$. For alternative A_i, the calculated value of the jth criterion is denoted by f_{ij}, and n is the number of criteria. The measure L_{Pi} shows the distance between alternative A_i and positive-ideal solution. Within the VIKOR method L_{1i} and $L_{\infty i}$ has been used to formulate ranking measure. The value obtained by minimum S_i is with a maximum group utility ('majority' rule) and the solution obtained by minimum R_i is with a minimum individual regret of the 'opponent' (Sanayei et al., 2010).

The compromise ranking traditional VIKOR algorithm consists following steps (Chang, 2010):

Step 1: Compute the positive-ideal solutions (best) value f_j^* and negative-ideal solutions (worst) value f_j^- for all criterion ratings (Wu and Liu, 2011; Kannan et al., 2009):

$$f_j^* = \begin{cases} \max\limits_{i=1,\dots,m} f_{ij}, & j \in C_1 \\ \min\limits_{i=1,\dots,m} f_{ij}, & J \in C_2 \end{cases} \quad \text{Fuzz best value} \tag{2.29}$$

$$f_j^- = \begin{cases} \min\limits_{i=1,\dots,m} f_{ij}, & j \in C_1 \\ \max\limits_{i=1,\dots,m} f_{ij}, & J \in C_2 \end{cases} \quad \text{Fuzzy worst value} \tag{2.30}$$

Here, $j = 1,\dots,n$ and C_1 is a benefit type criteria set, C_2 is a cost type criteria set.

Step 2: Compute the values of S_i and R_i $(i = 1,\dots,m)$, by using the relations:

$$S_i = \sum_{j=1}^{n} w_j \left(f_j^* - f_{ij}\right) / \left(f_j^* - f_j^-\right), \tag{2.31}$$

$$R_i = \max_{j=1,\dots,n} \left[w_j \left(f_j^* - f_{ij}\right) / \left(f_j^* - f_j^-\right)\right] \tag{2.32}$$

Here, S_i is the aggregated value of i^{th} alternatives with a maximum group utility and R_i is the aggregated value of i^{th} alternatives with a minimum individual regret of 'opponent'. w_j is the fuzzy weighted average of each criterion.

Step 3: Compute the values Q_i for $i = 1,\dots,m$ with the relation,

$$Q_i = \nu\left(S_i - S^*\right)/\left(S^- - S^*\right) + (1-\nu)\left(R_i - R^*\right)/\left(R^- - R^*\right) \tag{2.33}$$

Here, $S^* = \min_{i=1,\ldots,m} S_i, S^- = \max_{i=1,\ldots,m} S_i, R^* = \min_{i=1,\ldots,m} R_i, R^- = \max_{i=1,\ldots,m} R_i$ and ν is a weight for the decision making strategy of maximum group utility, and $\nu = 0.5$ where as $1-\nu$ is the weight of individual regret. The compromise can be selected with 'voting by majority' ($\nu > 0.5$), with 'consensus' ($\nu = 0.5$), with 'veto' ($\nu < 0.5$).

Step 4: Rank the alternatives by sorting each $S, R,$ and Q values in ascending order.

Step 5: If following two conditions are satisfied simultaneously, then the scheme with minimum value of Q in ranking is considered the optimal compromise solution. Such as,

C1. The alternative $Q\left(A^{(1)}\right)$ has an acceptable advantage; in other words,

$$Q\left(A^{(2)}\right) - Q\left(A^{(1)}\right) \geq 1/(m-1).$$

Here, $A^{(2)}$ is the alternative with second position in the ranking list by and m is the number of alternatives.

C2. The alternative $Q\left(A^{(1)}\right)$ is stable within the decision making process; in other words, it is also best ranked in S_i and R_i.

If condition C1 is not satisfied, that means $Q\left(A^{(m)}\right) - Q\left(A^{(1)}\right) < 1/(m-1)$, then alternatives $A^{(1)}$, $A^{(2)}$......$A^{(m)}$ all are the same compromise solution, there is no comparative advantage of $A^{(1)}$ from others. But for the case of maximum value, the corresponding alternative is the compromise (closeness) solution. If condition C2 is not satisfied, the stability in decision making is deficient while $A^{(1)}$ has comparative advantage. Therefore, $A^{(1)}$ and $A^{(2)}$ has same compromise solution.

Step 6: Select the best alternative by choosing $Q\left(A^{(m)}\right)$ as a best compromise solution with minimum value of Q_i and must have to satisfy with the above conditions (Park et al., 2011).

Chapter 3: Supply Chain Risk Assessment Module

3.1 Understanding of Risk

A. Risk Factors

Given an unfavorable event (danger, or threat) E [Damiani, 2011]:

Risk (E) = Probability (E)*Impact (E)

• Unfavorable external events that can affect a supply chain include

– Volatility of demand

– Technological or market dependencies

– Supplier concentration

– Scarce sources

– Issues related to the social and natural environment

– Security: related external events related to the chain's IT support must be considered, such as intrusions and viruses.

Traditionally, much attention has been given to risk factors *external* to the chain, and risk assessment based on a qualitative evaluation of the probabilities and impacts.

B. Threats to SC operation

A number of forces are increasing the probability and impact of supply chain disruptions:

– Increased use of contract manufacturing and other forms of outsourcing

– More demanding customers/consumers

– Reliance on sole suppliers for key raw materials

– Increased competition

– Trend toward increased regulation

– More unpredictable threats

Risks in SCM are inevitable and proper care must be taken to mitigate them. The main aim of the Supply Chain Risk Management is to check the optimality for both efficiency and risk. Its aim is to subdue risks, so that they don't affect the proper functionality of SC. It means decreasing the vulnerability of a supply chain, increasing its ability to withstand unexpected issues, improving sustainability or increasing resilience.

In this context an attempt has been made to analyze the affect of different risks involved in SC classified by [Berenji and Anantharaman, 2011]. Supply chain risks have been classified majorly into six categories viz. ***Supply risks***, ***Demand risks***, ***Operational risks***, ***Social/political risks***, ***Competitive/economic risks***, and ***control and plan risks***.

3.2 Proposed Risk Assessment Module: Case Study

Procedural steps of supply chain risk assessment module have been highlighted below.

Step 1: Formation of a group of experts (Decision-Makers "i.e.," DMs) for evaluating and assessing of supply chain risk.

Step 2: Selection of appropriate linguistic scale to represent DMs' subjective judgment in relation to likelihood of occurrence (probability) against each risk factors and at the same time to express their impact.

Step 3: Assignment of probability as well as impact of various risk indices using linguistic terms.

Step 4: Approximation of DMs' subjective judgment (in linguistic terms) by Generalized Trapezoidal Fuzzy Numbers (GTFNs).

Step 5: Estimation of SC overall risk extent.

Step 6: Categorization of various risks; identification of major risk prone areas which need future improvement.

