

Supply Chain Risk Assessment: A Fuzzy AHP Approach

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ABSTRACT

Managing supply chain risk is a big challenge for any organization. The purpose of the paper is to provide a methodology for assessing supply chain risk using the Fuzzy based Analytic Hierarchy Process (Fuzzy AHP). This study presents a comprehensive study to identify the Risk Factors (RFs) in supply chain and evaluate them. In this paper, sixteen risk factors were identified based on extensive literature survey. To limit the scope of the work, focus was on transaction and infrastructural risk and avoiding the demand risk. The RFs are formulated as hierarchy structure and Fuzzy AHP as a Multi Attribute Decision Making (MADM) tool applied to judge the viable candidates. A revised risk matrix with a continuous scale was proposed to assess the RFs classes. The result classifies the RFs in different categories (Extreme, High, Medium and Low). Based on this result, some management implications and suggestions are proposed. The revised risk matrix with continuous scale for risk assessment in supply chain is a novel approach.

Keywords: *supply chain risk, risk assessment, fuzzy AHP, multi attribute decision making*

1. INTRODUCTION

Supply Chain Management (SCM) is widely acknowledged as strategic for companies, because they contribute to build and maintain a competitive advantage (Hsu *et al.*, 2006). To make a prudent supply chain decision, it is important to plan for uncertainty to mitigate risk. Supply Chain Risk Management (SCRM) has been a growing field of interest among researchers in the area of supply chain. According to Hahn & Kuhn (2011) integrated performance and supply chain risk management is the key lever to increase shareholder value intrinsically. Risk in this field can be defined as the probability of danger or disruptions, under which events would obstruct a company in achieving its planned objectives (Zsidisin, 2000). Neiger, Rotaru & Churilov (2009) highlighted the incorporation of SCRM into business objective structure. According to them, incorporation of SCRM into business objective structure is yet to be implemented. Formby and Malhotra (2017), in their

study tried to understand how internal firm decisions affect supply risks and supply lead times. According to a literature survey by Tang & Musa (2011), the existing literature related to SCRM mainly consists of conceptual and descriptive models rather than quantitative models. This indicates growing need for quantitative models for system analysis and decision supporting. Neiger *et al.* (2009) identified a critical gap in existing supply chain risk knowledge manifested by the absence of supply chain risk assessment. The present work aims to address this gap by proposing an assessment methodology for supply chain risk (SCR) using Fuzzy Analytic Hierarchy Process (FAHP) technique.

Omera & Bernard (2007) highlighted the debate regarding qualitative and quantitative approaches for risk management in supply chains. They also opined that application of risk theory in supply chain management is still in its early stage. Tang (2006) examined the various models and summarized the manager's attitude towards risk and their initiatives for managing supply chain risk. On analyzing the model he concluded that most managers use various quantitative models but are not very comfortable with using probability estimates. As argued by Shapira (1995), very few managers like to define risk in terms of probability distributions. To overcome all these shortcomings, the present work employs the fuzzy theory to deal with the uncertainty and vagueness surrounding the subjective nature of the decision making and multiple attribute decision method to cater to the decision making of multiple decision makers. The purpose is to create a robust risk classification and prioritization system and simplifying and reducing the effort and time to solve for uncertainties.

In the present work, the objective is to present a comprehensive framework for supply chain risk factors by analyzing and framing them into a hierarchical structure. The supply chain risk factors are identified through an extensive literature survey. The risk factors were formulated as hierarchy structure and FAHP as a Multi Attribute Decision Making (MADM) tool applied to judge the viable candidates. Based on a FAHP approach, a revised risk matrix with a continuous scale was proposed to assess the RFs'

classes. The result classifies the RFs' in different categories.

The paper is organized in five sections. The different aspects of supply chain risk management are discussed first. This is followed by investigation of risk assessment and identifying the risk factors through literature survey. Section 3 describes the research method and the model. The results are discussed in section 4. At the end, general conclusions and limitations are provided.

2. LITERATURE REVIEW

2.1 Supply Chain Risk Management

According to Hallikas *et al.* (2004), a typical supply chain risk management process consists of four stages: (i) Risk identification— this includes the identification of risks, and the impact on the supply chain, organization and shareholders; (ii) Risk assessment— this involves determining the severity of risks, measuring the effect of risks and the potential extent of the loss; (iii) Risk monitoring and control — deals with control using planned actions in the short, medium and long term, implementation of technical or prevention and protection measures and the control indicators to monitor risk and the effectiveness of actions; and (iv) Decision and implementation of risk management actions — includes strategies for risk management such as risk transfer, risk taking, risk elimination, risk reduction, and further analysis of individual risks.

Risk assessment involves probability of an event occurring along with the significance of the consequences (Harland *et al.*, 2003). In the past decade, a number of risk assessment methods have emerged, especially for supply risk assessment. According to Blackhurst *et al.* (2005) and Craighead *et al.* (2007), there is a need for proactive supply chain risk management approach that focuses on assessing the likelihood of supply chain risk occurrence before the problem actually occurs.

As the importance of managing supply chain risk has grown, research within the supply chain field has increasingly centered on this strategic issue. Tang and Musa (2011) in their work to investigate research work in SCRM have shown that there has been a significant increase of research in this field during 2000-2010. The discipline has emerged from passively reacting to general issues towards more proactively managing supply chain risk from systems perspective.

