Analysis of Supply Chain Risk in Ceramic Industry: A Case Study

by

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CERTIFICATE OF APPROVAL

The thesis titled "Analysis of Supply Chain Risk in Ceramic Industry: A Case Study" submitted by Md. Abdullah -Al- Zubayer, Roll No.: 1015082102F, Session: October-15, has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Master of Engineering in Advanced Engineering Management on April 16, 2018.

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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Md. Abdullah -Al- Zubayer

This Work is Dedicated to My Parents

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List of Abbreviations

AHP	: Analytic Hierarchy Process
MCDM	: Multi-criteria Decision Making
SCM	: Supply Chain Management
SCRM	: Supply Chain Risk Management
TOPSIS	: Technique for Order of Preference by Similarity to Ideal Solution

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Abstract

Risk management has emerged as an important issue in managing supply chain effectively in the presence of uncertainties that result from unexpected variations along the supply chain. Assessing and managing supply chain risk are getting significant attention to practitioners and academics. At present, the ceramic industry of Bangladesh is growing. Thus, managers in the ceramic industry need to properly assess supply chain risks in order to mitigate them.

This thesis identifies and analyzes various supply chain risks occurring in a ceramic factory of Bangladesh. A model is proposed based on technique for order preference by similarity to ideal solution (TOPSIS) and fuzzy-TOPSIS method for evaluating supply chain risks. Twenty supply chain risks factors were identified through an extensive literature review and consulting with experts from the ceramic factory. TOPSIS and fuzzy-TOPSIS contributed to the analysis and assessment of those risks. Sensitivity analysis was performed to understand the stability of ranking of risks.

The result of this research indicates that lack of operational quality, lack of material quality and damage in inventory risks are the major risks. The outcome of this research is expected to assist industrial managers and practitioners in the ceramic sector to take proactive actions to minimize supply chain risks.

Chapter 1
Introduction

1.1 Introduction

To overcome uncertain conditions resulting from a worldwide rapid change in technology, market demand, and consumer preferences, at present organizations need to consider risk management in supply chains. Nowadays, the business process is more complex and there is an emergence of large risk events from various activities in business. These events lead to increase risk management activities more than earlier. Because of the uncertain nature and the system‟s effect on the firm‟s financial performance, the supply chain of an enterprise is now facing more risk than before.

Supply chain management (SCM) aids enterprises through optimizing core business practices, minimizing logistic expenses, improving customer satisfaction and so on (Sun et al., 2015). SCM must try to understand and manage various activities within supply chain in a systematic manner. One of the goals of the SCM is to respond to uncertainties without incurring any additional costs. SCM has to manage various uncertainties like errors in demand forecast, variation in lead times, natural calamity, machines breakdown, labor issues etc. Although, SCM has increased the efficiency of supply chain, it also added various risk (Berenji and Anantharaman, 2011). These risks are unavoidable and thus effort should be made to mitigate them.

Supply chain risks originate from various sources both within and outside the organization and can be considered as an exposure to events that obstruct the efficient management of supply chains (Ghadge et al., 2012). According to Hubbard (2009), risk is measurable because, it is the consequence of uncertainty having some possibilities like loss or other unwanted consequences. In general, it is observed that, supply chain risk management (SCRM) has become an integral part of holistic SCM (Christopher and Lee, 2004). According to Hessemi and Savoji (2011), SCRM can be thought of one of managerial functions. Gaonkar (2004) referred that supply chain practitioners must often seek some safety mechanisms to defend against unanticipated risks, thus nowadays; it has become tremendously essential for managers to engage risk management tools in SCM.

Because of the progression in construction and housing sector, the ceramic industry in Bangladesh has grown very rapidly and this leads to escalating demand for sanitary ware, floor and wall tiles (Mahmood et al., 2013). Like other manufacturing industries, the ceramic industry has its own supply chain network, including manufacturers, retailers, wholesalers and couriers (Georgise et al., 2014). As there are various risks involved in supply chain, identification and ranking of various risks are crucial for stakeholders who aim to produce best quality materials and products within minimum cost. Chamzini et al. (2013) proposed that it is necessary to identify significant risks in the first place to build strategies to mitigate them. Risk ranking is an important step towards a better fulfillment of this requirement. This thesis aims to identify and rank major supply chain risks that occur in the ceramic industry of Bangladesh.

1.2 Research Gap and Motivation

There are various works available in the context of ceramic sector. Bonavia and Marin (2006), Babu and Thirugnanam (2016) discussed about lean implementation in ceramic industry. Narapinij (2016) discussed about the waste reduction process in ceramic factory and Jahan (2010) discussed about the competitive environment of ceramic sector of Bangladesh. The extant literature reveals that there is no work on identifying and analyzing various supply chain risks in the context of ceramic industry in Bangladesh. Despite the growth of the ceramic sector, the literature lacks to identify the supply chain risks (SCR) in the context of Bangladesh.

Thus, this study attempts to fill this research gap in the supply chain risk management literature with the help of the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and fuzzy-TOPSIS approach. The major contribution of this research is the identification and analyzing of common SCR in the field of ceramic industry. TOPSIS and fuzzy-TOPSIS approach have been used in this research to effectively identify most significant risks. To realize the TOPSIS and fuzzy-TOPSIS framework, a real life case study on a ceramic factory is also introduced.

1.3 Objectives of the Present Work

The purpose of this thesis is to identify most influential SCR in the ceramic sector of Bangladesh. The objectives of this study are:

1. To identify major risks associated with supply chain for a ceramic factory in Bangladesh.
2. To evaluate and analyze most significant risks with the help of TOPSIS and fuzzy-TOPSIS approach.

1.4 Scope of the Thesis

The thesis is organized into five chapters including this one. The chapters are structured in the following way:

Chapter 1 gives the motivation and objectives of this thesis.

Chapter 2 presents the literature review of supply chain management, supply chain risk management, an overview of ceramic sector of Bangladesh.

Chapter 3 gives the research methodology. Also, an overview of TOPSIS method, fuzzy-TOPSIS method, and application of TOPSIS and fuzzy-TOPSIS methods is illustrated in Chapter 3.

Chapter 4 describes the data collection and analysis. Results, discussions on findings and sensitivity analysis are also included in this chapter.

Finally, conclusions, managerial implications and recommendations are presented in Chapter 5. References and appendix are presented at the end of the thesis.

Chapter 2
Literature Review

2.1 Supply Chain Management

Supply chain management can be described as a dynamic activity involving the management of materials, information and funds as they move in a process from supplier to manufacturer to wholesaler to retailer to consumer (Chopra and Meindl, 2007). Christopher (1992) described supply chain as a network of organizations from upstream players to downstream players that are involved in different processes and activities to produce value in the form of product and services for the end-users. Mentzer et al. (2001) defined supply chain as a set of three or more entities (organizations and individuals) those are directly involved in the flows of products, services, finance and information from source to the customers. Tan (2001) described supply chain as the integration of various functional areas within an organization with a view to enhancing the flow of goods from immediate strategic suppliers through manufacturing and distribution chain to the end users. The main objective of SCM is to maximize the overall profit along the supply chain. Successful supply chain requires many decisions for ensuring these flows. SCM activity is the root of maximizing profit of any kinds of industrial fields as well as service organizations. Therefore, it is necessary to improve the supply chain management activities for the successful business.

2.2 Supply Chain Risk Management

Risk can be defined as uncertain and unfavorable consequences. Risk is related to the deviation from the expected value of a certain performance measure; therefore it has a negative consequence of impact (Wagner and Bode, 2008). Bogataj and Bojataj (2007) identified risk as a variation of outcomes; the value added activity in a chain can be decreasd due to the influence of the risk. In the context of supply chain, risk can be defined as the uncertainty of an event occurrence and this event could affect one or more relationship within the supply chain and could have a negetive influence to the achievement of business objectives of a company (Tang, 2006). As supply chain is directly involved in the flows of products, materials and information from source to the customers, supply chain risks affect these flows of across organization boundaries (Jüttner et al., 2003). Therefore, the supply chain risk is the probability and impact of unexpected events or conditions and it has negative influence on any part of a supply chain that could lead to operational or strategic level failures or irregularities.

Supply chain performance is influenced negatively by the occurrence of risk events in different stages of the supply chain. An increase in uncertainty leads to increase in the supply chain vulnerability (Svensson, 2000). Unexpected variations in capacity constraints, breakdowns, quality problems or even natural disasters can make supply chain more vulnerable to risk. If any element of supply chain fails, it will potentially cause a disruption for all appertaining companies (Yang and Yang, 2010). Tang (2006) defined supply chain risk management (SCRM) as “the management of supply chain risks through coordination or collaboration among the supply chain partners so as to ensure profitability and continuity” (p. 453). Ho et al. (2015) defined SCRM as: “an inter-organizational collective endeavor” and they proposed to utilize “quantitative and qualitative risk management approaches to identify, evaluate, mitigate and monitor those adversely affected unanticipated events or conditions in the supply chain” (p. 5036). The SCRM process begins with identifying several risks. Risks identification is the key part of the risk assessment phase of the SCRM process. Various authors identified various risks affecting the supply chain. Unfortunately, there is no agreed consensus on classifying supply chain risks in the literature. In doing the literature review, a variety of supply chain risks were identified as discussed below.

- **Capacity risk**

Quin et al. (2014) highlighted the importance of managing capacity risk in the supply chain profitability. Capacity risks encompass the full spectrum of capacity issues that can occur at a production, distribution or transportation tier of the supply chain. This risk is associated with high or low capacity of plant and also includes a lack of capacity flexibility.

- **Control risk**

Ezeonwuka et al. (2017) identified control risk as one of major supply chain risks and stated that it is occurred due to misstatement. Chatterjee and Kar (2016) stated that control system is the rules and processes that administrate how an organization employs control over the processes. Control risk is the risk arising from the application or misapplication of these rules. This risk is associated with changes of managerial decision or crashes in operational schedule planning or failure of control tools/methods.

- **Demand risk**

Rathore et al. (2017) and Ho et al. (2015) referred demand risks as the factors that influence the change in demand. Demand risk relates to potential or actual disturbances in the flow of product and cash between local company and the market. The demand risk may involve inaccurate demand forecasting or other man made natural factors.

- **Economic risk**

Kara and Firat (2017) identified that economic risk incurs loss to supply chains due to changes in economic factors like exchange rate changes, collapse of stock markets or increase in the inflation rate. Economic risk also uncovers a firm to possible loss through changes in financial markets.

- **Environmental risk**

Environmental risk is associated with uncontrollable events and driven by external forces such as weather, earthquakes, port and depot blockades, closure of an entire industrial area due to fire or chemical spillage, events such as earthquake, cyclone, and volcanic activity (Wagner and Bode, 2006). Any uncertainties arising from the supply chain environment interactions are considered as environmental risk sources (Ghadge et al. 2012).

- **Information flow risk**

Information flow is considered as the relationship mediator between material flow and financial flow and this risk may cause by information inaccessibility, information inefficiency and data inaccuracy (Tang and Musa, 2011). Sun et al. (2015) stated that information flow risk results from information sharing, mainly caused by the bullwhip effect of the supply chain, by artificial exaggeration and manipulation in the information transfer process.

