Original Research

Supply Chain Risk Assessment of Steel Industry Using Hybrid Type Fuzzy TOPSIS Approach and Fuzzy Hierarchical Analysis

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Abstract
Supply chain management has critical role in business markets. Shorter technology cycles due to industry 4.0, increased supplier relationships, and sustainable development push the supply chain toward complexity. Increasing the complexity significantly results on the level of uncertainty and risk in the supply chain. Risk is a potential event that prevents information flow and also disruption. Risks negatively affect company performance, also effects on the supply chain performance; therefore, organizations should apply some suitable strategies to control the risks and manage them. It is an exploratory mix (qualitative-quantitative) with a modelling approach**.** Therefore, it seeks to provide a new model for measuring the risk of the steel industry in the supply chain using fuzzy hierarchy and type-2 fuzzy TOPSIS. The key finding of this paper shown, the first three ranks of risks in the supply chain of Steel companies are "raw material supplier performance risk", "production planning risk", and "information systems inconsistency risk", respectively. Therefore, it is suggested that a comprehensive and executive plan be designed and implemented to properly control and monitor these risks properly.

Keywords- Risk; Steel industry; Supply chain; Fuzzy hierarchy; Fuzzy TOPSIS Type-2

INTRODUCTION

Due to increased uncertainty and political concerns, technical developments, and catastrophes, enterprises must invest resources to forecast demand, supply, and internal uncertainties. The chain's susceptibility to risk and failure risk management is required to avoid failures due to risks such as inconsistent client demand, and man-made calamities. Risk rating is critical to this process because it establishes the superiority of each risk relative to other risks, allowing the decision maker to prepare for the amount of resources necessary to address each risk. Every risk assessment process should begin by developing a strategy for identifying and categorizing the unique hazards associated with each project or business. D. Hillson (2003) given the complexity and a vast number of risks that influence the supply chain, it is impossible to manage risks efficiently and effectively without first identifying and creating the structure of my risk failure. It is not a mineralizable substance. As a result, the RBS approach has been recognized as a useful instrument for focused identification and risk categorization in recent years. Numerous research has been conducted on risk management and assessment in general, and specifically in the supply chain. These studies can be classified into several categories. One is those in which they reviewed the risk management of supply chain literature. Thun, JH, Hoenig, D., and Rutherford, C., (2010), as well as in certain other risk assessment methodologies, such as FMEA, which has a high degree of risk. The product of the severity, detection rate, and likelihood of risk indicators is determined. Tuncel, G., Alpan, G., and Tuncel, G. (2010). S. Matook, R. Lasch, and R. Tamaschke (2009). Other research has identified flaws in the risk- measuring methodologies used in the preceding studies and stressed the unreliability of these approaches, which include the probability-effect matrix, FMEA, and others. C. B. Chapman, S. C. Ward (2003). One disadvantage of these approaches is that they may ignore the relevance of low-risk, high-impact hazards, and high-risk and low-risk risks compared to low-risk and low-risk risks. J. Pipattanapiwong (2004) Additional factors, are included in some other research. Calculation of the Risk Response Rate LR Waterland, S Venkatesh, S Unnasch (2003) Probability and its impact on a project's timeline, cost, and quality are considered during risk ranking. D. Baccarini, R. Archer (2001). Additionally, indications of manageability and risk occurrence closeness have been examined. Pertmaster Software (2002) was utilized, as well as socioeconomic and environmental implications.