In a recent review work by Hudnurkar *et al.* (2017), a new comprehensive conceptual risk classification framework has been presented. In another recent work, Chris Enyinda (2018) used a systematic approach to identify risk sources and to develop predictive enterprise risk management in operations and supply chain. Juttner *et al.* (2003) suggest organizing risk sources relevant for supply chains into three categories: External to the supply chain, Internal to the supply chain and Network related. Johnson *et al.* (2008) divides supply chains risks between supply risks (e.g. capacity limitations, currency fluctuations and supply disruptions) and demand risks (e.g. seasonal imbalances, volatility of fads, new products). Zsidisin *et al.* (2000)

focuses on supply risks related to design, quality, cost, availability, manufacturability, supplier, legal, and environmental, health and safety. Just as there is an abundance of supply chain risk definitions, approaches to mitigate supply chain risk have been placed encompassing numerous techniques. Supplier uncertainty as defined by Zsidisin (2000) is the chance a detrimental incident can occur with a specific supply source. Zsidisin *et al.* (2004) look at supply chain risk mitigation from the perspective of the purchasing organization. Zsidisin *et al.* (2005) discusses supply chain risk mitigation techniques in terms of tackling issues arising from processes external to the organization. They discuss many cases and address the issues of strengthening supplier quality, lessening the chance of supply disruptions, and improving the process through which goods and services are supplied by vendors. Managing risk from supplier's perspective can help companies to identify and manage sources of risk to their inbound supply. This was shown in Zsidisin and Ellram's (2003) finding that a supplier's failure to deliver inbound goods and services can have detrimental effect throughout the purchasing firm and the supply chain. Finch (2004) views supply chain risk management from the perspective of inter- organizational networking which includes issues internal and external to the organization. Tullous & Munson (1991) categorize supply chain uncertainty by need, market and supplier uncertainty. Wu *et al.* (2006) pointed that most of the existing research on SCR relies on a product focused approach and very few on supplier focused approach.

A common drawback with most of these approaches is that they focused on simulated data instead of using real case data. In their review work on SCRM research, Ho *et al.* (2015) did an extensive study on the papers published between 2003 and 2013 and presented certain gaps. They reviewed and synthesized the extant literature in SCRM in the past decade in a comprehensive manner. They did a detailed review associated with research developments in supply chain risk definitions, risk types, risk factors and risk management/mitigation strategies. According to them, the domain of infrastructural risks such as transportation, information and financial risks have been relatively ignored by the researchers compared to the supply risks. As infrastructure has an important role to play in the supply chain, our focus on this paper was to consider the infrastructure related risks along with the supply risks. According to Ho *et al.* (2015), most of the study related to supply chain has focussed on supply related risks thus ignoring the other aspects. The present paper builds on the premise that the risks for supply chain may not be managed effectively if one only focuses on reactive approach. It is important to properly assess the different types of risk to build a proper SCM system. Purposefully in this work, the demand risks are not considered, as the scope was to capture the transactional and infrastructural related risks. The purpose of this paper is to move beyond the limitations of existing risk assessment approaches in SCM and provide a risk assessment framework which incorporates all important risks. The paper proposes a revised risk matrix with continuous scale to assess the risks.

2.2 Supply Risk Assessment

Supply risk refers to risk associated with inbound supply and the subsequent impact on customers (Zsidisin, 2003). According to Ellis *et al.* (2010), supply risk is an individual's perception of the total potential loss associated with the disruption of supply of a particular purchased item from a particular supplier. Supply risk is one of the risks most discussed and researched in the literature. Wu *et al.* (2007) provides an integrated approach to classify, manage and assess supply risks. A number of supply chain risk assessment techniques (Zsidisin *et al.*, 2004) are available to prioritize the usage of resources for the supply chain risk management process. Without a supply chain risk management process in place, no risk can be identified, assessed and managed.

The approaches to mitigate supply chain risk have been placed encompassing numerous techniques. Hutchins (2003) views supply chain risk as caused by areas external to the organization. These are defined as the partner's abilities to meet contract, possibility of harm or loss if requirements are not achieved, probability of events with undesirable results, variations regarding requirements and their mitigation. Supplier uncertainty as defined by Zsidisin *et al.* (2000) is the chance that a detrimental incident can occur with a specific supply source. Managing risk from a supplier's perspective can help companies identify and manage sources of risk for their inbound supply. This was shown by Zsidisin & Ellram (2003), who found that a supplier's failure to deliver inbound goods and services can have detrimental effect throughout the purchasing firm and the supply chain. Most of the work done on the area of supply risk studied the supplier evaluation and selection problem while considering a variety of supply risks, such as poor quality (Talluri & Narasimhan 2003; Talluri *et al.*, 2006), late delivery (Talluri & Narasimhan 2003; Talluri, Narasimhan & Nair 2006), uncertain capacity (Kumar *et al.*, 2006; Viswanadham & Samvedi 2013), supplier failure to manage its own supplier (Kull & Talluri 2008; Ravindran *et al.* 2010; Ruiz-Torres *et al.*, 2013), supplier's financial stress (Lockamy & McCormack 2010). A wide range of quantitative methods have been proposed to deal with this problem, including mathematical programming and data envelopment analysis (DEA) approaches (Talluri & Narasimhan 2003; Kumar *et al.* 2006; Talluri *et al.*, 2006; Wu *et al.*, 2010), multicriteria decision-making and AHP approaches (Chan & Kumar 2007; Blackhurst *et al.*, 2008; Kull & Talluri 2008; Bayesian networks (Lockamy & McCormack 2010) and decision tree approach (Ruiz-Torres *et al.*, 2013).

2.3 Financial Risk Assessment

A relatively less researched but an important category related to supply chain risk is the financial risk. Financial risk management is concerned with risk that refers to deviations of expected monetary objectives. Originally, researchers considered the use of mathematical models for finding decisions which were initially mean-variance objective functions. Several characterizations of financial risk subsist, most of which are related to market, credit, currency or

liquidity risk (Kristian *et al.* 2003). These risks describe the potential for losses due to movements in market prices, debt payments, exchange rates and interest in trading certain assets (Wagner & Bode, 2008). The supply-chain-related cash flow risks were assessed by Tsai (2008) by measuring the standard deviations of cash inflows, outflows and net flows of each period in a planning horizon. The impact of foreign exchange risk and competition intensity on supply chain companies involved in offshore-outsourcing activities was modelled by Liu & Nagurney (2011). Franca *et al.* (2010) evaluated the financial risk using a multiobjective programming model with the Six Sigma concepts. They observed that as the financial risk decreases the sigma level increases. Liu & Cruz (2012) studied the impact of corporate financial risk and economic uncertainty on the values, profits and decisions of supply chains.