- **Inventory risk**

Ghadge et al. (2012) defined inventory risk as a risk arising from buffer or stock out inventories leading to unnecessary handling cost or lost opportunity cost. According to Gueant et al. (2013), inventory risk results from damage of inventory as well as from too high or too low inventory level.

- **Lead time related risk**

Lead time is the gap between placing and receiving an order and lead time uncertainty has an impact on safety inventories (Chopra and Meindl, 2007). Risk arises from variability of lead time in manufacturing, sourcing and delivery of products can be thought of as lead time risk (Lin, 2016).

- **Transportation risk**

Transportation risk has a multi-dimensional influence on the supply chain. Kara and Firat (2017) and Rathore et al. (2017) stated that transportation risks results from the uncertainty of the supply chain and the logistics network. Giunipero and Eltantawy (2004) identified that transportation risk could rapidly affect the overall supply chain. Transportation risk occurs because of delay or unavailability of either inbound or outbound transportation due to carrier breakdown or weather problems.

- **Management risk**

The supply chain is a network associated with many upstream and downstream enterprises. Management efficiency and quality of the supply chain have a direct influence on day to day operations of each enterprise. Ghadge et al. (2012)

described management risks as the risks from poor management ability to anticipate and react to the market demands.

- **Market risk**

Kara and Firat (2017) linked market risks with losses of customers and market position. Various factors related to market features and the company"s position may trigger the market risk. Astuti et al. (2013) described that market risks comprise mainly with threats from competitors and alternative products availability in market.

- **Material flow risk**

Material flow risks originate from the physical movement of products or services within and between supply chain elements (Tang and Musa, 2011).

- **Operational risk**

Borghesi and Gaudenzi (2013) defined operational risk as the risk associated with the execution of a company"s business functions. Ghadge et al. (2012) descried operational risk initiated with operational events disrupting material or information flow within the supply chain. Operational risks cover malfunction in process, operations complexity, equipment/ machinery breakdown, operational accidents etc.

- **Price related risk**

Organizations face price related risk in the procured products directly or indirectly through their supply chain processes. Risks related to the purchase price of raw materials, semi-finished or finished goods, auxiliary materials and operating materials are the example of price related risk as opined by Kaufmann et al. (2017).

- **Process risk**

Processes are the orders of value-adding and managerial activities accepted by the company. Process risk relates to disruptions to these processes (Chatterjee and Kar, 2016). It affects the execution of business process and is related to the introduction of new products, technology and customers and operating procedures.

- **Quality risk**

Because of supplier failure or problems at plant, quality risk may take place in the supply chain. Quality control is crucial to minimize the waste generated during the production process. Ghadge et al. (2012) described that outsourcing activity is in part accountable for quality risk in a supply chain.

- **Societal risk**

Societal risk for the supply chain stem mainly from changes in the social environment, changes in political stability, changes to relevant laws, the development and fluctuation of the economy. There are many examples of societal risk, including labour strike, technological risk (Rathore et al. 2017).

- **Supply risk**

Supply risk comprises any risk involving raw materials or semi-finished goods or finished goods that are supplied to the next level in the supply chain. Supply risk is related to the probable uncertainties to the product flow or information flow within the supply chain network of the company. This risk is associated with a firm‟s suppliers, or supplier‟s suppliers being inept to deliver the required materials the company needed to effectively meet its production requirement (Chatterjee and Kar, 2016).

From the above discussion it can be deducted that, various organizations or industries have different risk profiles and require separate SCRM activities. This thesis highlights the main supply chain risk factors that are involved in the ceramic sector of Bangladesh.

2.3 Application of multi-criteria decision making technique in supply chain

Several authors applied multi-critera decision making techniques in supply chains. Liou and Wang (2008) assumed that SCR evaluation under fuzzy environments as multi-criteria decision making (MCDM) problem. MCDM refers to screen, prioritize, rank or select a set of alternatives under usually independent, incommensurate or differing attributes (Gurung and Phipon, 2016).

Chatterjee and Kar (2016) used interval valued fuzzy set along with fuzzy-TOPSIS in the context of SCRM with a view to selecting the best supplier and with six different sets of criteria weights, they performed a sensitivity analysis for analyzing the robustness of the proposed method.

Mavia et al. (2016) identified nine criteria for evaluating suppliers in the context of supply chain risk management and used Shannon entropy mathod for weighing criteria and fuzzy-TOPSIS for ranking suppliers.

Sun et al. (2015) identified main supply chain risk factors related to manufacturing industries and presented a supply chain risk evaluation index.

Vosooghi et al. (2012) provided a comprehensive framework using Fuzzy-TOPSIS approach to aid managers in their decision making processes in the crude oil SCRM context. Berenji and Anantharaman (2011) used fuzzy analytic network process and fuzzy-TOPSIS for ranking the SCR and categorized the risks against the key factors to assess the overall impact of them on supply chain performance for a boiler manufacturing company.

Evaluating potential risks of ceramic industry"s supply chain is a multi-criteria decision making (MDCM) problem (Azari et al., 2011). This thesis applied TOPSIS and fuzzy-TOPSIS methods to evaluate the SCR associated with a ceramic factory. The conventional TOPSIS method of SCR evaluation has limitation in dealing with the imprecise or vague nature of linguistic assessment. In order to overcome this limitation, fuzzy-TOPSIS method is adopted.

2.4 Overview of Ceramic Industry in Bangladesh

In Bangladesh, ceramic industry has become one of the exports oriented, fast growing sectors and has been playing a dynamic role to our economy by earning and saving foreign currencies via ceramic goods exportation after meeting the local demand. Local factories in Bangladesh are capable of meeting almost 80% of the total demand of ceramic. With favorable international environment, Bangladesh has been able to attain a strong annual export growth rate of about 12% over the last decade. A recent article “An Overview of Bangladesh's Ceramics Industry,” (2017) contends that Bangladesh exports quality ceramic products to international market after fulfilling the 80 percent of local demand. In the end of 2017, there were 60 ceramic industrial units all over Bangladesh and more than 500,000 people involved in this sector. In last five years, there is 200% growth in production. Bangladesh exports ceramic products more than 50 countries. The United States, Canada, Italy, Spain, France, the UAE, New Zealand, the Netherlands, Australia and Sweden are the largest destination for exporting goods. In the international market, China and Thailand are the major competitors for Bangladeshi ceramic manufacturers. However, Bangladesh is in a strong position because of having the low labor costs.

The global ceramic industry is worth of US$20 billion. According to Bangladesh ceramic manufacturers and exporters association (BCMEA) Bangladesh, the industry earns more than USD 42 Million through export. Bangladesh is growing rapidly in this sector with its high quality, cost ratio and creative human resource base. Traditionally, ceramic industry is a labor-intensive sector and companies in developed countries like Italy, Spain are facing difficulties in competitive market owing to high labor cost and recent global financial crisis. Bangladesh is perfectly positioned to be a strategic partner in production and supply of ceramic goods because it has rich gas, low-labor cost and traditional „bone china" technology (Jahan, 2010).

Although Bangladeshi ceramic industry has managed to create a firm position in the international market, ceramic industry of Bangladesh are facing a stiff competition with some countries including India, Sri Lanka, China and Thailand. In the export market, some ceramic manufacturers like Monno Ceramic, Shienpukur Ceramic, Standard Ceramic, FARR Ceramic and Bengal Fine ceramic are still the foremost, and have been recently improving their share of export market by expanding their capacity. Other ceramic manufacturers are also increasing their production capacity to meet demand for ceramic wares. The developed countries are placing more orders to low-cost countries for quality ceramic wares as a result of the global declining impact and increasing labor cost. Bangladesh therefore has a potential to be one of the top ceramics-exporting countries in the world.

Chapter 3
Methodology

3.1 Research Methodology

The aim of this research work is to find out the most significant supply chain risks in the context of ceramic industry in Bangladesh. Figure 3.1 illustrates the methodology of this research. The proposed research consists of four steps as mentioned bellow.

Step 1: Identification of existing risk factors

The objective of this step is to generate a comprehensive list of risks based on the events that might have an adverse impact. In this step, most relevant supply chain risks are identified through a literature survey and from experts" input. A total of 25 supply chain risk factors are identified from reviewing the existing literature. After that, the risk factors are analyzed and finally the most relevant risk factors are identified.

Step 2: Selection of the evaluating criteria

Criteria selection is the beginning initiative for supply chain risk evaluation. Borghesi and Gaudenzi (2013) mentioned that supply chain risks can be evaluated on the basis of their priority and nature of actions required. Risk is considered as a function of expected loss and determined how often the risk will occur and by the severity of the risk. Quality of controls is specified to effectively eliminate, mitigate or to reduce associated risks to an acceptable level. Thereby, in this research, three evaluation criteria are used to evaluate the identified risks. Those are

Probability (C_1) – the likelihood of occurrence of each risk,

Severity (C_2) – potential effect of each risk type of the organization and

Quality of controls (C_3) – the quality of process, systems and cultural controls to mitigate these risks.

In this step, the weight of each criterion has also been identified.

Step 3: Evaluation of identified risks using TOPSIS and fuzzy-TOPSIS method

In this stage, supply chain risks are evaluated using TOPSIS and fuzzy-TOPSIS technique. For evaluation of ratings and weights of risk factors and criteria, linguistic terms are used. Table (4.10) represents the definition of linguistic terms and triangular fuzzy numbers.

Step 4: Sensitivity analysis

Sensitivity analysis is a convenient tool to depict how the change in the importance or weight of the criteria influences alternatives. Sensitivity analysis is imposed here to find out the consequence of criteria weights on decision making.