L. Xu, G. Liu (2009). Additionally, studies have explored how to react to specific hazards and risk response and management measures in the supply chain. A. Oke, M. Gopalakrishnan (2009). (2009), M. J. Braunscheidel, N. C. Suresh B. Ritchie, C. Brindley (2007). P. R. Kleindorfer, G. H. Saad (2005). Several researchers have identified, classified, and organized supply chain failure risks in their studies. S. Chopra, MS Sodhi (2004). Alternatively, in six categories: supply, production, demand, logistics, and risk associated with uncontrolled natural variables and uncontrollable societal hazards. Z. Liu, M. Lai, T. Zhou, and Y. Zhou, (2009). Risks are classified into five categories: supply, demand, process, control, and environment. , Or supply, demand, process, planning and management, and environmental risk, Juttner, U., 2005. A. Ziegenbein, J. Nienhaus (2004). Alternatively, in four distinct categories: supply, demand, operational, and safety and calamities, Manuj, I., and Mentzer, J. T., 2008. P. R. Kleindorfer, G. H. Saad (2005). Additionally, they identified many additional hazards in the three categories of deviations, failures, and accidents. S. G. Roshan, V. Nukala (2004). Alternatively, supply, demand, and catastrophic risks are classified into three groups. S. M. Wagner, C. Bode (2006). Alternatively, supply, demand, and other uncertainties all contribute to cost increases. L. Xu, G. Liu (2009). Alternatively, in terms of supply and demand A. Norrman, and U. Jansson (2004). Presented. These studies are generally incomplete and restricted in scope and do not offer a full framework for risk failure. Other studies have examined supply chain risk modelling and simulation using a variety of methodologies. The following techniques were used: randomization, interpretative structural model, multi-factor decision support system, and contingency theory.

M. Giannakis, M. Louis, S. M. Wagner, and N. Neshat, 2011. (2010). A. R. Ravindran, R. U. Bilsel, V. Wadhwa, T. Yang (2010). Risk is defined as the product of an injury's severity and its chance of happening. Risk assessment is a critical component of every company's safety strategy. Due to the plethora of risk assessment techniques, several ways are appropriate for each case, and selecting the appropriate approach is critical. Most of publications classify these techniques into two broad categories: qualitative and quantitative. The study used multi-criteria decision-making (MCDM) as a quantitative risk assessment technique. AHP is one of the most often used ways to MCDM, in which DMs make judgments based on a two-way comparison of criteria and possibilities. By using fuzzy numbers, fuzzy TOPSIS represents varying degrees of influence or causation in dry TOPSIS using five language contexts: "very high", "high", "low", "very low", and "no". The fuzzy direct impact matrix is used in dry direct impact assessments to eliminate uncertainty and ambiguity. Most currently available fuzzy TOPSIS algorithms are composed of linguistic variables based on the type-1 fuzzy set (T1FS). Lane (2013), for example, constructs a structural model using T1FS and TOPSIS to investigate the weight connections and influence of indicators in green supply chain management. Jasbi et al. (2011) used the T1FS and DEMATEL techniques to assess the balanced scorecard as the foundation for a strategic management system. Chang, Chang, and Wu (2011) used T1FS to find effective criteria for supplier selection using the fuzzy DEMATEL technique.

With the recent advancements in Type-2 (T2FS) fuzzy sets and the notions of Type-2 interval fuzzy sets (T2FS), the weight relationship in TOPSIS warrants a more extensive study of the flexibility of spaces expressing uncertainty than those using T1FS. They do, in fact, they are. IT2FS has recently been extensively implemented and effectively employed in concept computing and control systems. Ozone and Gribaldi (2004) modelled change in human decision-making using the form of type 2 fuzzy membership functions. In brief, since IT2FS is characterized by primary and secondary membership, it allows for more flexibility in representing uncertainty in the actual world. Additionally, IT2FS enables us to exhibit real-world uncertainty and ambiguity via increased degrees of freedom. As a result, the combination of IT2FS's increased flexibility with TOPSIS's unmatched weight ratio is seamless. However, there has been little talk of this merger so far. Hosseini and Tarakh (2013) presented an integration of the type-2 fuzzy set expansion and its application to conceptual computational decision-making. However, this strategy was limited to establishing a language or word using triangular fuzzy integers and intervals. Risk assessment is often conducted statistically or semi-quantitatively in research, but the identification of risks is very restricted. On the other hand, the scale of risks is not stated quantitatively or semi-quantitatively, so the criticality of risks is not conveyed. They are not related to one another, and they have also conducted more case studies. As a result of examining previous studies and investigations, it is clear that most of papers and research (more than 70%) have addressed risk management of supply chain principles, field and case studies, and literature reviews. Issues such as the application of modelling and simulation approaches are extremely limited, particularly in the field of comprehensive identification and classification of hierarchical risks of supply chain, as well as the evaluation and measurement of these risks and their magnitude and ranking, and particularly in the discussion of risk supply chain in the steel industry, no serious studies have been conducted. Thus, this work aims to develop a novel model for risk assessment in the steel industry's supply chain by using fuzzy hierarchy and type 2 fuzzy TOPSIS.