Aforesaid appraisement module has been adopted as case application in an *Indian famous automobile part manufacturing industry in Eastern part of India*. A two-level assessment hierarchy consisting of various risk indices has been designed as shown in Table 3.1.

For collecting expert opinion in relation to likelihood of occurrence (for each risk indices) at 2^{nd} level, a committee of five decision-makers (DMs), has been formed to express their subjective preferences in linguistic terms (Table 3.2). Similarly, the decision-making group has also been instructed to use the linguistic scale (as shown in Table 3.2) to express their subjective judgment on impact against each 2^{nd} level risk indices.

The risk impact of individual 2^{nd} level risk indices (in linguistic term) as given by the decision-making group has been furnished in Table 3.3. Also, the likelihood of occurrence against individual 2^{nd} level risk indices (in linguistic term) as given by the decision-making group has been furnished in Table 3.4.

Using the concept of fuzzy set theory, the linguistic variables have been approximated by Generalized Trapezoidal Fuzzy Numbers (GTrFNs). Next, the aggregated decision-making cum evaluation matrix has been constructed. The aggregated fuzzy risk impact (RI) against individual indices with corresponding likelihood of occurrence (LO) has been computed for the said supply chain. Aggregated fuzzy likelihood of occurrence as well as aggregated fuzzy risk impact corresponding to various 2^{nd} level risk indices have been shown in Table 3.5.

FRE represents the *Fuzzy Risk Extent*. The fuzzy risk extent has been calculated first at the 2^{nd} level, and then extended to the 1^{st} level indices.

Considering a 2-level general assessment system hierarchy for SC risk evaluation; the following notations need to be used for computational purpose.

C_i = i^{th} 1st level risk index (Cause of Risk/ Source of Risk); $i = 1,2,...,m.$

C_{ij} = j^{th} 2nd level risk index which is under i^{th} 1st level risk index C_i; $j = 1,2,...,n.$

The fuzzy risk extent of each of the 2nd level risk sources can be calculated as follows:

$$RE_{ij} = \left(LO_{ij} \otimes RI_{ij}\right) \tag{3.1}$$

Here RI_{ij} represents aggregated fuzzy risk impact; LO_{ij} represents aggregated fuzzy likelihood of occurrence corresponding to risk index C_{ij} at 2nd level. Here, RE_{ij} represents the computed risk extent corresponding to risk index C_{ij} at 2nd level.

The computed fuzzy risk extent of each of the 1st level evaluation indices can be calculated as follows:

$$RE_i = \frac{1}{n}\sum_{j=1}^{n}\left(LO_{ij} \otimes RI_{ij}\right) \tag{3.2}$$

Here RI_{ij} represents or aggregated impact and LO_{ij} represents aggregated fuzzy likelihood of occurrence corresponding to risk index C_{ij} at 2nd level. Also, RE_i represents the computed aggregated risk extent corresponding to the risk index C_i at 1st level.

Thus, overall fuzzy aggregated risk extent of the said supply chain $RE|_{SC}$ can be obtained as follows.

$$RE|_{SC} = \frac{1}{m}\sum_{i=1}^{m}(RE_i) \tag{3.3}$$

Here RE_i = risk impact of i^{th} 1st level risk index C_i as computed from Eq. (3.2).

Table 3.6 shows computed fuzzy risk extent of individual 1st level risk indices.

The $RE|_{SC}$ thus becomes: **(2.1254, 3.1748, 3.7475, 5.0380)** for the said SC under consideration.

After evaluating $RE|_{SC}$, simultaneously it is felt indeed necessary to identify and analyze major risk indices (sources) in which organizational SC may require future attention to mitigate risk extent. Therefore, 2nd level risk sources have been ranked in accordance with individual fuzzy risk extent RE_{ij}. The concept of fuzzy numbers ranking using '*Maximizing Set and Minimizing Set*' [Chou et al., 2011] has been adapted to identify (ranking) major risk prone areas. According to the aforesaid theory, fuzzy numbers can be ranked on the basis of total utility degree U_T^{α}. In this computation, three types of risk bearing attitude (α=0, 0.5, 1; for pessimistic, neutral and optimistic decision-maker) of the decision-making group have been analyzed.

The particular risk source, corresponds to higher value of total utility degree is assumed to be risk prone at higher side (major risk); it indicates major impact and high ranking order). According to the descending order of the total utility values; the ranking order of various risk sources/ indices has been determined (Table 3.7; Fig. 3.1 and 3.2).

3.3 Concluding Remarks

In today's world, supply chain risk management (SCRM) is a key strategic factor for increasing organizational effectiveness and for better realization of organizational goals such as enhanced competitiveness, better customer care and increased profitability. The era of both globalization of markets and outsourcing has begun, and many companies select supply chain and logistics to manage their operations. Most of these companies realize that, in order to evolve an efficient and effective supply chain, SC risks needs to be identified, evaluated and mitigated for its improved performance. In this context, present study attempts to develop an efficient fuzzy based assessment module for supply chain risk management. The theory behind fuzzy numbers set has been fruitfully explored in the aforesaid decision modeling.

Table 3.1: Supply Chain Risk Assessment Model

Goal, C	1st level indices, C_i	2nd level indices, C_{ij}
(SC risk assessment)	Supply Risks, C_1	Materials Quality, C_{11}
		Supplier Satiation, C_{12}
		Global Sourcing, C_{13}
		Exclusive Supplier, C_{14}
		Delivery Times, C_{15}
		Cargo Damages, C_{16}
		Bankruptcy of Suppliers, C_{17}
	Demand Risks, C_2	Sale Withdrawal, C_{21}
		Market Demand Changes, C_{22}
		After Sale Services, C_{23}
		Changes in Product Preference, C_{24}
		Non-Flexibility, C_{25}
	Operations Risks, C_3	Changes by Employer, C_{31}
		Changing Production Technology, C_{32}
		Human Error, C_{33}
		Sharing Comments among Departments, C_{34}
		Changes in Product Design and Engineering, C_{35}
		Operation Quality, C_{36}
	Social/Political Risks, C_4	Agreement Terms and Type, C_{41}
		Losing Personnel, C_{42}
		Grey Propaganda in Public, C_{43}
		Sociopolitical Lobby, C_{44}
		Sanctions, C_{45}
		Controlling Export/Import, C_{46}
		Custom Delays and Damages, C_{47}
	Competitive/Economic Risks, C_5	Inflation Rate, C_{51}
		Partners Bankruptcy, C_{52}
		Stock Market Crash, C_{53}
		Exchange Rate, C_{54}

		Financial Crisis, C_{55}
	Control and Plan Risks, C_6	Information Flow and Information Systems, C_{61}
		Control Tool and Methods, C_{62}
		Crashes and/or Changes in Planning, C_{63}

Table 3.2: Definitions of linguistic variables for expert judgment (A-7 member linguistic term set)