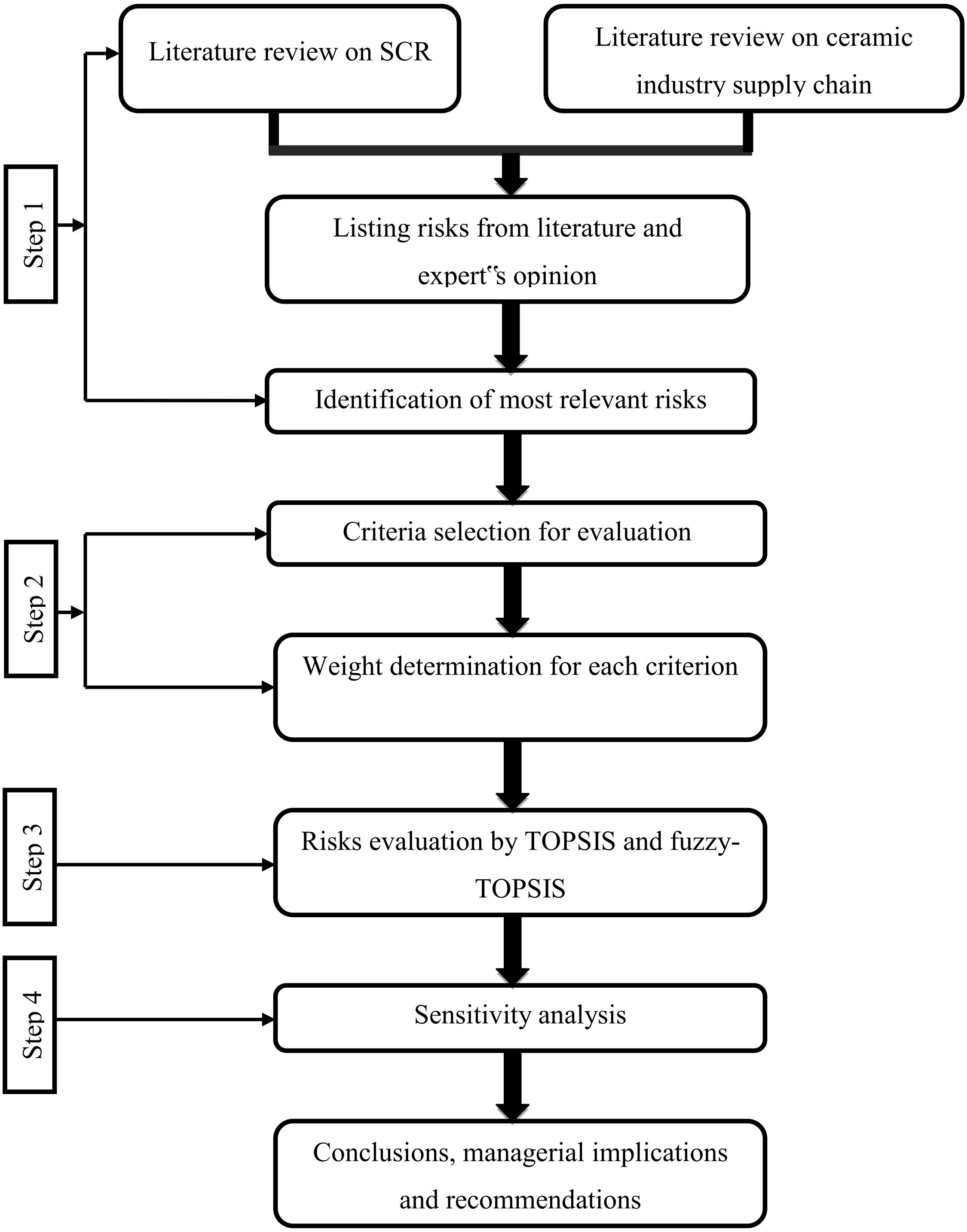

Fig. 3.1 Overall approach of the research methodology

3.2 Solution Methodology

In this section TOPSIS method, Fuzzy approach and fuzzy-TOPSIS methods are presented sequentially.

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3.2.1 TOPSIS Method

Hwang and Yoon in 1981 proposed the Technique for Order Preference by Similarity to Ideal Situation (TOPSIS). TOPSIS is one of the useful Multi Criteria Decision Making (MCDM). According to this technique, the best alternative would be the one that should have the shortest Euclidian distance from the positive ideal solution and farthest from the negative ideal solution.

A MCDM problem with m alternatives (A_1, A_2,…., A_m) that are evaluated by n attributes (C1, C2 ,…., C_n), decision matrix will be obtained with m rows and n columns as the following matrix. An element x_{ij} of the matrix indicates the performance rating of the i^{th} alternative, A_i, with respect to the j^{th} attribute, C_j, as shown in Eq. (1):

$$D = \begin{array}{c|cccccc|} & C_1 & C_2 & C_3 & \cdots & & C_n \\ \hline A_1 & X_{11} & X_{12} & X_{13} & . & . & . & X_{1n} \\ A_2 & X_{21} & X_{22} & X_{23} & . & . & . & X_{2n} \\ A_3 & X_{31} & X_{32} & X_{33} & . & . & . & X_{3n} \\ . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . \\ A_m & X_{m1} & X_{m2} & X_{m3} & . & . & . & X_{mn} \\ \hline \end{array} \qquad (3.1)$$

The steps regarding TOPSIS are as follows

Step 1: Construction of normalized decision matrix. This step transforms various attribute dimensions into non-dimensional attributes, which allows comparisons across criteria. The normalized value of x_{ij} is defined in Eq. (3.2).

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{j} x_{ij}^2}}, \qquad i = 1, 2, \ldots, m \;;\; j = 1, 2, \ldots, n \qquad (3.2)$$

Step 2: Construction of the weighted normalized decision matrix. Assume a set of weights for each criteria w_j such that $W = \{w_j \mid j = 1, 2, \ldots, n\}$.
Multiply each column of the normalized decision matrix by its associated weight gives the weighted normalized decision matrix. An element of the new matrix is:

$$v_{ij} = w_j \times r_{ij}, \; for\ i = 1, 2, \ldots, m; j = 1, 2, \ldots, n \qquad (3.3)$$

Step 3: Determination of the positive ideal (A+) and negative ideal (A–) solutions. The A* and A– are defined as positive ideal solution (PIS) and negative ideal solution (NIS) respectively, in terms of the weighted normalized values, as shown in Eqs. (3.4) and (3.5).
Positive Ideal solution:

$$A^* = \{v_1^*, \ldots\ldots, v_n^*\}, where\ v_j^* = \max\left(v_{ij}\right) if\ j \in J; \min\left(v_{ij}\right) if\ j \in J' \} \qquad (3.4)$$

Negative ideal solution:

$$A^- = \{v_1^-, \ldots\ldots, v_n^-\}, where\ v' = \min\left(v_{ij}\right) if\ j \in J; \max\left(v_{ij}\right) if\ j \in J' \} \qquad (3.5)$$

Where J is a set of benefit attributes (larger the better type) and J' is a set of cost attributes (smaller the better type).

Step 4: Calculation of the separation measures for each alternative.
The separation of each alternative from the positive ideal alternative is:

$$S_i^* = \sqrt{\sum (v_{ij} - v_j^*)^2} \text{ for i} = 1, 2, 3, \ldots\ldots, \text{m}. \qquad (3.6)$$

Similarly, the separation of each alternative from the negative ideal alternative is:

$$S_i^- = \sqrt{\sum (v_{ij} - v_j^-)^2} \text{ for i} = 1, 2, 3, \ldots\ldots, \text{m} \qquad (3.7)$$

Step 5: Calculation of the relative closeness to the ideal solution or similarities. Next, the relative closeness of alternative Ai with respect to the ideal solution A* is defined as follows:

$$C_i^* = \frac{S_i^-}{S_i^* - S_i^-} \; ; 0 \leq C_i^* \leq 1, \text{for i} = 1, 2, 3, \ldots\ldots, \text{m} \qquad (3.8)$$

Evidently, $C_i^* = 1$ if and only if $A_i = A^*$and $C_i^- = 0$ f and only if $A_i = A^-$.

Step 6: Ranking the preference order.

The best satisfied alternative can now be decided according to preference rank order of C_i^*. Choose an alternative with maximum C_i^* or rank the alternatives according to C_i^* in decreasing order.

3.2.2 Fuzzy Approach

Fuzzy set theory was introduced by Zadeh (1965). It is a powerful tool for handling imprecise data and it enables the decision makers to deal the uncertainties effectively (Chamzini et al., 2013). Fuzzy set theory has been used for modeling decision making processes based on imprecise and vague information (Zadeh, 1965). A fuzzy set is an example of crisp sets that allows partial membership. Different types of fuzzy numbers are available in the literature. The triangular fuzzy numbers (TFNs) are most popular and are convenient because they are computed simply and are useful in representation and information processing in a fuzzy environment (Yazdani et al., 2012).

3.2.3 Fuzzy-TOPSIS Method

TOPSIS method uses the exact values of the judgments done by the experts. According to Kabir and Hasin (2012), human preference is uncertain for many real-life situations and decision makers may be reluctant or inept to allocate precise values to their judgments. That is why the fuzzy-TOPSIS methodology is proficient to deal with multi criteria decision making. The linguistic values are converted into fuzzy numbers and thereby it allows the decision-makers to integrate vague or imprecise information into the decision model (Shukla et al., 2014).

Mathematical concepts of fuzzy-TOPSIS can be illustrated as follows:

Step 1: Selection of the linguistic evaluations for criteria and alternatives regarding to criteria.

The significant weights of evaluation criteria and the alternatives‟ ratings are considered as linguistic terms to calculate risk in fuzzy situation.

The weights of criteria and ratings of alternatives given by *p* decision makers, as expressed in Eqs. (3.9) and (3.10) respectively:

$$\widetilde{w}_j = \frac{1}{p}(\widetilde{w}_j^1 + \widetilde{w}_j^2 + \cdots \ldots \ldots + \widetilde{w}_j^p) \quad (3.9)$$

$$\tilde{x}_{ij} = \frac{1}{p}(\tilde{x}_{ij}^1 + \tilde{x}_{ij}^2 + \cdots \ldots \ldots + \tilde{x}_{ij}^p) \quad (3.10)$$

Step 2: Fuzzy decision matrix construction.

Fuzzy decision matrix of n criteria and m alternatives can be obtained with m rows and n columns as subsequent matrix:

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ . \\ . \\ A_m \end{array} \begin{array}{c} \begin{array}{cccccc} C_1 & C_2 & C_3 & . & . & C_n \end{array} \\ \begin{bmatrix} \check{X}_{11} & \check{X}_{12} & \check{X}_{13} & . & . & \check{X}_{1n} \\ \check{X}_{21} & \check{X}_{22} & \check{X}_{23} & . & . & \check{X}_{2n} \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ \check{X}_{m1} & \check{X}_{m2} & \check{X}_{m3} & . & . & \check{X}_{mn} \end{bmatrix} \end{array}$$

$$\widetilde{w} = (\widetilde{w}_1, \widetilde{w}_2, \ldots \ldots, \widetilde{w}_n) \quad (3.11)$$

Step 3: Fuzzy decision matrix normalization.

Linear scale transformation is used for the normalization of fuzzy decision. Eqs. (3.12), (3.13), (3.14) are used to calculate and to convert the criteria.

$$\tilde{R} = [\tilde{k}_{ij}]_{m \times n}, i = 1, 2, \ldots \ldots, m; j = 1, 2, \ldots \ldots, n \quad (3.12)$$

$\tilde{k}_{ij} = (\frac{l_{ij}}{u_j^+}, \frac{m_{ij}}{u_j^+}, \frac{u_{ij}}{u_j^+})$ and $u_j^+ = max_i\, u_{ij}$ (benefit criteria) (3.13)

$\tilde{k}_{ij} = (\frac{l_j^-}{u_{ij}}, \frac{l_j^-}{m_{ij}}, \frac{l_j^-}{l_{ij}})$ and $l_j^- = min_i\, l_{ij}$ (cost criteria) (3.14)

Step 4: Weighted normalized fuzzy decision matrix calculation.