A REVIEW OF LITERATURE

Kang (2014) suggested a methodology for assessing the risk associated with tank zones or oil storage reservoirs based on the principle of two categories of risks. Error tree analysis is used to identify controllable risk variables (FTA). AHP determines the factor weights. Then, for controlled dangers, the fuzzy comprehensive assessment mode is selected. The risk assessment of the oil storage tank was determined using the 5X5 risk matrix approach. The suggested approach combines the AHP core hazard technique, fuzzy comprehensive assessment, and a 5x5 risk matrix. Grassi et al. (200) established a multi-characteristic risk assessment approach for the Mortadella-producing firm in Italy (Italian sausage sample). They determined the risk index for hazardous activities using fuzzy TOPSIS. They did not, however, apply the pairwise comparison approach when analyzing the weights of the five risk variables. Additionally, they assessed five factors based on the performance of a single analyst. Marhavilas (2014) used fuzzy TOPSIS to identify and rate 86 risks in Kerman sediments. Using the fuzzy method's risk index, they classified the dangers into 12 categories. Additionally, they supplied control criteria after the research. Hu et al. (2009) used FMEA analyze the risk components containing hazardous chemicals. They selected criteria from FMEA and weighted them using FAHP. Each component's green component risk priority number was then computed by multiplying the two managers' weights and FMEA scores. Ebrahamnejad et al. (2010) developed a risk assessment model based on Multidimensional Preference Analysis (FLINMAP) for project development, operation, and transfer. They created a risk assessment approach for the BOT Iran power plant project. John et al. (2014) developed a fuzzy risk assessment system. They weigh risk variables using FAHP, while synthesizing and synthesizing them with ER. Liu and Tsai (2012) recommended that a Taiwanese construction business build a quality function (QFD), a fuzzy network analysis procedure (ANP), and a risk assessment approach based on FMEA. They utilized the QFD to demonstrate linkages between construction components, hazard categories, and hazards, the fuzzy ANP approach to determine hazard kinds and major hazards, and the FMEA to evaluate risk. Maine (2012) established four sub-stages for risk assessment. To begin, the risk rating method is chosen. The study often use a two-parameter scoring system (intensity and probability), such as the DMRA approach. Second, the intensity rating is determined for each danger. Severity is determined by the extent of personal harm, the value of damaged property or equipment, the amount of money lost or time lost from employment, and other factors. Thirdly, the likelihood of danger is determined. This relates to the frequency or frequency of exposure, the length and intensity of exposure, training and awareness, and risk factors. The fourth step is to establish the starting risk level for the risk scoring method chosen. This stage streamlines the process by using the risk management hierarchy to swiftly remove significant risks. Following risk reduction, a subsequent review is conducted to ensure that the selection criteria successfully decrease risk. This is the stage in which the remaining hazards are assessed. The decision step is then followed by the execution stage.