2.4 Information Risk Assessment

Jüttner, Peck & Christopher (2003) defined information risk as any risks for the information flows from original suppliers to the delivery of the final product for the end user. Information technology in relation to supply chain risk management plays very important role in present context as suggested by several authors (Atkinson, 2003; Giunipero & Eltantawy, 2004; Tang, 2006; Wilson, 2007). In general, the use of information technology could improve information visibility across the supply chain. How technology can help manage supply chain risks, would technology also pose other supply chain risks, how technology can be used to monitor supply chain risks are among interesting questions to tackle for the researchers and practitioners (Wilson, 2007). Olusola and Steve (2017) evaluated the transparency of cloud providers to determine the resultant risk of limited visibility of the supply chain. To enhance the transparency of the supply chain and ensure proper dissemination of information among the supply chain members in a timely manner, it is imperative to ensure seamless flow of information in the supply chain (Denolf *et al.* 2015). Due to the rapid pace of technological changes and the organizational changes they may impose, information risks continue to be a critical activity (Altuwajri & Khorsheed, 2011; Bannerman, 2008). The failures of information systems are a major concern despite surging investments and their importance for contemporary organizations (Baccarini *et al.*, 2004; Bannerman, 2008). Denolf *et al.* (2015) highlighted that selection of appropriate information systems remains a major concern for the organizations. The ability to assess the risks affects the success of information systems in different phases of their lifecycle; when the systems are selected, implemented and used. Durowoju *et al.* (2012) used discrete-event simulation to investigate the impact of disruption in the flow of critical information needed in manufacturing operations on collaborating members.

2.5 Manufacturing Risk Assessment

Manufacturing risk can be defined as risks initiated with operational events disrupting material or information flow within supply chain (Lockamy *et al.*, 2010; Colicchia *et al.*, 2010; Cigolini & Rossi, 2010). There is plenty of work

done in the field of manufacturing risk assessment in supply chain. The notable of them are related to quality risk (Hung 2011; Sun, Matsui & Yin 2012), lead time uncertainty (Li 2007), non-conforming product design (Khan *et al.*, 2008), capacity inflexibility (Hung 2011) and machine failures (Kenné *et al.*, 2012). Researchers have applied different methods to assess manufacturing risks in different supply chains. Cigolini & Rossi (2010) proposed the fault tree approach to analyse and assess the operational risk of an oil supply chain. Dietrich & Cudney (2011) assessed the risk coupled with manufacturing readiness level for emerging technologies in a global aerospace supply chain. Wang *et al.* (2018) examined the applicability of logistics capability for mitigating supply chain uncertainty and risk and improving logistics performance in the Australian courier industry. When a firm purchases goods and services from suppliers, unpredictable events may occur anywhere in the process of acquisition, delivery, and use. Supplier quality problems can cause delays, and if quality problems are not caught in time, they are likely to result in costly recalls later on (Sodhi & Lee, 2007). As such, the risk posed by the supplier delivery not meeting the buyer’s specifications, is insufficiently addressed in the literature (Tse & Tan, 2011; Tse *et al.*, 2011). Tse & Tan (2011) constructed a product quality risk and visibility assessment framework and argued that better visibility of risk in supply tiers could minimise the quality risk. A comprehensive list of all the risk factors is presented in **Table 1**.

Data sources play an important role in the way it can be used for analysis. Analytics can be further classified into Text, Audio Video, Web or Network analytics based on source of data. In the following section we discuss these in detail.

Table 1 Major supply chain risk factors

Supply Chain Risk Factors Identified
Supply Risk Factors (SF)
SF1- Ability to manage own supplier base: Chopra & Sodhi (2004), Wu, Blackhurst & Chidambaram (2006), Manuj & Mentzner (2008), Ravindran et al. (2010); Ruiz-Torres, Mahmoodi, & Zeng (2013)
SF2- Delivery Requirements: Zsidisin & Ellram (2003), Kull & Talluri (2006), Manuj & Mentzner (2008), Talluri & Narasimhan (2003); Talluri, Narasimhan, & Nair (2006), Ganguly (2013)
SF3- Quality Requirements : Zsidisin & Ellram (2003), Tummala & Schoenherr (2011), Kull & Talluri (2006), Talluri & Narasimhan (2003); Talluri, Narasimhan, & Nair (2006)
SF4- Ability to handle volume changes: Chopra & Sodhi (2004), Zsidisin & Ellram (2003), Tummala & Schoenherr (2011), Kumar, Vrat, & Shankar (2006); Viswanadham & Samvedi (2013)
Financial Risk Factors (FF)
FF1- Exchange rates and currency fluctuations: Tummala & Schoenherr (2011), Chopra & Sodhi (2004), Manuj & Mentzner (2008), Liu & Nagurney (2011)
FF2- Competitive Pricing : Cucchiella & Gastaldi (2006), Wu, Blackhurst & Chidambaram (2006), Schoenherr, Tummala & Harrison (2008)
FF3- Timings of cash flows, credit period for accounts receivable and payable: Tsai (2008), Lockamy & McCormack (2010)
FF4- Loss of Contract: Samvedi, Jain & Chan (2013), Hahn & Kuhn(2012),
Information Risk Factors (IF)