Extent of Risk Impact (RI)			Likelihood of Occurrence (LO)		
Fuzzy numbers	Terms	Notation	Fuzzy numbers	Terms	Notation
(0, 0, 1, 2)	Very Low Risk	VL	(0, 0, 0.1, 0.2)	Very Very Rare	VVR
(1, 2, 2, 3)	Low Risk	L	(0.1, 0.2, 0.2, 0.3)	Very Rare	VR
(2, 3, 4, 5)	Fairly Risky	FR	(0.2, 0.3, 0.4, 0.5)	Rare	R
(4, 5, 5, 6)	Risky	R	(0.4, 0.5, 0.5, 0.6)	Slightly Rare	SR
(5, 6, 7, 8)	Highly Risky	HR	(0.5, 0.6, 0.7, 0.8)	Seldom	S
(7, 8, 8, 9)	Very High Risk	VH	(0.7, 0.8, 0.8, 0.9)	Frequent	F
(8, 9, 10, 10)	Extremely High Risk	EH	(0.8, 0.9, 1, 1)	Very Frequent	VF

Table 3.3: Risk Impact of 2nd level indices assigned by the DMs using linguistic terms

2nd level indices, C_{ij}	Risk Impact of 2nd level indices assigned by the DMs using linguistic terms				
	DM1	DM2	DM3	DM4	DM5
C_{11}	FR	FR	R	FR	R
C_{12}	HR	R	FR	FR	HR
C_{13}	R	R	R	R	FR
C_{14}	VH	EH	VH	VH	VH
C_{15}	FR	L	L	FR	R
C_{16}	R	R	R	R	R
C_{17}	HR	HR	HR	R	HR
C_{21}	R	FR	FR	FR	FR
C_{22}	L	FR	L	L	FR
C_{23}	R	R	R	R	FR
C_{24}	VH	EH	EH	VH	VH
C_{25}	FR	FR	FR	FR	R
C_{31}	HR	HR	R	R	HR
C_{32}	L	FR	L	FR	L
C_{33}	R	R	HR	R	R
C_{34}	HR	HR	HR	HR	HR
C_{35}	L	L	L	L	FR
C_{36}	L	FR	R	FR	FR
C_{41}	R	R	R	R	FR
C_{42}	FR	FR	L	FR	R
C_{43}	R	R	R	R	R
C_{44}	HR	R	HR	R	HR
C_{45}	R	FR	FR	FR	FR
C_{46}	L	FR	L	L	L
C_{47}	R	R	FR	R	FR
C_{51}	R	R	R	R	R
C_{52}	HR	HR	HR	R	HR
C_{53}	R	FR	FR	R	FR

C_{54}	L	FR	L	L	FR
C_{55}	R	R	R	R	FR
C_{61}	VH	EH	EH	HR	VH
C_{62}	FR	FR	FR	FR	R
C_{63}	FR	R	FR	R	FR

Table 3.4: Likelihood of occurrence of 2nd level indices assigned by the DMs using linguistic terms

2nd level indices, C_{ij}	Likelihood of occurrence of 2nd level indices assigned by the DMs using linguistic terms				
	DM1	DM2	DM3	DM4	DM5
C_{11}	F	S	S	F	S
C_{12}	VF	S	F	F	F
C_{13}	SR	F	F	F	S
C_{14}	S	S	S	S	F
C_{15}	SR	S	SR	S	F
C_{16}	F	F	S	F	S
C_{17}	VF	F	S	S	F
C_{21}	SR	S	F	F	S
C_{22}	S	S	S	S	F
C_{23}	SR	S	S	S	F
C_{24}	F	S	F	F	S
C_{25}	VF	F	F	F	F
C_{31}	SR	S	F	F	S
C_{32}	S	S	S	S	F
C_{33}	S	S	S	S	F
C_{34}	F	F	S	F	S
C_{35}	S	F	S	F	F
C_{36}	SR	S	F	F	S
C_{41}	S	S	F	S	F
C_{42}	F	F	S	F	S
C_{43}	VF	VF	F	F	F
C_{44}	SR	S	F	F	S

C_{45}	S	S	S	S	F
C_{46}	S	S	S	S	F
C_{47}	F	F	S	F	S
C_{51}	F	S	F	F	S
C_{52}	VF	F	F	F	F
C_{53}	S	S	F	F	F
C_{54}	S	S	S	S	F
C_{55}	S	S	S	S	F
C_{61}	F	F	F	F	S
C_{62}	S	F	S	F	F
C_{63}	F	S	F	F	S

Table 3.5: Aggregated fuzzy likelihood of occurrence as well as risk impact of 2nd level indices

2nd level indices, C_{ij}	Aggregated risk impact, RI_{ij}	Aggregated fuzzy likelihood of occurrence, LO_{ij}
C_{11}	(2.8,3.8,4.4,5.4)	(0.58,0.68,0.74,0.84)
C_{12}	(3.6,4.6,5.4,6.4)	(0.68,0.78,0.82,0.90)
C_{13}	(3.6,4.6,4.8,5.8)	(0.60,0.70,0.72,0.82)
C_{14}	(7.2,8.2,8.4,9.2)	(0.54,0.64,0.72,0.82)
C_{15}	(2.0,3.0,3.4,4.4)	(0.50,0.60,0.64,0.74)
C_{16}	(4.0,5.0,5.0,6.0)	(0.62,0.72,0.76,0.86)
C_{17}	(4.8,5.8,6.6,7.6)	(0.64,0.74,0.80,0.88)
C_{21}	(2.4,3.4,4.2,5.2)	(0.56,0.66,0.70,0.80)
C_{22}	(1.4,2.4,2.8,3.8)	(0.54,0.64,0.72,0.82)
C_{23}	(3.6,4.6,4.8,5.8)	(0.52,0.62,0.68,0.78)
C_{24}	(7.4,8.4,8.8,9.4)	(0.62,0.72,0.76,0.86)
C_{25}	(2.4,3.4,4.2,5.2)	(0.72,0.82,0.84,0.92)
C_{31}	(4.6,5.6,6.2,7.2)	(0.56,0.66,0.70,0.80)
C_{32}	(1.4,2.4,2.8,3.8)	(0.54,0.64,0.72,0.82)
C_{33}	(4.2,5.2,5.4,6.4)	(0.54,0.64,0.72,0.82)
C_{34}	(5.0,6.0,7.0,8.0)	(0.62,0.72,0.76,0.86)
C_{35}	(1.2,2.2,2.4,3.4)	(0.62,0.72,0.76,0.86)
C_{36}	(2.2,3.2,3.8,4.8)	(0.56,0.66,0.70,0.80)
C_{41}	(3.6,4.6,4.8,5.8)	(0.58,0.68,0.74,0.84)
C_{42}	(2.2,3.2,3.8,4.8)	(0.62,0.72,0.76,0.86)
C_{43}	(4.0,5.0,5.0,6.0)	(0.74,0.84,0.88,0.94)
C_{44}	(4.6,5.6,6.2,7.2)	(0.56,0.66,0.70,0.80)
C_{45}	(2.4,3.4,4.2,5.2)	(0.54,0.64,0.72,0.82)
C_{46}	(1.2,2.2,2.4,3.4)	(0.54,0.64,0.72,0.82)
C_{47}	(3.2,4.2,4.6,5.6)	(0.62,0.72,0.76,0.86)
C_{51}	(4.0,5.0,5.0,6.0)	(0.62,0.72,0.76,0.86)
C_{52}	(4.8,5.8,6.6,7.6)	(0.72,0.82,0.84,0.92)
C_{53}	(2.8,3.8,4.4,5.4)	(0.62,0.72,0.76,0.86)