The risk assessment team determines which hazards should be lowered to an acceptable level. The last stage is to document the findings. Tanaka et al. 1981 investigated type-2 fuzzy sets where algebraic multiplication operators were used. By 1990, the majority of studies had concentrated on type-1 fuzzy sets, with relatively few papers devoted to type-2 fuzzy sets. Mendel et al. expanded on Tanaka et al. work in 1998. To investigate the community of sharing and complementarity operators and to demonstrate the general form of type 2 fuzzy logic relations in algebraic and arithmetic computations. it demonstrated in 2005 that uncertainty is a critical property of information, making the computation of uncertainty in type-2 fuzzy set theory one of the most active study areas in recent years. Rickard et al. introduced the idea of the subset of degrees in the Type-2 fuzzy set in 2008. In 2009, Mendel and Dion offered a theory of representation for a type-2 fuzzy set based on the level, as well as a technique for computing the five dimensions of the notion of uncertainty in a type-2 fuzzy set, namely variance, center of gravity, asymmetry, fuzzy, and primary. They created these five conceptions of uncertainty recently. Tang and Binon (2005) analyzed the development and use of long-term investments using FAHP. Their investigation was designed to determine the sort of racing automobile a car rental firm would accept. Bashigol (2005) developed an analytical technique for determining which software produced the best levels of customer satisfaction. Tang et al. (2005) proposed a multivariate model of the laptop market in Taiwan. Their concept used a combination of correspondence and the FAHP technique. Toisuz and Ghahraman (2006) developed an analytical approach for estimating project risk when information is sparse or unclear. They utilized FAHP to determine the costs associated with a failed information technology project at a Turkish company.Ayagh and Ozdemir (2006) suggested an intelligent technique for assessing different machine tool designs based on FAHP. They first weighed the options using FAHP and then performed a break-even point analysis using each alternative's FAHP weights and costs. Li et al. (2008) suggested a strategy for evaluating the IT sector in Taiwan's industrial sectors based on FAHP and a balanced evaluation. GargashOghli and Ortukrol (2006) selected the finest textile partner in Turkey using FAHP. Haq and Kanan (2006) suggested an AHP and FAHP-based structural model for assessing computer component manufacturers. Chan and Kumar (2007) proposed a methodology for developing a framework for selecting its primary supplier, considering the organization's risk factors. They selected the primary supplier using FAHP. T. C. E. Cheng, 2019 investigates the use of social media in risk management operations and supply chain management in the manufacturing business. He thinks that social media should be included as a variable in supply chain management models to help mitigate industry risks since it is a type of advertising that may impact an industry's performance and efficiency. Lóránt Venter et al. (2018) evaluated the effect of risk management on supply chain performance. Paid. They established that supply chain management is a well-established and extensively researched field of management science. Their objective is to develop and test a model that demonstrates how, in addition to the tools available to control the flow of information, Yan Coelho Albertin, 2017 handled the supply chain and developed a thorough grasp of the chain's hazards. This intricate and vast supply chain and the increased demand for managers introduce several hazards into the network. These risks are unforeseeable incidents that might jeopardize the flow of commodities or scheduled activities. They may include supply delays, inaccurate predictions, or more unusual occurrences such as storms and earthquakes. Guy Underwood, CPRM, AFRMIA.2016 dissected the critical components of a risk management of supply chain framework in depth. This article aims to educate readers on the importance of successful management. Risk in the supply chain is discussed in detail in this paper, along with examples of risk reduction measures that may assist firms in managing this risk. A supply chain management review serves as an introduction to the notion and evaluation of the several facets a firm should handle efficiently. They aspire to establish a supply chain that is both sustainable and ethical. Badieh et al. (2014) used a hierarchical analytic technique to rank the components contributing to supply chain risk in research. The horizontal and vertical supply chains were investigated, and risk factors were discovered. Finally, involvement in resource sharing and skill development was the most significant signal in the sheer supply chain style. In contrast, participation in information sharing was the most essential indicator in the horizontal supply chain mode. Lavaster et al. (2012) studied risk management of supply chain in French businesses in a research. This research is critical for risk management of supply chain in the context of violent conduct (correct process prediction). This article discusses ways to address supply chain risk, the most critical of which is to appropriately and adequately react to market demands via industry-specific measures. This study included 50 factories and 142 managers. Finally, this research recommends collaboration, joint deployment, and cross-cutting procedures for risk management of supply chain that are both effective and efficient.