Supply Chain Risk Factors Identified
IF1- Information security issues: Chopra & Sodhi (2004), Warren & Hutchinson (2000),
IF2- Lack of effective system integration: Tummala & Schoenherr (2011), Chopra & Sodhi (2004), Lee & Whang (2000),
IF3- Information transparency and delay: Cucchiella & Gastaldi (2006), Gaudenzi & Borghesi (2006)
IF4- Lack of compatibility among different IT platforms of supply chain partner: Tummala & Schoenherr (2011), Fawcett et. al. (2007)
Manufacturing Risk Factors (MF)
MF1- Labour dispute: Tuncel & Alpan (2010), Tummala & Schoenherr (2011), Wu, Blackhurst & Chidambaram (2006),
MF2- Production capacity/capabilities: Wu, Blackhurst & Chidambaram (2006), Hung 2011
MF3- Quality issues: Hung (2011); Sun, Matsui, & Yin (2012), Khan, Christopher, & Burnes (2008)
MF4- Resource breakdown, Machine failure: Hahn & Kuhn(2012), Samvedi, Jain & Chan (2013), Tuncel & Alpan (2010), Kenné, Dejux, & Gharbi (2012), Tse & Tan (2011)

The relevant attributes thus found out through published literature are the major Risk Factors for the study. This study thus categorizes supply chain risk into four categories: Supply factor, Finance factor, Information factor and Manufacturing factor. This is depicted in **Figure 1**(Annexure).

3. THE GROUP DECISION MAKING EVALUATION

3.1 Research Method

In this paper, the RFs for supply chain were identified and a (F-AHP) approach is then employed to weigh those RFs, including both weights of consequence and likelihood. Based on those weights, a revised risk matrix with a continuous scale is proposed to assess the risk classes of the RFs. An AHP questionnaire with a nine point rating scale was designed to measure the subject’s perceived likelihood and consequence on each RF respectively. Based on the hierarchical structure of RFs in **Figure 1**, an AHP survey with four criteria and 16 sub-criteria was created.

Since this paper employs the risk factors for SCM, as an empirical study to validate the proposed model, top managers from five large industries were surveyed. Of these, two were from Fast Moving Consumer Goods (FMCG) industry; two from automobile sector and one from electronics component manufacturing industry. Among these industries, automobile industry is considered as a prime industry and can be related to the current wealth of a nation’s economy (Childerhouse *et al.*, 2003). Automobile manufacturing has its own complexities and long lead-times, making it suitable for the study of SCRM. The FMCG industry is characterized by intense competition (Sahay, 2003). The engineering industry has its complexity in form of product development and long lead-time in manufacturing. The organizations of study were subjected to all the uncertainties in market demand faced by its customers and playing in a very complex and dynamic condition. All these were large organizations having exposed to different types of transactional risk and infrastructural risk. A total of

22 managers were surveyed in the process. This included the SCM managers, senior managers from the company and representatives of manufacturing, finance and information management experts. The team gathered information related to the problems of the existing supply chain. Other parameters studied to recognize the characteristics of the supply chain were industry characteristics and the business environment. The profiles of the validated 22 respondents are shown in **Table 2**. The data shows that all the subjects had at least ten years of experience. Also the significant qualifications of the respondents endorse the reliability of the survey findings. The industries under study had make-to stock manufacturing principle. The strategic objectives of the supply chain were deliberated in detail and issues related to risks faced were pointed out. It was unanimously agreed that the risk factors identified were highly relevant and needed effort to manage them.

Table 2 Profiles of the respondents

Characteristics	Position	Frequency	Percentage (%)
Job Title	IT Manager	7	31.82
	Supply Chain Manager	9	40.9
	Chief Information officer	4	18.18
	Chief Operations Officer	2	9.1
Age	Under 40	08	36.36
	41-50	09	40.9
	51-60	04	18.18
	Above 60	01	4.56
Educational Level	High School	0	0
	Graduate	09	40.9
	Post Graduate and above	13	59.1
Experience	5-10	03	13.63
	11-15	05	22.72
	16-20	10	45.45
	Above 20	04	18.2
Industry	Automobile	13	59.1
	FMCG	04	18.18
	Electronics	05	22.72
	Component		

The supply chain risk factors were converted into the evaluation attributes. This was followed by formulating the hierarchical structure. In this paper, FAHP as a MADM was applied to judge the viable candidates. In MADM problems, the assessment of the importance of evaluation criteria is done along with performance of potential candidates versus each criterion. AHP is a useful tool for MADM. AHP can be used for solving complex decision making problems involving a number of alternatives based on their performance with respect to various criteria (Zhang *et al.*, 2011). The assessment of weights and performance are carried out either in a “crisp” or in a “fuzzy” environment. However, the strength of human preference cannot be exactly expressed using a crisp number. The uncertainty and the vagueness of the experts opinion leads to impreciseness

of human judgements. This can be handled through fuzzy mathematics as proposed by Zadeh (1994). Hence, a FAHP is proposed in the present research to assess the RFs. The adoption of the fuzzy approach allows Decision Makers (DM) to express ill-defined judgements. FAHP is a systematic approach using concepts of fuzzy set theory and hierarchical structure analysis (Bozdag *et al.*, 2003). It is the approach that resolves the limitation of pair-wise comparison which is the inability to handle the uncertainty and imprecision associated with the mapping of the decision makers perception to a crisp number (Deng, 1999), but allows the decision makers to use the advantage of the AHP performances. FAHP is developed by various researchers along the line of the fuzzy set theory. The applications of the fuzzy AHP appear in numerous areas including supply chain management (Ganguly, 2013).