Weighted normalized decision matrix, $\tilde{V}$ is calculated by multiplying the weights of the criteria, $\tilde{w}_j$, by the elements $\tilde{k}_{ij}$ of the normalized fuzzy decision matrix

$\tilde{V} = \left[\tilde{v}_{ij}\right]_{m\times n}, i = 1, 2, \ldots.., m; j = 1, 2, \ldots.., n$ (3.15)

Where $\tilde{v}_{ij} = \tilde{k}_{ij} \times \tilde{w}_{ij}$ (3.16)

Step 5: The fuzzy positive ideal solution (FPIS A^+) and fuzzy negative-ideal solution (FNIS A^-) are determined as described in the following part.

$A^+ = \{ \tilde{v}_1^+, \tilde{v}_2^+, \ldots.. \tilde{v}_m^+ \}$ (3.17)

$A^- = \{ \tilde{v}_1^-, \tilde{v}_2^-, \ldots.. \tilde{v}_m^- \}$ (3.18)

Where $\tilde{v}_j^+ = (1,1,1)\ and\ \tilde{v}_j^- = (0,0,0)$

Step 6: By using Eqs. (3.19) and (3.20) the distance of every alternative from A+ and A- are calculated.

$d_i{}^+ = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^+),\ \ i = 1, 2, \ldots \ldots, m$ (3.19)

$d_i{}^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-),\ \ i = 1,2, \ldots \ldots, m$ (3.20)

Where the distance between two fuzzy number $\tilde{y} = (y_1, y_2, y_3)$and $\tilde{z} = (z_1, z_2, z_3)$ can be calculated as follows:

$d(\tilde{y}, \tilde{z}) = \sqrt{{}^1/_3\,[(y_1 - z_1)^2 + (y_2 - z_2)^2 + (y_3 - z_3)^2}$ (3.21)

Step 7: Closeness coefficient calculation.

The closeness coefficient (CC_i) considers the distance of the FPIS, $d_i{}^+$and the FNIS, $d_i{}^-$ instantaneously. Using Eq. (3.22), closeness coefficient for each alternative is obtained as follows:

$CC_i = \frac{d_i^-}{d_i^- + d_i^+}$ (3.22)

Step 8: Preference order ranking.

Based on the closeness coefficient, CC_i, the ranking order of all alternatives can be determined and the best one from a set of alternatives can be selected the best alternatives are closest to the FPIS and farthest to the FNIS.

3.2.4 Sensitivity Analysis

In a MCDM problem, if there is an alteration of weight of the P[th] attribute by Δp, then other attributes weight would be altered by Δj, where:

$$\Delta j = \frac{\Delta p.w_j}{w_p - 1}, j = 1, 2, \dots \dots, k; \;\; j \neq p \tag{3.23}$$

Alinezhad and Amini (2011), Poovarasan and Kaviyarasu (2014) described that, in a MCDM problem, if the weight of the P[th] attribute alters from w_p to w'_p, the main result would be: $w'_p = w_p + \Delta p$ (3.24)

Then, other attributes" weight would change as:

$$w'_j = \frac{(1 - w_p - \Delta p).w_j}{1 - w_p} = \frac{1 - w'_p}{1 - w_p}.w_j, j = 1, 2, \dots \dots, k; \;\; j \neq p \tag{3.25}$$

Then, new weights of the attributes would be $W'^t = (w'_1, w'_2, w'_3, \dots \dots w'_k)$, that is:

$$w'_j = \begin{cases} w_j + \Delta p, \; and \; j = p \\ \frac{1 - w'_p}{1 - w_p}.w_j, \; and j = 1, 2, \dots \dots, k, \; j \neq p \end{cases} \tag{3.26}$$

$$w'_p = w_p + \Delta p \rightarrow \begin{cases} if \; w'_p > w_p & \rightarrow w'_j < w_j \\ if \; w'_p < w_p & \rightarrow w'_j > w_j \end{cases}, j = 1, 2, \dots \dots, k; \;\; j \neq p \tag{3.27}$$

In a decision making problem solved by TOPSIS, the final score of alternatives will be changed, if the weight of one attribute changes (Alinezhad and Amini, 2011).

Chapter 4
Data Collection and Analysis

4.1 Data collection

The developed methodology has been applied to a real case study and used to rank the supply chain risks a ceramic factory in Bangladesh. The ceramic factory „X-Ceramics Limited‟ has been taken for case study. The case factory requires the identification of major supply chain risks and the ranking of those risks to take necessary proactive measures. Table A1 (in appendix A) represents the profile of the case company.

In this research, two steps have been followed for collecting the necessary data and information. In Step 1, most relevant supply chain risks in the ceramic sector were identified, and in Step 2, the analysis of the identified risks with the help of experts‟ input was prepared.

During data collection phase, a group of three experts, i.e. decision makers (DM), from relevant factory having professional experience more than six years is formed. Experts‟ profile is shown in Table 4.1. The required data have been collected from the experts.

Table 4.1 Experts‟ profile

Name of the experts	Position	Years of experience
DM1	Production Manager	12 years
DM2	Supply chain coordinator	7 years
DM3	Senior executive	6 years

The two step data collection process is explained as below:

Step 1: Identification of most relevant supply chain risks in ceramic sector

At first, twenty five supply chain risks have been identified through an existing literature survey and investigating the case factory. To endorse the list, the experts were requested to make necessary modification, add or remove any risk relevant to the supply chain of Bangladeshi ceramic sector. Subsequently the responses were gathered from experts in order to finalize the risks. Therefore, twenty possible supply chain risks (sub-risks) were identified for ceramic sector in Bangladesh and presented in Table 4.2.

Table 4.2 Supply chain risk assessment

Risk	Major Risks	Sub-risks
Supply chain risks	Demand risks	Sales withdrawal (A1)
		Changes in market demand (A2)
	Inventory risks	Inventory level (A3)
		Damage in inventory (A4)
	Capacity risks	Lack of capacity flexibility (A5)
	Lead time risks	Manufacturing lead time (A6)
		Product delivery lead time (A7)
		Sourcing lead time (A8)
	Price related risks	Raw material purchasing price (A9)
		Operating material price (A10)
	Supply risks	Lack of material quality (A11)
		Inbound supply delay (A12)
	Transportation risks	Damage of goods during transportation (A13)
		Transport delay (A14)
		High Transportation cost (A15)
	Operational risks	Changes in design (A16)
		Lack of operational quality (A17)
		Human error (A18)

Table 4.2 continued

Risk	**Major Risks**	**Sub-risks**
	Environmental risks	Natural disaster (A19)
	Societal risks	Labor unrest (A20)

Step 2: Analysis of identified risks with the help of experts‟ input for ranking these risks.

In this step, the identified finalized risks were ranked using TOPSIS and fuzzy-TOPSIS with the help of experts‟ input. To support the analysis, the experts were requested to contribute to a group meeting. With the help of experts‟ feedback, a pairwise comparison table was formed to determine the relative importance of weights of the assessment criteria. Thereafter using the experts‟ input the supply chain risk assessment was performed.

Supply chain risk analysis consists of three levels are shown in Figure 4.1. At the highest level the objective of the problem is stated, however, the criteria and the risk factors are presented respectively in the second level and the third level. Each of the twenty risks is responsible for probability (C1), severity (C2), and quality of controls (C3).

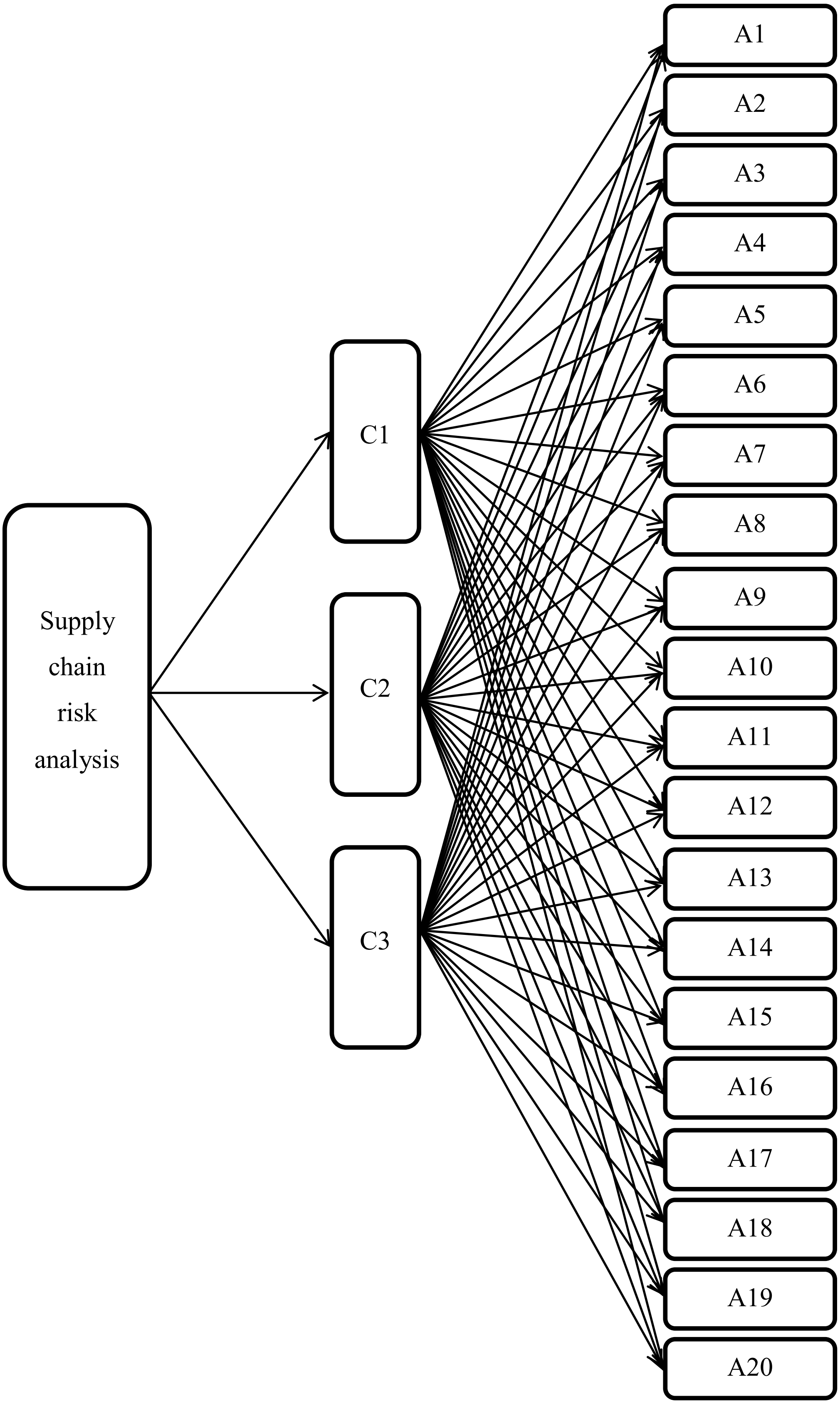

Figure 4.1 Supply chain risk analysis hierarchy

4.2 Evaluating the Existing Risks Using TOPSIS and Fuzzy-TOPSIS

4.2.1 TOPSIS

Table 4.3 represents the decision matrix constructed based on the performance ratings (1-10 scale where 10 indicate very risky) given by the experts for three criteria as well as the twenty risk factors. Based on the first stage of the TOPSIS procedure, each element is normalized by Eq. (3.2). The resulting normalized decision matrix for the TOPSIS analysis is shown Table 4.4.