Similar research has been undertaken in Iran on the rating of organizations and predicting corporate risk using Altman and "AHP" models, as well as neural networks. Among them are the following: Gholizadeh (2018) discussed rating enterprises using the AHP technique in his PhD dissertation. Another relevant study may be found in "Soleimani's" (2017) dissertation on corporate risk prediction utilizing the Altman Z model and rated businesses' risk prediction criteria. Rezaei Nik et al. (2017) provided a model for assessing and rating supply chain risk responses in a fuzzy environment by combining the DEMATEL and ANP methods. Today's worldwide trends have prompted firms to study supply chain management to navigate the unpredictable environment in which they operate. Increased supply chain complexity limits transparency and control over operations, and as a result, these disruptions result in supply chain risk. Any interruption or danger in the supply chain will directly affect the company's operations, and the customer will ultimately bear the brunt. In this case, risk management in the supply chain seems to be required. While defining and rating supply chain hazards, this article identifies and ranks the responses to these risks. Each risk or reaction to risk may be investigated individually and independently of the others in a qualitative evaluation. While in the actual world, risks and reactions have independent effects, the occurrence of one raises or lowers the possibility of the other happening or its impact. As a result, the fuzzy DEMATEL-ANP approach was utilized to take these interactions into account as well. The combination strategy employed significantly decreases the model's calculation and complexity. A case study was undertaken in the hydraulic structures industry, and after assessing the data, competitive hazards were placed at the top among the most significant concerns. Among the responses, the primary priority was assigned to developing strategic economic strategies. Sheidaee (2017) uses the Analytic Hierarchy Process (AHP) to identify and prioritize the risk variables impacting the leasing business, using a public joint stock corporation case study. Among the several forms of descriptive research is survey research, which focuses on identifying and rating risk factors in leasing. Cronbach's alpha test and the views of experts and academics were utilized to establish the questionnaire's reliability and validity; SPSS statistical software was used to conduct the analysis. In aggregate, all of the study hypotheses' components, including operational risks, liquidity risks, interest rates, reputation risks, credit risks, legal risks, and portfolio risks, represent significant hazards in the sector. Mellat outsourcing is a leasing and outsourcing firm, and there is a strong correlation between credit risk, liquidity risk, interest rate risk, reputation risk, operational risk, legal risk, and portfolio risk, as well as its sub-factors. The Tehran Stock Exchange sectors were self-ranked based on risk criteria from the viewpoint of institutional investors; the Data Envelopment Analysis (DEA) technique was used to assess industry risk measures. In this qualitatively quantitative study, risk factors were ranked using hierarchical analysis, and industries were ranked using cover analysis. The findings of this research reveal that eight risk factors are used to rate the stock industry from the standpoint of institutional investors. The most critical risk factors are, in order, the range of industry returns, the range of price volatility relative to industry revenue, and the total number of days of industry symbol downtime. From the standpoint of institutions and risk criteria, the most efficient and least hazardous stock market businesses are the primary metals infrastructure industry and financial and intermediation activities. Sarvestani et al. (2015) contrasted the electro-fuzzy technique and the Jack Knife sampling method with interval analysis for evaluating effective elements in risk management of supply chain. Given the quick and extensive changes in the supply chain, firms must conduct an exhaustive risk identification and assessment process to stay competitive and adopt effective supply chain management. When data are scarce owing to a lack of knowledge or time restrictions, several current models may not offer an appropriate rating of risks of supply chain. To address this issue, this article employs Jack Nife's sampling technique. Additionally, it is difficult to assess the precise level of risk in practice; to accomplish this, this research utilized the fuzzy mode and interval analysis methods to estimate risks in the form of intervals based on the concept of confidence intervals and expert opinions. As a result, this paper evaluates and ranks the most effective factors in risk management of supply chain through the use of the electro-fuzzy method, as well as the Jack Nife sampling method and interval analysis. The calculations reveal that when Jack Nife's sampling approach is combined with interval analysis, it produces a more accurate ranking than electrofuzzy method, with the external environment component being the most significant and the support factor being the least essential. Is critical. Additionally, political risks are the most significant external environmental concerns, while social risks are the least significant. Fakour and Ulfat (2014) examined risk management of supply chain using fuzzy TOPSIS to identify and address weak areas. Rapid changes in the business environment, global supply chain expansion, and the complexity of the relationships between chain members have increased the likelihood of accidents and risk, as well as the vulnerability of businesses' supply chains, resulting in increased disruptions in production or customer service. This approach involves the use of novel risk management techniques. This research aims to manage supply chain risk by identifying the most critical vulnerabilities and implementing the most effective countermeasures. To accomplish this, the detrimental characteristics of production business "A" were prioritized using the fuzzy TOPSIS approach, and then relevant capabilities to deal with them were provided using the Delphi method. The research's final findings reveal that the most significant disadvantages of Company "A" are external variables and sourcing constraints. As a result, the business must prepare for successful risk management by assembling the necessary competencies.