3.2 Procedure for Risk Assessment in Supply Chain

In this paper, 22 pairwise comparison matrices are obtained for each comparison of RFs in each layer. These matrices were obtained for each comparison of RFs. Most of relevant studies in the same line have employed arithmetic mean or geometric mean to present multiple subjects’ opinions which are sensitive to extreme values. To integrate the 22 subjects’ perceptions, fuzzy numbers are considered. The geometric mean was employed to represent the consensus of respondents (Satty 1980; Buckley 1985). The next step was to integrate the 22 pairwise comparison matrices into a fuzzy positive reciprocal matrix. For the purpose, a triangular fuzzy number was characterized. This number was having minimum, geometric mean and maximum of the measuring scores. Then, a FAHP approach was employed based on this matrix to weight the RFs for both of the measurements of respondent’s perceived “likelihood” and “consequence”. This method is employed in different fields of application (Wen *et al.*, 2014) but applying it in SCRM is a novel idea. Among many areas of application, the method has been applied for evaluating the service requirements of Taiwanese port distribution centres (Wen *et al.*, 2014 and 2015).

3.2.1 The Fuzzy Reciprocal Matrix

Suppose $\tilde{A} = [\tilde{a}_{ij}]_{n \times n}$ is a fuzzy positive reciprocal matrix where

$\tilde{a}_{ij} = [l_{ij}, m_{ij}, u_{ij}]$ is a triangular fuzzy number where

$$[l_{ij}, m_{ij}, u_{ij}] = \begin{cases} [1, 1, 1], & \text{if } i=j \\ [1/u_{ji}, 1/m_{ji}, 1/l_{ji}], & \text{if } i \neq j \end{cases}$$

As an easy exposition, let $A^{(k)} = [a_{ij}^{(k)}]_{n \times n}$ denote the pairwise comparison matrix with n RFs for the kth subject. Then, according to the above integration procedure, the 22 pairwise comparison matrix $A^{(k)}$, $k = 1, 2, \dots, 22$ can be integrated into the fuzzy positive reciprocal matrix as follows:

$$\tilde{A} = [\tilde{a}_{ij}]_{n \times n} \tag{1}$$

where

$$a_{ij} = \left[\min_{1 \leq k \leq 22} \{a_{ij}^{(k)}\}, \left(\prod_{k=1}^{22} a_{ij}^{(k)} \right)^{1/22}, \max_{1 \leq k \leq 22} \{a_{ij}^{(k)}\} \right]$$

is a triangular fuzzy number.

$i=1,2, n$ and $j=1,2,n$. According to the arithmetic operations of fuzzy numbers (Kaufman & Gupta, 1991), the fuzzy positive reciprocal matrix $\tilde{A} = [\tilde{a}_{ij}]_{n \times n}$ can be expressed as follows:

$$\tilde{a}_{ij} = [1,1,1] \text{ if } i=j;$$

$$(\tilde{a}_{ji})^{-1} \text{ if } i \neq j;$$

The NGMR (Normalization of the Geometric Mean of the Rows) method by Saaty (1980) was adopted to determine the local weights of RFs in \tilde{A} . This was based on the special structure of the positive reciprocal matrix \tilde{A} . Firstly, by the arithmetic operations of fuzzy members (Kaufnami & Gupta, 1991), the geometric means of the triangular fuzzy numbers for the i th RF ($i=1,2,\dots,n$):

$$\tilde{w}_i = \left(\prod_{j=1}^n a_{ij} \right)^{1/n} = \left[\left(\prod_{j=1}^n l_{ij} \right)^{1/n}, \left(\prod_{j=1}^n m_{ij} \right)^{1/n}, \left(\prod_{j=1}^n u_{ij} \right)^{1/n} \right], i=1,2,\dots,n \quad (2)$$

Summing up the $w_i, i=1,2,\dots,n$

$$\sum_{i=1}^n \tilde{w}_i = \left[\sum_{i=1}^n \left(\prod_{j=1}^n l_{ij} \right)^{1/n}, \sum_{i=1}^n \left(\prod_{j=1}^n m_{ij} \right)^{1/n}, \sum_{i=1}^n \left(\prod_{j=1}^n u_{ij} \right)^{1/n} \right] \quad (3)$$

The fuzzy weight for the i th RFs ($i=1,2,\dots,n$) can be found as:

$$\tilde{w}_i = \tilde{w}_i / \sum_{i=1}^n \tilde{w}_i = \left[\left(\frac{\left(\prod_{j=1}^n l_{ij} \right)^{1/n}}{\sum_{i=1}^n \left(\prod_{j=1}^n l_{ij} \right)^{1/n}} \right), \left(\frac{\left(\prod_{j=1}^n m_{ij} \right)^{1/n}}{\sum_{i=1}^n \left(\prod_{j=1}^n m_{ij} \right)^{1/n}} \right), \left(\frac{\left(\prod_{j=1}^n u_{ij} \right)^{1/n}}{\sum_{i=1}^n \left(\prod_{j=1}^n u_{ij} \right)^{1/n}} \right) \right], i=1,2,\dots,n \quad (4)$$

This paper adopted Yager's (1981) index to defuzzify the \tilde{W}_i into a crisp number $W_i, i=1,2,\dots,n$

This was because the local weight \tilde{W}_i of the i th RF ($i=1,2,\dots,n$) is fuzzy. For convenience of explanation let,

$$\tilde{W}_i = [l_i^w, m_i^w, u_i^w], \text{ where}$$

$$[l_i^w, m_i^w, u_i^w] = \left[\left(\frac{\left(\prod_{j=1}^n l_{ij} \right)^{1/n}}{\sum_{i=1}^n \left(\prod_{j=1}^n l_{ij} \right)^{1/n}} \right), \left(\frac{\left(\prod_{j=1}^n m_{ij} \right)^{1/n}}{\sum_{i=1}^n \left(\prod_{j=1}^n m_{ij} \right)^{1/n}} \right), \left(\frac{\left(\prod_{j=1}^n u_{ij} \right)^{1/n}}{\sum_{i=1}^n \left(\prod_{j=1}^n u_{ij} \right)^{1/n}} \right) \right], i=1,2,\dots,n$$