C_{54}	(1.4,2.4,2.8,3.8)	(0.54,0.64,0.72,0.82)
C_{55}	(3.6,4.6,4.8,5.8)	(0.54,0.64,0.72,0.82)
C_{61}	(7.0,8.0,8.6,9.2)	(0.66,0.76,0.78,0.88)
C_{62}	(2.4,3.4,4.2,5.2)	(0.62,0.72,0.76,0.86)
C_{63}	(2.8,3.8,4.4,5.4)	(0.62,0.72,0.76,0.86)

Table 3.6: Computed risk extent of 1st level indices

1st level indices, C_i	Computed fuzzy aggregated risk extent, RE_i
C_1	(2.3817,3.4760,4.0634,5.3857)
C_2	(2.0576,3.0936,3.6872,4.9336)
C_3	(1.7793,2.7627,3.3413,4.6280)
C_4	(1.8451,2.8480,3.3468,4.6097)
C_5	(2.0744,3.1144,3.6320,4.9336)
C_6	(2.6147,3.7547,4.4147,5.7373)

Table 3.7: Ranking of various risk sources/indices (at 2nd level)

2nd level indices, C_{ij}	Fuzzy Risk Extent ($RE_{ij}=LO_{ij}*RI_{ij}$)	Ranking based on Overall Utility Degree					
		Optimistic α=1		Moderate α=0.5		Pessimistic α=0	
		Crisp value	Ranking order	Crisp value	Ranking order	Crisp value	Ranking order
C_{11}	(1.624,2.584,3.256,4.536)	0.434145	21	0.529317	22	0.095172	22
C_{12}	(2.448,3.588,4.428,5.760)	0.600142	7	0.757064	10	0.156923	12
C_{13}	(2.160,3.220,3.456,4.756)	0.463163	18	0.597913	15	0.134749	14
C_{14}	(3.888,5.248,6.048,7.544)	0.839139	3	1.102751	3	0.263612	3
C_{15}	(1.000,1.800,2.176,3.256)	0.272883	28	0.321038	28	0.048155	28
C_{16}	(2.480,3.600,3.800,5.160)	0.515001	12	0.673512	11	0.158511	10
C_{17}	(3.072,4.292,5.280,6.688)	0.724455	6	0.926857	6	0.202402	6
C_{21}	(1.344,2.244,2.940,4.160)	0.386592	25	0.460961	25	0.074369	25
C_{22}	(0.756,1.536,2.016,3.116)	0.252112	29	0.283142	29	0.03103	30
C_{23}	(1.872,2.852,3.264,4.524)	0.433931	22	0.546618	21	0.112687	18
C_{24}	(4.588,6.048,6.688,8.084)	0.919407	2	1.235451	2	0.316045	2
C_{25}	(1.728,2.788,3.528,4.784)	0.47015	15	0.575299	18	0.105149	19
C_{31}	(2.576,3.696,4.340,5.760)	0.594465	8	0.75957	8	0.165105	8
C_{32}	(0.756,1.536,2.016,3.116)	0.252112	29	0.283142	29	0.03103	30
C_{33}	(2.268,3.328,3.888,5.248)	0.527223	11	0.669373	13	0.14215	13
C_{34}	(3.100,4.320,5.320,6.880)	0.742654	5	0.946987	5	0.204333	5
C_{35}	(0.744,1.584,1.824,2.924)	0.225758	32	0.257624	32	0.031866	29
C_{36}	(1.232,2.112,2.660,3.840)	0.345477	27	0.411654	27	0.066177	27
C_{41}	(2.088,3.128,3.552,4.872)	0.477821	14	0.607045	14	0.129224	15
C_{42}	(1.364,2.304,2.888,4.128)	0.380689	26	0.457549	26	0.076861	24
C_{43}	(2.960,4.200,4.400,5.640)	0.589484	10	0.784799	7	0.195316	7
C_{44}	(2.576,3.696,4.340,5.760)	0.594465	8	0.75957	8	0.165105	8
C_{45}	(1.296,2.176,3.024,4.264)	0.399469	24	0.470004	24	0.070534	26
C_{46}	(0.648,1.408,1.728,2.788)	0.210297	33	0.233446	33	0.023148	33
C_{47}	(1.984,3.024,3.496,4.816)	0.470058	16	0.592162	16	0.122103	16

C_{51}	(2.480,3.600,3.800,5.160)	0.515001	12	0.673512	11	0.158511	10
C_{52}	(3.456,4.756,5.544,6.992)	0.764565	4	0.996146	4	0.231582	4
C_{53}	(1.736,2.736,3.344,4.644)	0.447653	19	0.551627	19	0.103973	20
C_{54}	(0.756,1.536,2.016,3.116)	0.252112	29	0.283142	29	0.03103	30
C_{55}	(1.944,2.944,3.456,4.756)	0.463163	17	0.581357	17	0.118193	17
C_{61}	(4.620,6.080,6.708,8.096)	0.921458	1	1.239737	1	0.318279	1
C_{62}	(1.488,2.448,3.192,4.472)	0.425291	23	0.511179	23	0.085888	23
C_{63}	(1.736,2.736,3.344,4.644)	0.447653	19	0.551627	19	0.103973	20