Table 4.3 Decision matrix

Risks	C1	C2	C3
A1	9	9	5
A2	6	9	8
A3	8	9	9
A4	7	10	9
A5	2	4	6
A6	5	7	7
A7	4	7	7
A8	3	8	7
A9	6	8	7
A10	9	6	8
A11	7	9	9
A12	5	9	6
A13	7	9	8
A14	8	8	7
A15	7	10	9
A16	4	9	9
A17	10	9	10
A18	7	6	8
A19	6	8	4
A20	3	7	6

Table 4.4 Normalized decision matrix

Risks	C1	C2	C3
A1	0.3092	0.3092	0.1718
A2	0.2062	0.3092	0.2749
A3	0.2749	0.3092	0.3092
A4	0.2405	0.3436	0.3092
A5	0.0687	0.1374	0.2062
A6	0.1718	0.2405	0.2405
A7	0.1374	0.2405	0.2405
A8	0.1031	0.2749	0.2405
A9	0.2062	0.2749	0.2405
A10	0.3092	0.2062	0.2749
A11	0.2405	0.3092	0.3092
A12	0.1718	0.3092	0.2062
A13	0.2405	0.3092	0.2749
A14	0.2749	0.2749	0.2405
A15	0.2405	0.3436	0.3092
A16	0.1374	0.3092	0.3092
A17	0.3436	0.3092	0.3436
A18	0.2405	0.2062	0.2749
A19	0.2062	0.2749	0.1374
A20	0.1031	0.2405	0.2062

To calculate the weighted normalized matrix the attribute weight information is required. From the analytical hierarchy process (AHP), the relative weight of each criterion has been estimated. The linguistic definitions for the importance ratios are shown in Table 4.5. The experts were requested to participate in pair wise comparison matrix. There were various arguments in the discussion process. The discussion needed to synchronize to arrive at a harmony for each comparison matrix. The pairwise comparison on the three criteria and associated weights are shown in Table 4.6.

Table 4.5 Linguistic definition for importance ratios of two selected items

Level of importance (a_{ij})	Linguistic definition for comparison of the i^{th} and the j^{th} items
1	The i^{th} item is equal important as the j^{th} item
3	The i^{th} item is slightly more important than the j^{th} item
5	The i^{th} item is more important than the j^{th} item
7	The i^{th} item is strongly more important than the j^{th} item
9	The i^{th} item is extremely more important than the j^{th} item
2, 4, 6, 8	The intermediate values between two adjacent judgments
$1/a_{ij} = a_{ji}$	The transposed evaluation between the i^{th} and the j^{th} items

Table 4.6 The pairwise comparison table of the relative importance

	C1	C2	C3	Weights
Probability (C1)	1	3	5	0.106
Severity (C2)	0.333	1	3	0.260
Quality of control (C3)	0.2	0.333	1	0.633

The weighted normalized decision matrix is shown in Table 4.7. The positive ideal solution and the negative ideal solution are shown in Table 4.8. Here, C1, C2 are the cost criteria and C3 is the benefit criteria. Finally, the separation measures, relative closeness coefficient and the ranking order of different risks are shown in Table 4.9.

Table 4.7 The weighted normalized decision matrix

Risks	**C1**	**C2**	**C3**
A1	0.032	0.067	0.117
A2	0.021	0.067	0.187
A3	0.028	0.067	0.211
A4	0.025	0.074	0.211
A5	0.007	0.030	0.140
A6	0.018	0.052	0.164
A7	0.014	0.052	0.164
A8	0.011	0.059	0.164
A9	0.021	0.059	0.164
A10	0.032	0.045	0.187
A11	0.025	0.067	0.211
A12	0.018	0.067	0.140
A13	0.025	0.067	0.187
A14	0.028	0.059	0.164
A15	0.025	0.074	0.211
A16	0.014	0.067	0.211
A17	0.035	0.067	0.234
A18	0.025	0.045	0.187
A19	0.021	0.059	0.094
A20	0.011	0.052	0.140

Table 4.8 The positive ideal solution and the negative ideal solution

	C1	**C2**	**C3**
PIS A*	0.007	0.030	0.234
NIS A-	0.035	0.074	0.094

Table 4.9 TOPSIS analysis results

Risks	S^*	S^-	C_i*	Rank
A1	0.125	0.025	0.165	19
A2	0.061	0.095	0.607	9
A3	0.049	0.118	0.707	4
A4	0.053	0.118	0.688	5
A5	0.094	0.071	0.430	16
A6	0.074	0.076	0.504	12
A7	0.074	0.077	0.509	11
A8	0.076	0.076	0.499	13
A9	0.078	0.073	0.485	14
A10	0.055	0.098	0.641	8
A11	0.047	0.118	0.714	3
A12	0.101	0.051	0.333	18
A13	0.062	0.095	0.603	10
A14	0.079	0.072	0.477	15
A15	0.053	0.118	0.688	6
A16	0.044	0.119	0.728	2
A17	0.047	0.141	0.751	1
A18	0.052	0.099	0.654	7
A19	0.144	0.020	0.124	20
A20	0.096	0.057	0.373	17

The final result obtained using TOPSIS method is the ranking order of the risks as follows A17> A16> A11> A3> A4> A15> A18> A10> A2> A13> A7> A6> A8> A9> A14> A5> A20> A12> A1> A19. According to the final scores, it can be concluded that A17, lack of operational quality, has obtained the highest priority among the supply chain risks from the viewpoint of experts‟ perception. The risk A19, natural disaster, obtained the lowest position in this evaluation.

4.2.2 Fuzzy-TOPSIS

The decision makers evaluated the weight of criteria and the ratings of risk factors according to the linguistic terms. To assign the assessment values of these variables, triangular fuzzy numbers (TFN), presented in Table 4.10, were used. The criteria‟s weight given by three decision makers, involved in the selection process, is demonstrated in Table 4.11. The linguistic variables displayed in Table 4.12 are transformed into triangular fuzzy numbers (TFN). The fuzzy weights (w_i) for each criterion, given by the experts, are computed by using Eq. (3.9). Table 4.13 represents the TFN of the fuzzy decision matrix resulting from aggregation of the experts‟ judgments presented in Table 4.9. Tables 4.14 and 4.15 demonstrate the normalized fuzzy decision matrix and the weighted normalized fuzzy decision matrix.

Table 4.10 Definitions of linguistic variables for expert judgment

Linguistic variable to evaluate the weight of the criteria			**Linguistic variable to evaluate the ratings of the risk**		
Terms	Notation	TFN	Terms	Notation	TFN
Very low	VL	0, 0, 0.1	Very poor	VP	0, 0, 1
Low	L	0, 0.1, 0.3	Poor	P	0, 1, 3
Moderately low	ML	0.1, 0.3, 0.5	Moderately poor	MP	1, 3, 5
Moderate	F	0.3, 0.5, 0.7	Fair	F	3, 5, 7
Moderately high	MG	0.5, 0.7, 0.9	Moderately risky	MR	5, 7, 9
High	G	0.7, 0.9, 1	Risky	R	7, 9, 10
Very high	VG	0.9,1, 1	Very risky	VR	9,10, 10