The Yager's index (1981) for the $\tilde{W}_i (i=1,2,\dots,n)$ can be found as:

$$W_i = (l_i^w + 2m_i^w + u_i^w) / 4, \quad i=1,2,\dots,n \quad (5)$$

Finally, normalizing the $W_i (i=1,2,\dots,n)$, then we have the crisp local weight of the i th RFs as:

$$\omega_i = W_i / \sum_{i=1}^n W_i, \quad i=1,2,\dots,n \quad (6)$$

3.2.2 The Global Weights of Risk Factors

To find the global weights of the RFs, low level of local weights were multiplied by their corresponding high level of global weights. The results of the RFs weights for likelihood measurement are shown in **Table 2**. The global weights of the RFs in the first layer are shown in the second field. The RFs in the second layer are shown in the last field. The results indicate that for the first layer of RF constructs, SF (30.68%) has the highest likelihood weight followed by MF (27.21%), IF (23.08%) and FF (21.32%). The results are in line with earlier works where the focus has been mainly on supply related risks. For the second layer of RFs, the RFs with the higher likelihood weights are MF3 (9.32%) and MF4 (7.38%). In the same manner, the result of the RFs weights for consequence is shown in **Table 3**. The results indicate that for the first layer of RF constructs, the RFs with the highest consequence weight is SF (32.25%), followed by MF (27.21%), FF (22.34%) and IF (19.11%). For the second layer of RFs, the RFs with higher consequence weight are: SF2 (8.45%) and SF3 (8.11%).

3.2.3 The Revised Risk Matrix

A RF with higher likelihood weight and consequence weight should be a RF with higher risk. Based on this concept, a Risk Index (RI) is thus constructed by the product of consequence weight and likelihood weight (Cox,2008, Levine, 2012). Let $\omega_i^L X \omega_i^F$ be the consequence weight and likelihood weight of i th RF respectively. Then, the RI of i th RF is defined as

$$RI_i = \omega_i^L X \omega_i^F, \quad i=1,2,\dots,n \quad (7)$$

Finally the RI can be normalized as

$$RI_i = \frac{\omega_i^L x \omega_i^F}{\sum_{i=1}^n (\omega_i^L x \omega_i^F)} \times 100\%, \quad i=1, 2,\dots,n \quad (8)$$

Based on Equation (8) and the RFs' likelihood and consequence weights in **Table 3** and **Table 4**, the RIs for each RF can be found in the last field of **Table 5**. The result indicates the RF with the highest risk is MF4 (7.42%), followed by SF2 (7.32%) and SF3 (7.30%).

According to RIs, a risk assessment matrix is constructed. As shown in **Figure 2**, the consequence weight and likelihood weights are depicted in x axis and y axis respectively. According to equation 8, different RI means are obtained. The first RI= 5.6, found by averaging all of the 16 RFs' RIs and dividing all of the RIs into two groups. This RI is for the entire RFs. Group one contains 5 RFs which are mainly the high risk factors. The RI= 7.15 is obtained by averaging the RFs of MF4, SF2, SF3, MF2 and MF3. The average of the rest of 11 RFs' RIs is in the other group representing the low risk factors, their average value being 5.37. The three RFs (MF4, SF2, SF3) can be classified as E (Extreme Risk) category. Similarly the two RFs (MF2, MF3) classified as H (High Risk), six RFs (MF1, SF1, IF2, FF2, IF3, FF1) as M (Medium Risk) and five RFs (IF1, FF3, FF4, SF4, IF4) as L (Low Risk). Naturally, the SCM managers have to pay more attention towards the first two classes.

4. DISCUSSIONS

In the traditional risk matrix, both the consequence and likelihood are measured by a category scale and the subjects need to score each RF directly based on their perceptions. In practice, it may be difficult for subjects to score a RF precisely in such a direct scoring measurement. A traditional risk matrix using a discrete scale measurement (Cox, 2008; Levine, 2012) often limits its application for example difficulty in maintaining the consistency between the risk matrix and quantitative measure, subjective classification of likelihood and consequence. There is a usual practice to color the cells in the matrix to classify the RFs. A respondent may be more comfortable to compare which RF is more likely to occur rather than score each of the two RF's likelihoods directly. To raise the measurement validity of the subjects, a fuzzy AHP approach is used in this paper with relatively comparable scoring to assess the RFs. In this paper the RFs are weighted with continuous score using fuzzy AHP and a continuous scale is proposed to classify the RFs. A decreasing curve is proposed to classify the RFs which can improve the practical application of the revised risk matrix. This paper adopted a fuzzy AHP approach with a relatively comparable scoring to assess the RFs to raise the measurement validity of the subjects, leading to improved performance of the traditional risk matrix. The empirical result shows three RFs, classified as extreme risk: MF4, SF2 and SF3 and two RFs classified as high risk: MF2 and MF3. This result indicates Supply Factor (SF), which contains two extreme risk classes of RFs (SF2 and SF3) is the RF construct with the highest risk. Based on the results, suggestions are proposed for improving the system.

A long term relationship with supplier based on mutual trust and confidence may help tackle the quality and delivery related issues. The focus on supply chain information system can ensure proper dissemination of information and improve the supply management. The organization should set up and maintain the sourcing goals so that the proper supplier selection is assured. The sourcing goal should create a win-win situation for both manufacturer and supplier so that it will drive towards supplier development process. A strategic plan for managing risk will impact issues like risk sharing, continual risk assessment and information security. The supplier selection process has to assess the possibility of sharing the risk with the suppliers, in order to control the supplier's behaviors and to make their goals conform to a specific purpose. Therefore, a greater focus on the Supply Risk Management Process (SRMP) is deemed necessary. To ensure a proper risk mitigation plan and performance measures there is a need for standardization in terms of internal reporting, which leads to formal and extensive use of SRMP. A high level of supplier evaluation criteria and performance measures leads to a greater focus on the SRMP because there is a need of knowledge about what happens in a supply, in order to allocate the contingencies for deviations or disruptions. To address the issue of manufacturing factor specially related to the Machine failure/breakdown related risk as identified in this work, a focus on Total Productive Maintenance can be an effective solution. A focus on autonomous maintenance by making the workers responsible

and accountable can increase the availability of the resources.