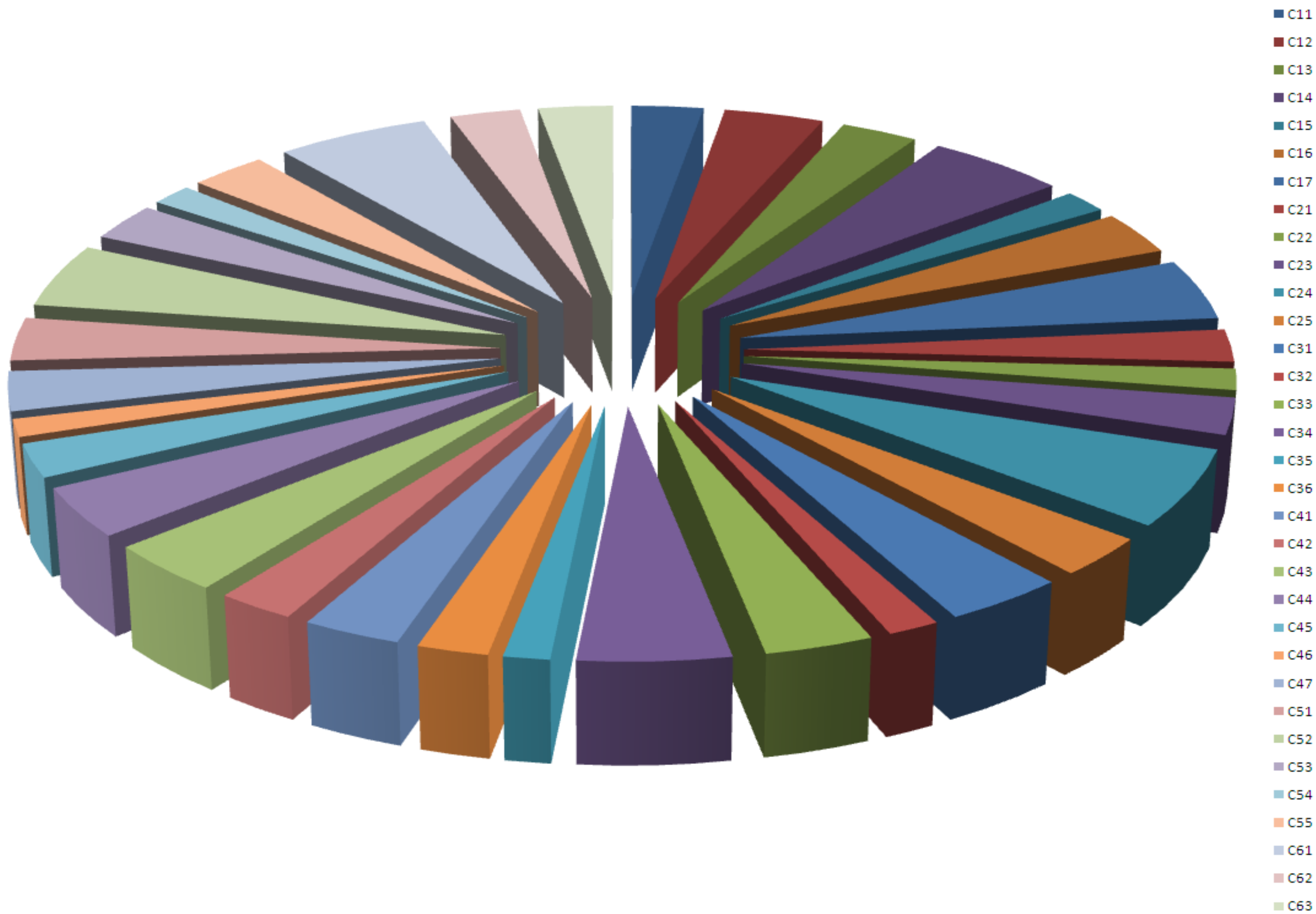

Fig. 3.1 Pictorial representation on ranking of various risk indices (at 2nd level)

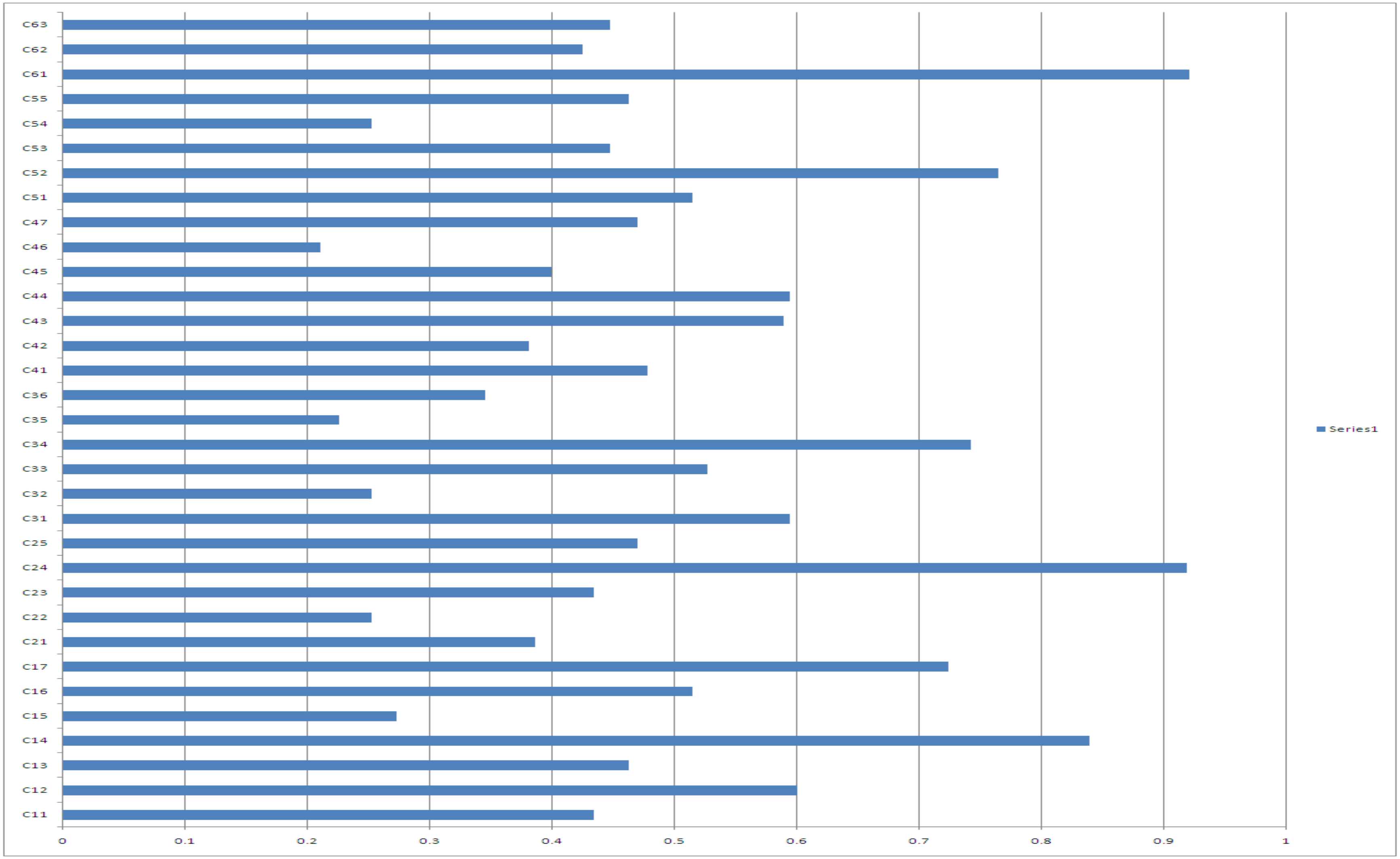

Fig. 3.2 Bar diagram representing ranking order of various risk indices (at 2nd level)