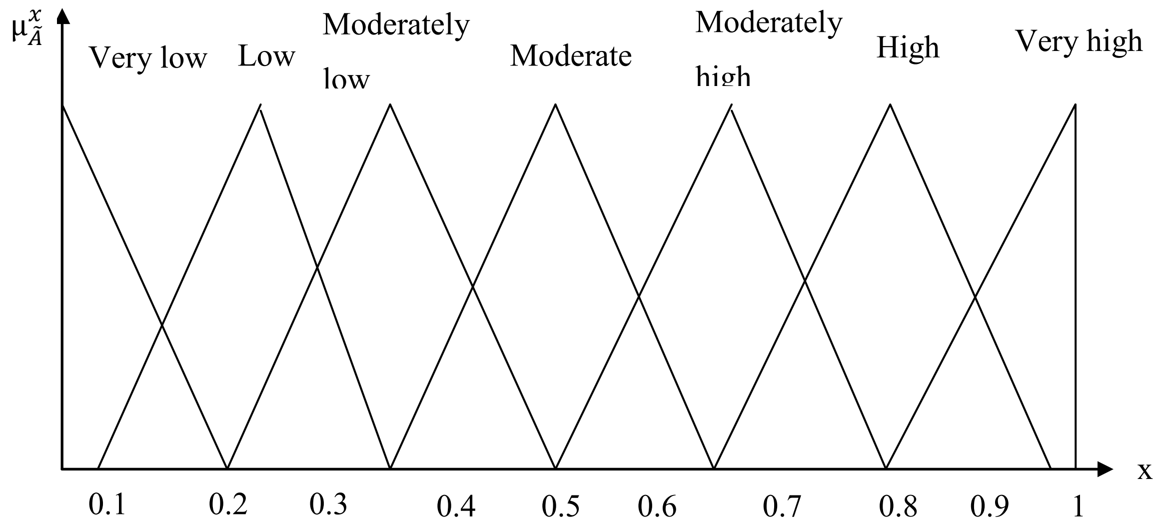

Figure 4.2 Linguistic variable to evaluate the weight of the criteria

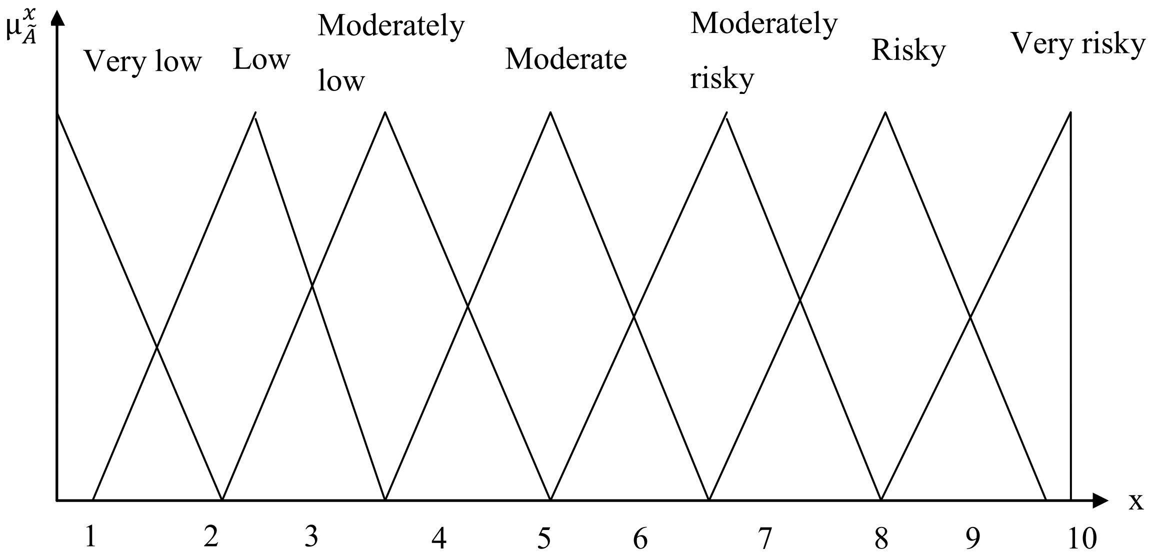

Figure 4.3 Linguistic variable to evaluate the ratings of the risk

Table 4.11 Linguistic assessments for the 3 criteria

Decision Makers	Criteria		
	C1	C2	C3
DM1	ML	H	VH
DM2	H	MH	H
DM3	M	VH	VH

Table 4.12 Linguistic assessments for the twenty risks factors

Risks	DMs	C1	C2	C3	Risks	DMs	C1	C2	C3
A1	DM1	R	R	F	A11	DM1	F	R	R
	DM2	MR	R	F		DM2	MR	R	R
	DM3	R	VR	MP		DM3	R	VR	VR
A2	DM1	MR	R	R	A12	DM1	F	R	MR
	DM2	F	R	R		DM2	MP	R	F
	DM3	F	R	F		DM3	F	MR	F
A3	DM1	VR	R	VR	A13	DM1	R	R	F
	DM2	F	R	F		DM2	F	R	R
	DM3	R	R	VR		DM3	F	VR	R
A4	DM1	MR	VR	R	A14	DM1	MR	F	MR
	DM2	R	VR	R		DM2	MR	R	MR
	DM3	F	R	R		DM3	R	VR	MR
A5	DM1	P	F	F	A15	DM1	F	R	R
	DM2	MP	MP	F		DM2	F	VR	R
	DM3	P	P	MR		DM3	R	VR	R
A6	DM1	F	MR	MR	A16	DM1	MP	R	R
	DM2	MP	MR	MR		DM2	P	R	R
	DM3	MR	F	F		DM3	F	R	R
A7	DM1	MP	MR	F	A17	DM1	R	R	VR
	DM2	F	F	MR		DM2	VR	R	VR
	DM3	MP	MR	MR		DM3	VR	VR	R
A8	DM1	MP	MR	F	A18	DM1	MR	F	MR
	DM2	P	MR	F		DM2	F	F	MR
	DM3	MP	R	R		DM3	R	MR	R
A9	DM1	F	MR	MR	A19	DM1	F	MR	MP
	DM2	MR	MR	F		DM2	F	MR	MP
	DM3	F	R	MR		DM3	MR	R	F
A10	DM1	MR	F	MR	A20	DM1	MP	MR	F
	DM2	R	MR	R		DM2	P	F	MR
	DM3	R	F	MR		DM3	MP	R	F

Table 4.13 Aggregated fuzzy decision matrix

Risks	Criteria								
	C1			C2			C3		
A1	6.333	8.333	9.667	7.667	9.333	10.000	2.333	4.333	6.333
A2	3.667	5.667	7.667	7.000	9.000	10.000	5.667	7.667	9.000
A3	6.333	8.000	9.000	7.000	9.000	10.000	7.000	8.333	9.000
A4	5.000	7.000	8.667	8.333	9.667	10.000	7.000	9.000	10.000
A5	0.000	0.667	2.333	1.333	3.000	5.000	3.667	5.667	7.667
A6	3.000	5.000	7.000	4.333	6.333	8.333	4.333	6.333	8.333
A7	1.667	3.667	5.667	4.333	6.333	8.333	4.333	6.333	8.333
A8	0.667	2.333	4.333	5.667	7.667	9.333	4.333	6.333	8.000
A9	3.667	5.667	7.667	5.667	7.667	9.333	4.333	6.333	8.333
A10	6.333	8.333	9.667	3.667	5.667	7.667	5.667	7.667	9.333
A11	5.000	7.000	8.667	7.667	9.333	10.000	7.667	9.333	10.000
A12	2.333	4.333	6.333	6.333	8.333	9.667	3.667	5.667	7.667
A13	4.333	6.333	8.000	7.667	9.333	10.000	5.667	7.667	9.000
A14	5.667	7.667	9.333	6.333	8.000	9.000	5.000	7.000	9.000
A15	4.333	6.333	8.000	8.333	9.667	10.000	7.000	9.000	10.000
A16	1.333	3.000	5.000	7.000	9.000	10.000	7.000	9.000	10.000
A17	8.333	9.667	10.000	7.667	9.333	10.000	8.333	9.667	10.000
A18	5.000	7.000	8.667	3.667	5.667	7.667	5.667	7.667	9.333
A19	3.667	5.667	7.667	5.667	7.667	9.333	1.667	3.667	5.667
A20	0.667	2.333	4.333	5.000	7.000	8.667	3.667	5.667	7.667
w_{ij}	0.367	0.567	0.733	0.700	0.867	0.967	0.833	0.967	1.000

w_{ij} = Weights of criteria

Table 4.14 Normalized fuzzy decision matrix

Risks	Criteria								
	C1			C2			C3		
A1	0.034	0.040	0.053	0.133	0.143	0.174	0.233	0.433	0.633
A2	0.043	0.059	0.091	0.133	0.148	0.190	0.567	0.767	0.900
A3	0.037	0.042	0.053	0.133	0.148	0.190	0.700	0.833	0.900
A4	0.038	0.048	0.067	0.133	0.138	0.160	0.700	0.900	1.000
A5	0.091	0.200	1.000	0.267	0.444	1.000	0.367	0.567	0.767
A6	0.048	0.067	0.111	0.160	0.211	0.308	0.433	0.633	0.833
A7	0.059	0.091	0.200	0.160	0.211	0.308	0.433	0.633	0.833
A8	0.077	0.143	0.500	0.143	0.174	0.235	0.433	0.633	0.800
A9	0.043	0.059	0.091	0.143	0.174	0.235	0.433	0.633	0.833
A10	0.034	0.040	0.053	0.174	0.235	0.364	0.567	0.767	0.933
A11	0.038	0.048	0.067	0.133	0.143	0.174	0.767	0.933	1.000
A12	0.053	0.077	0.143	0.138	0.160	0.211	0.367	0.567	0.767
A13	0.042	0.053	0.077	0.133	0.143	0.174	0.567	0.767	0.900
A14	0.036	0.043	0.059	0.148	0.167	0.211	0.500	0.700	0.900
A15	0.042	0.053	0.077	0.133	0.138	0.160	0.700	0.900	1.000
A16	0.067	0.111	0.250	0.133	0.148	0.190	0.700	0.900	1.000
A17	0.033	0.034	0.040	0.133	0.143	0.174	0.833	0.967	1.000
A18	0.038	0.048	0.067	0.174	0.235	0.364	0.567	0.767	0.933
A19	0.043	0.059	0.091	0.143	0.174	0.235	0.167	0.367	0.567
A20	0.077	0.143	0.500	0.154	0.190	0.267	0.367	0.567	0.767
w_{ij}	0.367	0.567	0.733	0.700	0.867	0.967	0.833	0.967	1.00

Table 4.15 Weighted normalized fuzzy decision matrix

Risks	C1			C2			C3		
A1	0.01	0.02	0.04	0.09	0.12	0.17	0.20	0.42	0.63
A2	0.02	0.03	0.07	0.09	0.13	0.18	0.48	0.74	0.90
A3	0.01	0.02	0.04	0.09	0.13	0.18	0.59	0.81	0.90
A4	0.01	0.03	0.05	0.09	0.12	0.16	0.59	0.87	1.00
A5	0.03	0.11	0.74	0.19	0.39	0.97	0.31	0.55	0.77
A6	0.02	0.04	0.08	0.11	0.18	0.30	0.36	0.61	0.83
A7	0.02	0.05	0.15	0.11	0.18	0.30	0.36	0.61	0.83
A8	0.03	0.08	0.37	0.10	0.15	0.23	0.36	0.61	0.80
A9	0.02	0.03	0.07	0.10	0.15	0.23	0.36	0.61	0.83
A10	0.01	0.02	0.04	0.12	0.20	0.35	0.48	0.74	0.93
A11	0.01	0.03	0.05	0.09	0.12	0.17	0.64	0.91	1.00
A12	0.02	0.04	0.11	0.10	0.14	0.20	0.31	0.55	0.77
A13	0.02	0.03	0.06	0.09	0.12	0.17	0.48	0.74	0.90
A14	0.01	0.02	0.04	0.10	0.15	0.20	0.42	0.68	0.90
A15	0.02	0.03	0.06	0.09	0.12	0.16	0.59	0.87	1.00
A16	0.02	0.06	0.19	0.09	0.13	0.18	0.59	0.87	1.00
A17	0.01	0.02	0.03	0.09	0.12	0.17	0.70	0.94	1.00
A18	0.01	0.03	0.05	0.12	0.20	0.35	0.48	0.74	0.93
A19	0.02	0.03	0.07	0.10	0.15	0.23	0.14	0.36	0.57
A20	0.03	0.08	0.37	0.11	0.17	0.26	0.31	0.55	0.77

According to Chen (2000), the Fuzzy Positive Ideal Solution (FPIS, A+) and the Fuzzy Negative Ideal Solution (FNIS, A−) can be defined as

$A+= \ [(0\ ,0\ ,0),(0\ ,0\ ,0),(1\ ,1\ ,1)]$

$A-= \ [(1,1,1),(1,1,1),(0,0,0)]$

The distances of d_i^+ and d_i^- from A^+ and A^-, calculated using Eqs. (18) – (22), are presented in Tables 4.16 and 4.17 respectively.

Table 4.16 Distances of the ratings of each risk type from A+ with respect to each criterion

Risks	FPIS	C1	C2	C3	Total
A1	d(A1, A+)	0.027	0.132	0.61	0.77
A2	d(A2, A+)	0.044	0.141	0.342	0.527
A3	d(A3, A+)	0.028	0.141	0.269	0.437
A4	d(A4, A+)	0.034	0.125	0.249	0.408
A5	d(A5, A+)	0.433	0.612	0.495	1.541
A6	d(A6, A+)	0.053	0.212	0.44	0.706
A7	d(A7, A+)	0.091	0.212	0.44	0.744
A8	d(A8, A+)	0.219	0.168	0.445	0.832
A9	d(A9, A+)	0.044	0.168	0.44	0.653
A10	d(A10, A+)	0.027	0.246	0.339	0.612
A11	d(A11, A+)	0.034	0.132	0.213	0.379
A12	d(A12, A+)	0.067	0.153	0.495	0.716
A13	d(A13, A+)	0.038	0.132	0.342	0.512
A14	d(A14, A+)	0.03	0.157	0.387	0.573
A15	d(A15, A+)	0.038	0.125	0.249	0.413
A16	d(A16, A+)	0.114	0.141	0.249	0.503
A17	d(A17, A+)	0.022	0.132	0.177	0.331
A18	d(A18, A+)	0.034	0.246	0.339	0.618
A19	d(A19, A+)	0.044	0.168	0.669	0.882
A20	d(A20, A+)	0.219	0.188	0.495	0.903

Table 4.17 Distances of the ratings of each risk type from A^{-} with respect to each criterion

Risks	FPIN	C1	C2	C3	Total
A1	d(A1, A-)	0.975	0.872	0.453	2.3
A2	d(A2, A-)	0.961	0.865	0.728	2.554
A3	d(A3, A-)	0.975	0.865	0.777	2.616
A4	d(A4, A-)	0.97	0.878	0.838	2.686
A5	d(A5, A-)	0.772	0.588	0.573	1.933
A6	d(A6, A-)	0.954	0.806	0.634	2.394
A7	d(A7, A-)	0.928	0.806	0.634	2.367
A8	d(A8, A-)	0.853	0.842	0.619	2.314
A9	d(A9, A-)	0.961	0.842	0.634	2.437
A10	d(A10, A-)	0.975	0.779	0.742	2.496
A11	d(A11, A-)	0.97	0.872	0.863	2.705
A12	d(A12, A-)	0.944	0.854	0.573	2.372
A13	d(A13, A-)	0.966	0.872	0.728	2.566
A14	d(A14, A-)	0.973	0.85	0.695	2.518
A15	d(A15, A-)	0.966	0.878	0.838	2.682
A16	d(A16, A-)	0.912	0.865	0.838	2.615
A17	d(A17, A-)	0.979	0.872	0.889	2.74
A18	d(A18, A-)	0.97	0.779	0.742	2.491
A19	d(A19, A-)	0.961	0.842	0.395	2.198
A20	d(A20, A-)	0.853	0.825	0.573	2.251

The ranking of each risk factor was measured by the closeness coefficient, CC_i, by using Eq. (3.22) and presented in Table 4.18. The closeness coefficient CC_i value used to rank the supply chain risks.