A better assessment of risk in supply chain can help achieve the better management of the chain. It is imperative to create awareness and educate the users about the risk factors in the supply chain. This should be supported by better infrastructure facilities for the integration of the supply chain. This has to be done collectively by the management of the companies belonging to a supply chain. As the major risk factors identified relate to all the major entities of a supply chain, the major stakeholders in the supply chain should take the initiative to address these issues. To ensure this, joint meetings of all the major entities of the supply chain may prove useful. Among these activities, some are related to integrating functions of the organizations with each other while some are to do with external entities such as customers and suppliers. The development and utilization of long-term Information Technology (IT) plans will be beneficial for the supply chain. The IT plan has to be extensive addressing the competencies of the firm and most importantly the integration of the firm's IT infrastructure with the partners. This can be ensured by trained work force with high level of IT capabilities. A proper IT plan should ensure seamless information flow between the different functions and proper communication between IT executives and SCM executives. Different stakeholders may have varying or even conflicting perspectives on risks related to supply chain. An effective risk management will require broad involvement and collaboration of stakeholders.

5. CONCLUSION

Research on assessing the risk factors for supply chain management has been fragmented (Ho. et. al.2015). A better understanding and analysis can help supply chains to successfully manage the SCR. The main objective was therefore to identify the major risk factors for SCM and propose a risk matrix to evaluate the risks. After extensive literature survey, 16 risk factors related to SCM were identified. The risk factors are general in nature and not specific to a supply chain. However, sector specific study of supply chain may yield different risk factors. The risk factors identified indicates the nature and dynamics of a complex supply chain system. First, it can serve as a checklist of areas that require attention when improving a supply chain system. Second, through grouping, risk factors are presented in a more systemic way. It shows from a management perspective, that the risk factors can be grouped into the following dimensions: "Supply Factors", "Finance Factors", "Information Factors" and "Manufacturing Factors". To limit the scope of the work, focus was on transaction and infrastructural risk and avoiding the demand risk. The framework offers a comprehensive set of dimensions in which every risk factor are a part of one dimension. The work proposes a revised risk matrix with continuous scale for risk assessment in supply chain. Further, based on a fuzzy AHP approach, a revised risk matrix with a continuous scale was proposed to assess the RFs' classes. The revised risk matrix may provide a theoretical reference for methodological research in risk assessments.

The practical application of the proposed model was validated. The risk assessment for SCM was empirically investigated. For data collection, interview survey was used to get in depth idea and enhance the validity. In this paper, managers from five different organizations were surveyed to validate the proposed model. The result classifies the RFs into different categories (Extreme, High, Medium and Low). The classification can help managers to manage risks in a supply chain on a priority basis. Based on this result, some management implications and suggestions are proposed. It can be claimed that this is one of the few studies done on SCRM in a comprehensive manner. The techniques utilized in this research viz. Fuzzy AHP have, in various forms, been applied in other environments so their performance there is known. Combining this knowledge with the theoretical background of these techniques and experience with the study done provide insights into the advantages of proposed methodologies. The MADM technique used has well developed theoretical backgrounds. They are also flexible enough to accommodate application to a variety of risk situations and supply chain environments. This work adds a significant contribution to the group participating in risk assessment problems. By implementing methodologies that allow each organization in the group to evaluate the situation from their own perspective and then have this input coordinated in a quantitative fashion, the results are certain to be superior to ad hoc methods that frequently results to solutions that are acceptable to few. The present study addresses few industry sectors only. For future scope of study, it is suggested to go for more representative samples which can be sector specific to ensure better confirmation of the empirical results as a course of future studies. It is suggested that further research should investigate the application of the proposed framework in different supply chains. The framework can be used as a basis for assessing risk in various types of supply chains. It will be interesting to identify specific tactics for the risk factors with linked responsibilities to allow managers for better SCRM.