Chapter 4:
Suppliers Selection Considering Suppliers Risk

4.1 Supplier Selection by VIKOR Method

Supplier selection is a multi-criteria decision making (MCDM) problem. Different methods like Analytical Hierarchy Process (AHP), Analytical Network Process (ANP), TOPSIS method etc. have been applied in literature towards supplier selection decision-modeling. Here VIKOR method has been applied for the selection of suppliers. VIKOR method was developed to solve multi-criteria decision problems with conflicting ideas and completely different aspect in the criteria. This method indents to rank and obtain a compromise solution based on the given criteria. VIKOR method determines the feasible solution which is closest to the ideal solution and farthest from the worst solution or negative ideal solution. Compromise solution thus obtained could be accepted by the decision makers because it provides a maximum group utility for majority and a minimum individual regret for opponent. The compromise solutions could be the base for negotiation, involving the decision makers' preference by criteria weights (Opricovic and Tzeng, 2007).

4.2 Proposed Suppliers Selection Module

Based on concept of fuzzy set theory and VIKOR method, the proposed fuzzy-VIKOR method has been applied to find the best compromise solution under multi-person, multi-criteria decision making supplier selection problem. Usually, decision making problems are dealing with some alternatives which can be ranked, with respect to the distinct criteria. Ratings of the alternatives and the weights of each criterion are the two most significant data which can effect on the results of decision making problems. Therefore, the proposed methodology has been used here, to calculate the definite weight of criteria and ranking of the alternatives. In this chapter, the importance weights of various criteria and ratings of qualitative criteria are measured as linguistic variables, because linguistic assessment can only have a capability to approximate the subjective judgment through decision maker's opinion. Moreover, linear triangular membership functions are considered for capturing the vagueness of these linguistic assessments. The definition of triangular fuzzy membership functions and its corresponding fuzzy numbers with operational rules have been described in **Chapter 2**. The proposed algorithm consists of following steps:

Step 1: *Make a list of feasible alternatives, find the evaluation criteria, and constitute a group of decision makers.* Suppose, there are k decision makers $(D_t, t = 1,...,k)$, whom are responsible for assessing m alternatives $(A_i, i = 1,..., m)$, with respect to the importance of each of the n criteria, $(C_j, = 1,..., n)$.

Step 2: *Identify appropriate linguistic variables and their positive triangular fuzzy numbers.* Linguistic variables are used to calculate the importance weights of criteria and the ratings of the alternatives with respect to distinct criteria.

Step 3: *Construct a fuzzy decision matrix by pulling the decision makers' opinions to get the aggregated fuzzy weight of criteria, and the aggregated fuzzy rating of alternatives.*

Let k is the number of decision makers in a group and, the aggregated fuzzy weight ($\tilde{w}_j$) with respect to each criterion can be calculated as:

$$\tilde{w}_j = \frac{1}{k}\left[\tilde{w}_{j1} \oplus \tilde{w}_{j2} \oplus .... \oplus \tilde{w}_{jk}\right]. \tag{4.1}$$

And also the aggregated fuzzy ratings ($\tilde{x}_{ij}$) of alternatives with respect to each criterion can be calculated as:

$$\tilde{x}_{ij} = \frac{1}{k}\left[\tilde{x}_{ij1} \oplus \tilde{x}_{ij2} \oplus .... \oplus \tilde{x}_{ijk}\right]. \quad (4.2)$$

In supplier selection problem, the value of aggregated weights and ratings are expressed in matrix format as follows:

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix}, \tilde{W} = \left[\tilde{w}_1 \quad \tilde{w}_2 \quad \cdots \quad \tilde{w}_n\right],$$

$i = 1,..., m$ for alternatives, and $j = 1,..., n,$ for criteria

Step 4: Defuzzify the fuzzy decision matrix and fuzzy weight of each criterion in to crisp values using the relation BNP_i based on Centre of Area method of defuzzification given by the equation,

$$BNP_i = \frac{[(c-a)+(b-a)]}{3} + a, \qquad \forall_i, \quad (4.3)$$

Step 5: Determine best rating (crisp value) $\left(f_j^*\right)$ and worst rating (crisp value) $\left(f_j^-\right)$ for all criterion ratings, $(j = 1,..., n)$ by using the relations:

$$\left(f_j^*\right) = \max_i \tilde{x}_{ij}, \quad . \left(f_j^-\right) = \min_i \tilde{x}_{ij}, \quad (4.4)$$

Step 6: Compute the values utility measure or better avg. score' S_i 'and regret measure or worse group score ' R_i 'given by the equations as,

$$S_i = \sum_{j=1}^{n} w_j \left(f_j^* - f_{ij}\right) / \left(f_j^* - f_j^-\right), \quad (4.5)$$

$$R_i = \max_{j=1,...,n} \left[w_j \left(f_j^* - f_{ij}\right) / \left(f_j^* - f_j^-\right)\right] \quad (4.6)$$

Step 7: Compute the values Q_i using equations defined as,

$$Q_i = v\left(S_i - S^*\right)/\left(S^- - S^*\right) + (1-v)\left(R_i - R^*\right)/\left(R^- - R^*\right) \quad (4.7)$$

Step 8: Rank the alternatives by sorting each $S, R,$ and Q values in ascending order.

Step 9: Select the best alternatives as a compromise solution by referring ***Step 5*** given in VIKOR method.

4.3 Numerical Illustration

The proposed supplier selection approach has been made in following steps:

Step 1: Company has to select a suitable supplier from shortlisted four suppliers from a pool of suppliers. These four suppliers are given by S_1, S_2, S_3, and S_4. Here, the evaluating criteria for the selection of suppliers are their extent of risk and how can the cope with them. Risk sources (Table 4.1) in relation to suppliers' performance here considered are (Shemshadi et al., 2011):

C_1 :Capacity constraints

C_2 :Cost reduction capabilities

C_3 :Lead time

C_4 :Environmental performance,

C_5 :Financial health,

C_6 :Failure to meet delivery requirements

C_7 :Inbound transportation

C_8 :Information systems compatibility and sophisticated inventory management

C_9 :Management vision

C_{10} :Process technology changes

C_{11} : Volume and mix requirement changes

Five decision makers D_1, D_2, D_3, $D_{4,}$ and D_5 have been grouped to resolve the problems of entire selection process.