Table 4.18 Closeness coefficients (CC_i) of the twenty risks factors

Risks	d_i*	d_i-	CC_i	Ranking
A1	0.770	2.300	0.749	16
A2	0.527	2.554	0.829	8
A3	0.437	2.616	0.857	5
A4	0.408	2.686	0.868	3
A5	1.541	1.933	0.556	20
A6	0.706	2.394	0.772	13
A7	0.744	2.367	0.761	15
A8	0.832	2.314	0.735	17
A9	0.653	2.437	0.789	12
A10	0.612	2.496	0.803	10
A11	0.379	2.705	0.877	2
A12	0.716	2.372	0.768	14
A13	0.512	2.566	0.834	7
A14	0.573	2.518	0.814	9
A15	0.413	2.682	0.867	4
A16	0.503	2.615	0.839	6
A17	0.331	2.740	0.892	1
A18	0.618	2.491	0.801	11
A19	0.882	2.198	0.714	19
A20	0.903	2.251	0.714	18

The closeness coefficient for each supply chain risk is shown in Table 17, yielding a final ranking of A17> A11> A4> A15> A3> A16> A13> A2> A14> A10> A18> A9> A6> A12> A7> A1> A8> A20> A19> A5. It is observed that A17, lack of operational quality risk, has the highest ranking among these twenty risk factors because it has the largest closeness coefficient (CC_i), while A5, lack of capacity flexibility risk, represents the least supply chain risk factor.

4.2.3 Sensitivity Analysis for Fuzzy-TOPSIS Method

Sensitivity analysis is applied to see if the importance of the criteria is changed, how the risk factors will be changed. Sensitivity analysis has a goal to identify which criteria have the greatest substantial influence in the decision making procedure. For this purpose, thirteen trials were made using Eqs. (24) to (28) and summarized as in Table A2 (in appendix A). With the varying of the weight of the criteria, a sensitivity analysis was performed to identify the changes in ranking of the criteria, a sensitivity analysis was performed to identify the changes in ranking of the supply chain risks. It is vivid from the experiment that change in weight of criteria has a significant effect in changing the ranks of the risk factors. Sensitivity analysis result shows that whatever the value of the weight of the criteria, operational quality risk (A17) always got topmost ranking, although ranking of the other risks has changed from trial to trail. Fig. 4.2 represents the summery of the analysis.

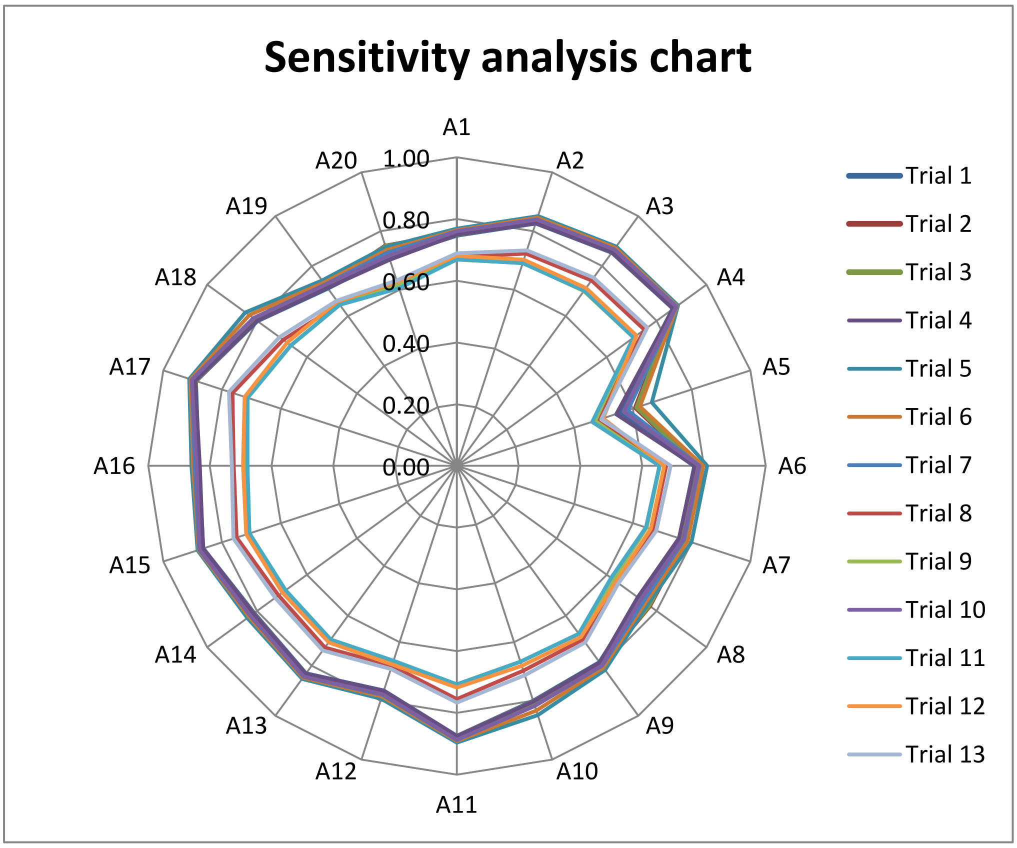

Figure 4.4 Sensitivity analysis

4.2.4 Result

The order of preference for the risk factors is summarized in Table 4.19 in accordance with the TOPSIS and fuzzy-TOPSIS methods. It is obvious that both methods identify risk A17, operational quality risk, the most crucial risk in ceramic industry. The fuzzy-TOPSIS determines ranking order, A17> A11 > A4> A15> A3> A16> A13> A2> A14> A10> A18> A9> A6> A12> A7> A1> A8> A20> A19> A5 whereas TOPSIS method determines the ranking order, A17> A16> A11> A3> A4> A15> A18> A10> A2> A13> A7> A6> A8> A9> A14> A5> A20> A12> A1> A19. Kabir and Hasin (2012), Ataei (2013) proposed that fuzzy-TOPSIS is a preferred choice when the performance ratings are vauge and imprecise. The proposed methodology aimed to recommend a systematic evaluation model to identify and rank the supply chain risks that occur in ceramic industry as well as the TOPSIS and fuzzy-TOPSIS comparison. An approach to slendering the number of risks types and to facilitate the decision making process is prescribed by the proposed method.

Table 4.19 The ranking of risk factors for different method

Risks		TOPSIS Ranking	Fuzzy-TOPSIS Ranking
A1	Sales withdrawal	19	16
A2	Change in market demand	9	8
A3	Inventory level	4	5
A4	Damage in inventory	5	3
A5	Lack of capacity flexibility	16	20
A6	Manufacturing lead time	12	13
A7	Product delivery lead time	11	15
A8	Sourcing lead time	13	17
A9	Raw material purchasing price	14	12
A10	Operating material price	8	10

Table 4.19 continued

Risks		TOPSIS Ranking	Fuzzy-TOPSIS Ranking
A11	Lack of material quality	3	2
A12	Inbound supply delay	18	14
A13	Damage of goods during transportation	10	7
A14	Transport delay	15	9
A15	High transportation cost	5	4
A16	Changes in design	2	6
A17	Lack of operational quality	1	1
A18	Human error	7	11
A19	Natural disaster	20	19
A20	Labor unrest	17	18

4.2.5 Discussion and Validation

This section validates the obtained results based on the literature and feedback from the experts.

From Table 4.19 it can be seen that operational quality and material quality risks possess the highest position among the supply chain risks encountered in ceramic industry of Bangladesh. Narapinij (2016) mentioned that quality control is compulsory to minimize the waste generated in the production process. He also mentioned that most of the wastage arouse from ceramics burning process. Fish (2011) mentioned that there is a positive relationship between quality management and supply chain management. Clearly, the proposed results are consistent with existing studies.

Inventories are held by firms to satisfy demand. Inventory risk arises from keeping inventories for future uses or from stock out of inventories which leads to excess handling cost or loss of opportunity cost (Cachon, 2004). Narapinij (2016) identified that inventory can be damaged in ceramic industry because of not using appropriate trolley to transport the products and for incorrect arrangement methods. This particular research also shows that damaged inventory is one of the risk factors in the supply chain and this perspective is also supported via existing literature.

Transportation risk has a multi-dimensional influence on the supply chain. Kara and Firat (2017); Rathore et al. (2017) and Sun et al. (2015) identified the relationship between transportation risks and supply chain risks and stated that transportation risks results from the uncertainty of the supply chain. Giunipero and Eltantawy (2004) identified transportation disruption as a source of risk and it could rapidly affect the overall SC. Several risks may arise from transportation disruption such as transportation delay, which may leads to production shutdown. It is also possible that valuable goods may be damaged in transit (Hishamuddin et al., 2013). Furthermore, transportation cost is also one of the supply chain risks and because of political unrest in 2014-2015, manufacturers of Bangladesh had to face an unusually higher transportation cost (Rayhan and Nahid, 2015). Sreenivas and Srinivas (2006) showed that enterprises spent around two thirds of the logistics costs for the transportation of goods. Therefore, transportation risks should be handled tactfully to minimize the supply chain risks.

A study done by Bangladesh Tariff Commission (BTC) identified that Bangladesh has shortage of raw materials for ceramic goods and the manufacturers are 100% dependent on import of raw materials from overseas. Besides, close competitors like China and India have their own raw materials (Jahan, 2010). For this, Bangladesh has to face a fierce competition with the neighboring countries in maintaining lead time. Manufacturing lead time, product delivery lead time and sourcing lead time have become the risk factors in the management of supply chain in ceramic industry in Bangladesh.