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APPENDICES

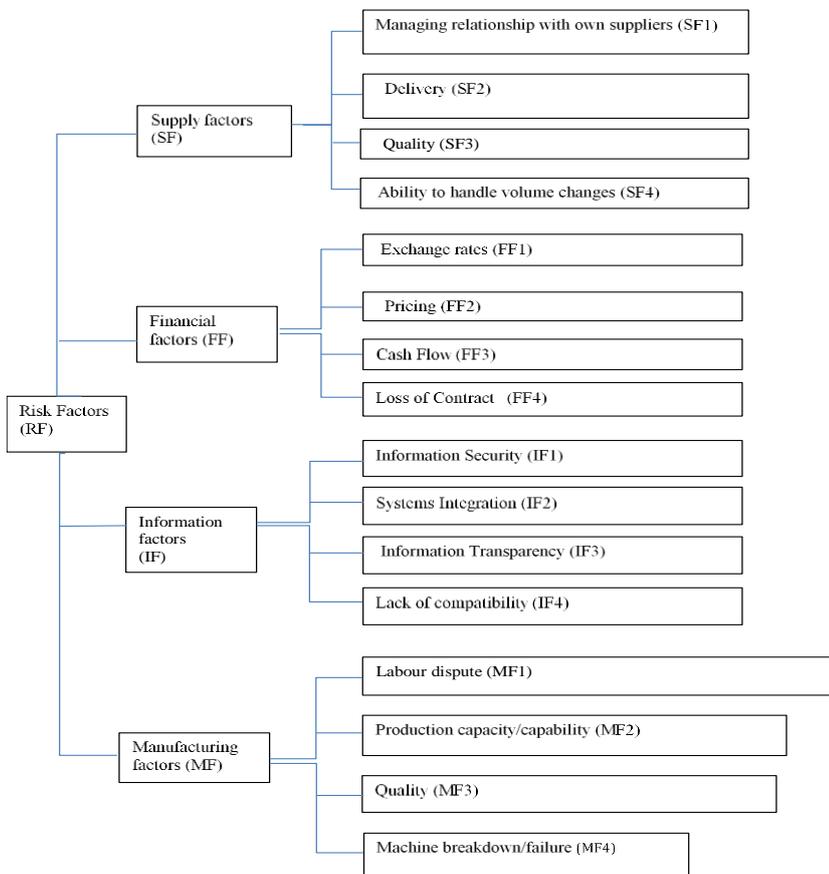


Figure 1 Supply chain risk factors attributes hierarchy

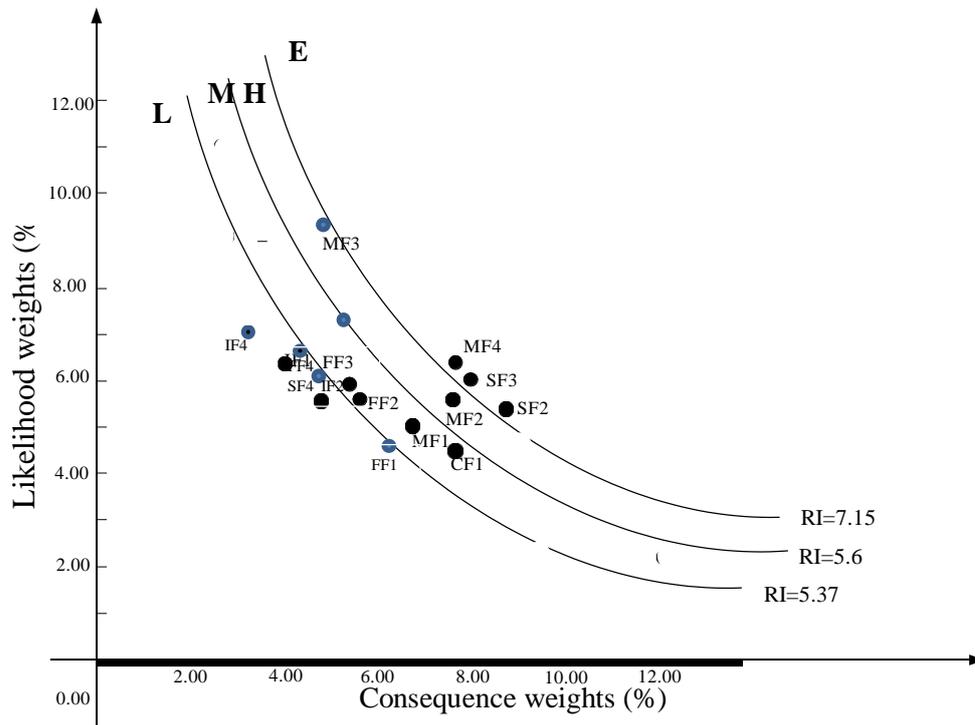


Figure 2 The revised risk matrix

Table 3 The likelihood weights of risk factors (RFs)

Layer 1 RFs	The global weights of Layer1	Layer 2 RFs	The local weights of Layer 2	The global weights of Layer 2
SF	30.68	SF1	13.00	6.54
		SF2	26.02	6.19
		SF3	14.00	6.87
		SF4	47.87	5.78
FF	21.32	FF1	20.12	4.42
		FF2	26.12	5.54
		FF3	27.77	6.35
		FF4	27.44	6.32
IF	23.08	IF1	17.87	5.76
		IF2	20.12	5.96
		IF3	37.02	7.05
		IF4	27.04	6.43
MF	27.21	MF1	20.02	5.04
		MF2	22.21	5.69
		MF3	35.00	9.32
		MF4	23.78	7.38

The bold numbers show the RFs with higher weights

Table 4 The consequence weights of risk factors (RFs)

Layer 1 RFs	The global weights of Layer1	Layer 2 RFs	The local weights of Layer 2	The global weights of Layer 2
SF	32.25	SF1	35.33	7.22
		SF2	25.03	8.45
		SF3	30.12	8.11
		SF4	7.85	4.55
FF	22.34	FF1	35.57	7.55
		FF2	24.45	5.34
		FF3	23.43	5.00
		FF4	17.87	4.10
IF	19.11	IF1	27	4.77
		IF2	44.34	7.65
		IF3	15.22	3.55
		IF4	15.45	3.67
MF	27.21	MF1	26.34	6.88
		MF2	29.44	7.56
		MF3	18.13	4.43
		MF4	29.45	7.67

The bold numbers show the RFs with higher weights

Table 5 The classification of risk factors (RFs)

RFs	Likelihood weights (%)	Consequence weights (%)	Risk Index (%)	Risk class
MF4	7.38	7.67	7.42	E
SF2	6.19	8.45	7.32	
SF3	6.87	8.11	7.30	
MF2	5.69	7.56	6.90	H
MF3	9.32	4.43	6.81	M
MF1	5.04	6.88	6.21	
SF1	6.54	5.88	6.18	
IF2	5.96	7.65	5.90	
FF2	5.54	5.34	5.85	
IF3	7.05	3.55	5.50	
FF1	4.42	6.55	5.49	
IF1	5.76	5.77	5.32	L
FF3	6.35	5.00	5.12	
FF4	6.32	4.10	4.77	
SF4	5.78	4.55	4.71	
IF4	6.43	3.67	4.26	

The bold numbers show the RFs with higher weights

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