Step 2: Decision-makers used five scale linguistic variables for probability assessment and impact shown in Table 4.2 and seven scale linguistic variables for giving the weight rating of the risks (Table 4.3). Priority weights (in linguistic term) assigned by the Decision-makers group have been given by the Table 4.4. The risk impacts given by the decision-makers group have been shown in Table 4.5. The likelihood or probability of occurrence of risks assigned by the decision-makers has been shown in Table 4.6. The priority weights assigned by decision-makers have been represented by fuzzy numbers and aggregated fuzzy weights have been furnished in Table 4.7.

Step 3: The aggregated fuzzy weight ($\tilde{w}_j$) of each criterion and aggregated risk impact of each criterion against suppliers $(\tilde{x}_{ij})$ have been calculated next.

Step 4: Then these both the aggregated fuzzy weights and aggregated risk impact have been multiplied to get the Risk Extent of the each criterion against the respective suppliers (Table 4.8).

Step 5: Compute the crisp values of this risk extent matrix and the aggregated weights shown in the Table 4.8.

Step 6: Best and worst fuzzy Risk Extent or generally ratings have been determined from the crisp values as shown in Table 4.9. Next compute the values of S, R and Q for all suppliers and shown in Table 4.10.

Step 7: Maximum of R and S have been given in the Table 4.10 and Table 4.11 shows the ranking of suppliers via S, R and Q in ascending order has been shown in Table 4.12.

Step 8: From Table 4.12, it can be concluded that the suppliers S_1 ranked one in Q and R or/and S being which it satisfies both the conditions C_1 and C_2 meaning supplier S_1 has competitive advantage compared to other suppliers.

4.4 Concluding Remarks

Supplier selection is an important task in the process of whole purchasing process. Studies say that organisations spend approximately 40-50% of their expenditure on procuring raw materials on manufacturing industries. Hence it has a great impact over the expenditure and as a result on the profit. A little saved in time or money spent in acquiring raw materials can result in considerable savings overall. Also the impact of risk on the supplier will directly impact the buyer. Hence, here analysis has been done on the selection of supplier considering different risks that might affect the buyer directly or indirectly or determined and tried to find the supplier with lesser risk than the others. For this we have used VIKOR method in fuzzy environment to determine this compromise solution so that the selected supplier will have a comparable advantage over others and the supplier with required criteria is obtained. This method as it considers the opinion of different decision makers there is no problem of one being biased to a particular idea. This method is easier to evaluate and can be programmed in basic computer languages to evaluate for more number of suppliers and criteria.

Table 4.1: Different Risk Sources in Relation to Suppliers' Performance

Sl. No.	Risk Sources	Notation
1	Capacity constraints	C_1
2	Cost reduction capabilities	C_2
3	Lead time	C_3
4	Environmental performance	C_4
5	Financial health	C_5
6	Failure to meet delivery requirements	C_6
7	Inbound transportation	C_7
8	Information systems compatibility and sophistication Inventory management	C_8
9	Management vision	C_9
10	Process technological changes	C_{10}
11	Volume and mix requirement changes	C_{11}

Table 4.2: Probability and Impact Assessment Scale

Impact Assessment Scale			Probability Assessment Scale		
Subjective Estimate	Linguistic Notation	Fuzzy Representation	Subjective Estimate	Linguistic Notation	Fuzzy Representation
No Impact	NI	(0, 0, 0.25)	Very Unlikely	VU	(0, 0, 0.25)
Minor Impact	MNI	(0, 0.25, 0.5)	Improbable	I	(0, 0.25, 0.5)
Medium Impact	MI	(0.25, 0.5, 0.75)	Moderate	M	(0.25, 0.5, 0.75)
Serious Impact	SI	(0.5, 0.75, 1)	Probable	P	(0.5, 0.75, 1)
Catastrophic Impact	CI	(0.75, 1, 1)	Very Probable	VP	(0.75, 1, 1)

Table 4.3: Weight Assessment Scale

Weight Assessment Scale		
Subjective Estimate	Linguistic Notation	Fuzzy Representation
Very Low	VL	(0, 0, 0.1)
Low	L	(0, 0.1, 0.3)
Medium Low	ML	(0.1, 0.3, 0.5)
Medium	M	(0.3, 0.5, 0.7)
Medium High	MH	(0.5, 0.7, 0.9)
High	H	(0.7, 0.9, 1)
Very High	VH	(0.9, 1, 1)

Table 4.4: Priority Weight Assigned by the Decision-Making Group

C_i	Priority Weight Assigned by the Decision-Making Group in Linguistic Term				
	DM1	DM2	DM3	DM4	DM5
C_1	VH	VH	H	VH	H
C_2	H	H	H	H	H
C_3	VH	H	VH	H	VH
C_4	MH	H	H	H	MH
C_5	MH	H	MH	H	MH
C_6	H	H	H	H	MH
C_7	VH	VH	H	VH	VH
C_8	H	H	H	VH	H
C_9	H	VH	H	H	H
C_{10}	H	VH	VH	VH	VH
C_{11}	H	H	VH	H	VH

Table 4.5: Risk Impact Assigned by the Decision-Making Group

S_1	C_i	Risk Impact Assigned by the Decision-Making Group				
		DM1	DM2	DM3	DM4	DM5
	C_1	MI	MI	SI	MI	MI
	C_2	NI	NI	MNI	MNI	MNI
	C_3	SI	SI	MI	SI	SI
	C_4	NI	MNI	MNI	MNI	MNI
	C_5	SI	SI	SI	MI	SI
	C_6	MI	MI	SI	MI	MI
	C_7	SI	CI	SI	CI	SI
	C_8	MI	MNI	MNI	MNI	MI
	C_9	NI	NI	MNI	NI	NI
	C_{10}	SI	CI	SI	SI	SI
	C_{11}	MI	SI	MI	MI	MI
S_2	C_1	MI	SI	SI	SI	MI
	C_2	NI	NI	NI	MNI	MNI
	C_3	SI	SI	SI	CI	CI
	C_4	MNI	MNI	MNI	MNI	MNI
	C_5	SI	SI	SI	SI	SI
	C_6	MI	SI	SI	MI	SI
	C_7	MI	MI	SI	MI	MI
	C_8	MI	MI	MI	MI	MI
	C_9	NI	NI	NI	MNI	MNI
	C_{10}	MI	MI	SI	MI	MI
	C_{11}	SI	SI	SI	SI	MNI
S_3	C_1	MI	MI	MI	MI	MI
	C_2	MNI	MNI	MNI	MNI	MNI
	C_3	SI	SI	SI	SI	SI
	C_4	MNI	MI	MI	MNI	MI
	C_5	CI	CI	SI	CI	SI
	C_6	SI	SI	MI	MI	MI