The execution of competitive strategy for an industry largely depends on pricing that is significant attribute in supply chain management. Bangladesh needs to import 100% raw materials that are accounted for 35-40 percent of the total production cost of the ceramic products for producing ceramic wares. Besides, Bangladesh also needs to import the equipment and machineries for ceramic industry which gives the supplier more leverage in bargaining the price (Jahan, 2010). This research also supports the fact.

Demand risk often is influenced by a change in the market. Rathore et al. (2017) and Ho et al. (2015) identified demand risk as a major risk factor in SCRM. Demand risk includes sale withdrawal, changes in market demand, changes in product preference etc. This study also coincides with the literature and expert‟s opinion.

Chapter 5
Conclusions, Managerial Implications and Recommendations

5.1 Conclusions

The fast increasing challenges like global competition, raw material‟s dependency, increased product diversity, demanding customer and, globalization have a key impact on the ceramic industry. Ceramic sector of Bangladesh is vulnerable to various risks. Risks may arise in any position of the supply chain, and thus may harm the efficiency of it. Therefore, it is necessary to take preventive measure to mitigate those risks and their effects. The following conclusions are drawn from this study.

- A TOPSIS and fuzzy-TOPSIS based model is proposed for evaluating the supply chain risks in the context of ceramic sector.
- Twenty relevant supply chain risks in the context of ceramic sector were identified through the existing literature review and from the experts‟ feedback. After that, TOPSIS and fuzzy-TOPSIS methods were used to rank these risks.
- The results show that lack of operational quality, lack of material quality and damage in inventory are the top three risks among the twenty risk factors.
- There are some variations in ranking of risks using TOPSIS and fuzzy-TOPSIS methods, and it is suggested that fuzzy-TOPSIS method‟s ranking is desired option for vague and inaccurate performance ratings.

5.2 Managerial Implication

Reducing various supply chain risks is a crucial task for a company‟s success. For that reason, it is necessary for managers to identify the risks and thus, take necessary steps to minimize them. The main contribution of this research is the identification and evaluation of supply chain risks in ceramic sector. This study will assist the managers to identify the most important supply chain risks in ceramic sector and to guide to minimize the risks. It will be easier for the managers to take proactive policies for reducing risks in ceramic sector. Some issues are provided for assisting managers to reduce the occurrence of supply chain risks as follows:

- Providing quality products is very crucial for any business firm and any compromise in quality will cause severe loss both in reputation and finance. So, managers of ceramic sector must scrutinize every step in the supply chain to ensure the quality.
- Managers in the ceramic sector must be wary about pricing related risks. Because, Bangladesh has a deficiency in raw materials. So, raw materials are purchased from other countries and that requires the managers to be very competitive in pricing negotiations.
- Ceramic items are very fragile and brittle. So, it is possible to break down during storage and handling. From the managerial context, it is suggested to use appropriate handling method and proper storage to minimize the loss of produced items.
- Furthermore, for improving the supply chain resilience, performance and effectiveness it is necessary for the managers to understand the supply chain risks. This research will assist them in this context. The ranking established by this research would be helpful for risks mitigation process and thus, it will also be helpful for burgeoning the efficiency of the supply chain in ceramic sector of Bangladesh.

5.3 Recommendations

This research presents a model to evaluate risks in the context of ceramic sector in Bangladesh using TOPSIS and fuzzy-TOPSIS technique. Identification of risks can be done with other MCDM techniques such as ELECTRE, VICKOR, and MOORA etc. In this study the impact of supply chain risks has not been showed. Therefore, further research can be continued on the impact of the identified risks on overall supply chain of the ceramic industry. Also, in this study the risks are considered independent. However, fuzzy-AHP method could be used to identify the interrelation among them. The thesis has demonstrated an integrated TOPSIS and fuzzy-TOPSIS framework for supply chain risk assessment in the context of ceramic sector. Nevertheless, this framework can be used for risk assessment in other sectors also, such as automobile, pharmaceuticals, cement industry, garments sector, manufacturing, etc.

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APPENDIX A

Table A1 Profile of the case company

Name of the company	Year of establishment	Types of product	Company size (Area, Employees, Annual production capacity)
X-Ceramics Limited	2008	Ceramic and homogeneous tiles	Location: Sreepur, Gazipur Area: 75 acres Employees: 733 Machinery: Chinese and Italy‟s Annual Production Capacity: 3.5 million Sq. Metre

Table A2 Sensitivity analysis

No	Weight of the criteria			Ranking
	C1	C2	C3	
1	0.37 0.57 0.74	0.70 0.87 0.97	0.84 0.97 1.00	A17> A11> A4> A15> A3> A16> A13> A2> A14> A10> A18> A9> A6> A12> A7> A1> A8> A20> A19> A5
2	0.74 0.24 0.31	0.70 0.87 0.97	0.83 0.97 1.00	A17> A11> A4> A15> A3> A16> A13> A2> A14> A10> A18> A9> A6> A12> A7> A8> A1> A20> A19> A5
3	0.13 0.85 0.26	0.70 0.87 0.97	0.83 0.97 1.00	A17> A11> A4> A15> A3> A16> A13> A2> A14> A10> A18> A9> A6> A12> A7> A8> A1> A20> A19> A5
4	0.06 0.09 0.95	0.70 0.87 0.97	0.83 0.97 1.00	A17> A11> A4> A15> A3> A13> A16> A2> A14> A10> A18> A9> A6> A12> A7> A1> A8> A19> A20> A5
5	0.37 0.57 0.73	0.95 0.15 0.17	0.84 0.97 1.00	A17> A11> A4> A15> A3> A16> A13> A2> A10> A18> A14> A9> A6> A7> A12> A1> A8> A20> A19> A5
6	0.37 0.57 0.73	0.27 0.95 0.37	0.84 0.97 1.00	A17> A11> A4> A15> A3> A16> A13> A2> A10> A14> A18> A9> A6> A7> A12> A1> A8> A20> A19> A5
7	0.37 0.57 0.74	0.21 0.26 0.99	0.84 0.97 1.00	A17> A11> A4> A15> A3> A16> A13> A2> A14> A10> A18> A9> A6> A12> A7> A1> A8> A20> A19> A5
8	0.37 0.57 0.74	0.70 0.87 0.97	0.95 0.31 0.32	A17> A11> A4> A15> A3> A13> A2> A16> A14> A10> A18> A9> A12> A6> A1> A7> A19> A8> A20> A5
9	0.37 0.57 0.74	0.70 0.87 0.97	0.00 1.00 0.00	A17> A4> A11> A15> A3> A13> A2> A14> A16> A9> A1> A10> A18> A12> A6> A7> A19> A8> A20> A5
10	0.06 0.09 0.95	0.21 0.26 0.99	0.84 0.97 1.00	A17> A11> A4> A15> A3> A13> A16> A2> A14> A10> A18> A9> A6> A12> A7> A1> A8> A19> A20> A5
11	0.06 0.09 0.95	0.70 0.87 0.97	0.00 1.00 0.00	A17> A4> A11> A15> A3> A13> A2> A14> A16> A9> A1> A10> A18> A12> A6> A19> A7> A8> A20> A5
12	0.37 0.57 0.74	0.21 0.26 0.99	0.00 1.00 0.00	A17> A4> A11> A15> A3> A13> A2> A14> A16> A9> A10> A1> A18> A12> A6> A7> A19> A8> A20> A5

Table A2 continued

No	Weight of the criteria			Ranking
	C1	**C2**	**C3**	
13	0.06 0.09 0.95	0.21 0.26 0.99	0.95 0.31 0.32	A17> A11> A4> A15> A3> A13> A2> A16> A14> A10> A18> A9> A6> A12> A1> A7> A19> A8> A20> A5

Table A3 Questionnaire

Sl. No	Questionnaire	Response						
		VP	P	MP	F	MR	R	VR
1	What is the probability of happening sales withdrawal?							
	What is the severity level of sales withdrawal?							
	How is the sales withdrawal risk related to quality of control?							
2	What is the probability of happening changes in market demand?							
	What is the severity level of change in market demand?							
	How is the change in market demand risk related to quality of control?							
3	What is the probability of happening inventory level?							
	What is the severity level of inventory level risk is?							
	How the inventory level risk is related to quality of control?							
4	What is the probability of happening damage in inventory?							
	What is the severity level of damage in inventory risk?							
	How is the damage in inventory risk related to quality of control?							
5	What is the probability of happening lack of capacity flexibility?							
	What is the severity level of lack of capacity flexibility?							

Table A3 continued

Sl. No	Questionnaire	Response						
		VP	P	MP	F	MR	R	VR
	How is the lack of capacity flexibility risk related to quality of control?							
6	What is the probability of happening manufacturing lead time?							
	What is the severity level of manufacturing lead time?							
	How is the manufacturing lead time risk related to quality of control?							
7	What is the probability of happening product delivery lead time?							
	What is the severity level of product delivery lead time?							
	How is the product delivery lead time risk related to quality of control?							
8	What is the probability of happening sourcing lead time risk?							
	What is the severity level of sourcing lead time risk?							
	How is the sourcing lead time risk related to quality of control?							
9	What is the probability of happening raw material purchasing price risk?							
	What is the severity level of raw material purchasing price risk?							
	How is the raw material purchasing price risk related to quality of control?							
10	What is the probability of happening operating material price risk?							
	What is the severity level of operating							

Table A3 Continued

Sl. No	Questionnaire	Response						
		VP	P	MP	F	MR	R	VR
	material price?							
	How is the operating material price risk related to quality of control?							
11	What is the probability of lacking of material quality?							
	What is the severity level of lacking of material quality?							
	How is the lack of material quality related to quality of control?							
12	What is the probability of happening inbound supply delay risk?							
	What is the severity level of inbound supply delay risk?							
	How is the inbound supply delay risk related to quality of control?							
13	What is the probability of happening damage of goods during transportation?							
	What is the severity level of damage of goods during transportation?							
	How is the damage of goods during transportation related to quality of control?							
14	What is the probability of happening transport delay?							
	What is the severity level of transport delay?							
	How is the transport delay risk related to quality of control?							
15	What is the probability of happening							

Table A3 Continued

Sl. No	Questionnaire	Response						
		VP	P	MP	F	MR	R	VR
	high transportation cost?							
	What is the severity level of high transportation cost?							
	How is high transportation cost risk related to quality of control?							
16	What is the probability of happening changes in design?							
	What is the severity level of changes in design?							
	How is the change in design risk related to quality of control?							
17	What is the probability of lacking of operational quality?							
	What is the severity level of lacking of operational quality?							
	How is the lack of operational quality related to quality of control?							
18	What is the probability of happening human error?							
	What is the severity level of human error?							
	How is the human error risk related to quality of control?							
19	What is the probability of happening natural disaster?							
	What is the severity level of natural disaster?							
	How is the natural disaster risk related to quality of control?							

Table A3 Continued

Sl. No	Questionnaire	Response						
		VP	**P**	**MP**	**F**	**MR**	**R**	**VR**
20	What is the probability of happening labor unrest?							
	What is the severity level of labor unrest?							
	How is the labor unrest risk related to quality of control?							