	C_7	MI	MI	MI	SI	MI
	C_8	NI	MNI	MI	MI	MI
	C_9	MNI	MNI	MNI	MNI	NI
	C_{10}	MI	MI	MI	MI	MI
	C_{11}	SI	SI	SI	MI	MI
S_4	C_1	MNI	MI	MI	MNI	MI
	C_2	NI	MI	MI	MNI	MI
	C_3	SI	MI	MI	MI	MI
	C_4	MI	MI	MI	MI	MI
	C_5	SI	CI	SI	SI	SI
	C_6	SI	SI	MI	MI	MI
	C_7	SI	MI	SI	MI	SI
	C_8	NI	NI	MNI	MNI	MI
	C_9	NI	NI	NI	MNI	NI
	C_{10}	MI	MI	MI	SI	MI
	C_{11}	MI	MI	MI	MI	MI

Table 4.6: Likelihood/ (Probability of Occurrence) of Risk Assigned by the Decision-Making Group

S_1	C_i	Priority Weight Assigned by the Decision-Making Group in Linguistic Term				
		DM1	DM2	DM3	DM4	DM5
	C_1	P	VP	M	M	P
	C_2	M	M	M	M	M
	C_3	P	P	M	P	P
	C_4	VP	VP	P	P	P
	C_5	VP	P	VP	P	P
	C_6	M	M	M	M	P
	C_7	M	I	I	I	M
	C_8	I	M	P	M	M
	C_9	M	M	P	M	P
	C_{10}	M	P	P	P	M

	C_{11}	I	I	M	I	M
S_2	C_1	VU	I	I	I	I
	C_2	I	M	I	M	M
	C_3	M	M	M	M	M
	C_4	P	M	M	M	P
	C_5	VP	P	P	P	VP
	C_6	M	I	I	I	M
	C_7	M	M	M	M	M
	C_8	VU	VU	VU	I	VU
	C_9	I	I	M	I	M
	C_{10}	M	M	M	M	M
	C_{11}	P	VP	P	P	P
S_3	C_1	P	P	P	P	VP
	C_2	M	P	M	P	M
	C_3	M	M	M	M	M
	C_4	M	P	M	P	P
	C_5	I	I	M	I	I
	C_6	I	M	VU	VU	VU
	C_7	I	M	I	M	M
	C_8	P	M	P	M	M
	C_9	VP	VP	P	P	P
	C_{10}	M	M	M	M	M
	C_{11}	VU	VU	VU	I	VU
S_4	C_1	I	I	M	I	M
	C_2	M	M	M	M	M
	C_3	P	VP	P	P	P
	C_4	P	P	P	P	VP
	C_5	M	P	M	P	M
	C_6	M	M	M	M	M
	C_7	M	P	M	P	P
	C_8	I	I	M	I	I
	C_9	M	M	M	M	M

	C_{10}	VU	VU	VU	I	VU
	C_{11}	I	I	M	I	M

Table 4.7: Priority Weight Assigned by the Decision-Making Group Represented by Fuzzy Numbers

	Priority Weight Assigned by the Decision makers				
	DM1	DM2	DM3	DM4	DM5
C_1	(0.9,1,1)	(0.9,1,1)	(0.7,0.9,1)	(0.9,1,1)	(0.7,0.9,1)
C_2	(0.7,0.9,1)	(0.7,0.9,1)	(0.7,0.9,1)	(0.7,0.9,1)	(0.7,0.9,1)
C_3	(0.9,1,1)	(0.7,0.9,1)	(0.9,1,1)	(0.7,0.9,1)	(0.9,1,1)
C_4	(0.5,0.7,0.9)	(0.7,0.9,1)	(0.7,0.9,1)	(0.7,0.9,1)	(0.5,0.7,0.9)
C_5	(0.5,0.7,0.9)	(0.7,0.9,1)	(0.5,0.7,0.9)	(0.7,0.9,1)	(0.5,0.7,0.9)
C_6	(0.7,0.9,1)	(0.7,0.9,1)	(0.7,0.9,1)	(0.7,0.9,1)	(0.5,0.7,0.9)
C_7	(0.9,1,1)	(0.9,1,1)	(0.7,0.9,1)	(0.9,1,1)	(0.9,1,1)
C_8	(0.7,0.9,1)	(0.7,0.9,1)	(0.7,0.9,1)	(0.9,1,1)	(0.7,0.9,1)
C_9	(0.7,0.9,1)	(0.9,1,1)	(0.7,0.9,1)	(0.7,0.9,1)	(0.7,0.9,1)
C_{10}	(0.7,0.9,1)	(0.9,1,1)	(0.9,1,1)	(0.9,1,1)	(0.9,1,1)
C_{11}	(0.7,0.9,1)	(0.7,0.9,1)	(0.9,1,1)	(0.7,0.9,1)	(0.9,1,1)

N.B: Risk extent: RI x L

Table 4.8: Risk Extent for Each of the Criteria Expressed in Crisp Values

Criteria	SUPPLIERS (crisp values)				Weight (Crisp)
	S1	S2	S3	S4	
C_1	0.413333	0.178333	0.429167	0.181667	0.926667
C_2	0.125	0.089167	0.191667	0.195833	0.866667
C_3	0.531667	0.441667	0.416667	0.468333	0.926667
C_4	0.206667	0.191667	0.301667	0.429167	0.8
C_5	0.605	0.645833	0.284167	0.5075	0.766667
C_6	0.3175	0.269167	0.149167	0.341667	0.833333
C_7	0.319167	0.316667	0.261667	0.464167	0.946667
C_8	0.216667	0.083333	0.2575	0.103333	0.886667
C_9	0.095	0.081667	0.206667	0.129167	0.886667
C_{10}	0.546667	0.316667	0.291667	0.089167	0.946667
C_{11}	0.234167	0.546667	0.100833	0.216667	0.906667

Table 4.9: Best and Worst Values of the Criteria Ratings

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}
f^+	0.4292	0.1958	0.5317	0.4292	0.6458	0.3417	0.4642	0.2575	0.2067	0.5467	0.5467
f^-	0.1783	0.0892	0.4167	0.1917	0.2842	0.1492	0.2617	0.0833	0.0817	0.0892	0.1008

Table 4.10: Computation of ‘Q’, ‘R’ and ‘S’ Values

Suppliers	Q	S	R
S_1	0	3.888007	0.792089
S_2	0.935307648	6.571204	0.926667
S_3	0.776344062	5.370978	0.946667
S_4	0.645773084	4.670283	0.946667

Table 4.11: Computed S^* and S^- Values

$S^* = \min_{i=1,\dots,m} S_i$	3.888007	$R^* = \min_{i=1,\dots,m} R_i$	0.792089
$S^- = \max_{i=1,\dots,m} S_i$	6.571204	$R^- = \max_{i=1,\dots,m} R_i$	0.946667

Table 4.12: Final Ranking Order Based on ‘Q’, ‘R’ and ‘S’ Values

	Ranking Order			
	1	**2**	**3**	**4**
By ‘Q’	S1	S4	S3	S2
By ‘R’	S1	S2	S3	S4
By ‘S’	S1	S4	S3	S2

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