ZandHesami and Savoji (2012) highlighted risk management as a component of supply chain management and utilized the DEMATEL approach in their research. Environmental, financial, strategic, human resource, equipment and technology, and information technology hazards were all evaluated. Finally, they concluded that environmental variables (government laws and regulations) are the most effective element in causing supply chain risk. Nasrollahi and Shirviehzad (2012) published a research titled Supply Chain Risk Assessment Using Data Envelopment Analysis in the Home Appliance Industry, in which they proposed another methodology for supply chain risk assessment. The first half of this study evaluates risks of supply chain in terms of their relevance to the supply chain, and the second section prioritizes existing risks using the data envelopment analysis approach. Mir Fakhreddini et al. (2011) used a hierarchical analysis process, electro, topsis, and taxonomy, followed by an average method, to rank supply chain risk in information technology for small and medium-sized enterprises. The Pearson correlation coefficient was used to detect rank convergence. External and uncontrolled catastrophes, natural disasters, government acts, and supply market, nature of products or raw materials, supplier organization, rapid fashion changes in the product market, acceptability or acceptance are all examples of hazards highlighted in this study's conceptual model. New product, short product life, abrupt flood or cancellation of customer orders, rise in the expense of developing an appropriate infrastructure for information interchange, non-compliance and integration of business party systems, inadequate supply chain management business practices, market selection Suitability for activity, transaction denial due to a lack of an attribution system, information security, the ability to cite and rely on information, dishonesty in inter-organizational relationships, information sharing, business parties' commitment to the commitment and ability to do so, and business partners abusing the organization's trust; Finally, natural disasters were identified as the most significant risk. The current work seeks to expand fuzzy TOPSIS by substituting IT2 trapezoidal fuzzy numbers for triangular fuzzy numbers. TOPSIS FUZZY IT2 is expected to use matrices or graphs to show the structure of complicated weight connections. This new model will evaluate the steel industry's supply chain risk. In “Evaluating of effective factors on green supply chain management using statistical methods and SWARA approach”, Abbas Nasiri et al. declare that the primary purpose of this research is the identification and evaluation of influential factors on the implementation of Green Supply Chain Management (GSCM) at Fanavaran Petrochemical Company by using statistical methods of Kolmogorov-Smirnov, mean and decision-making method by topic SWARA (Stepwise Weight Assessment Ratio Analysis). The present research methodology based on purpose is practical and based on the data-gathering method of descriptive measurement. To extract the influential factors on GSCM at the company, first, by literature review, 22 factors were identified. Then, data were gathered using the opinions of population members, consisting of 55 experts and senior managers in the company’s first class. Finally, after analyzing the questionnaires and statistical tests above, 11 factors were confirmed and selected. The SWARA technique evaluates the final factors and ranks them based on their importance in the GSCM system’s successful implementation. The outcome of this technique showed that the second factor, “Designing products to reduce energy and material consumption, reuse and recycling of materials, prevent the use of hazardous materials in the production process”, by most weight, is extracted as the most critical factor. The factors of “Materials and compliance with the standards required for the purchase of raw materials” and “Procurement, distribution and reverse logistics” are placed in the following ranks based on importance. The “total environmental quality management” factor by the least weight is the last factor in implementing GSCM at the company. At the end of the research, it is proposed that organizations focus on environmental problems to acquire green environment skills and advantages through green supply chain activities.

RESEARCH METHODOLOGY

In terms of methodology, this study is an exploratory combination (qualitative-quantitative) with a modelling approach since the research's product is a model presentation. The qualitative section employs the fuzzy Delphi technique. It has employed a mix of fuzzy multi-criteria decision techniques to a lesser degree. Kaufman and Gupta pioneered the fuzzy Delphi technique in the 1980s (Lin and Cheng, 2002). They apply this strategy to reach an agreement and make judgments on topics when the objectives and criteria are not well-defined, yielding very beneficial outcomes. This technique is distinguished by its ability to offer a flexible framework that addresses various issues connected to inaccuracy and explicitness. Expert views are sometimes ambiguous. As a result, it is preferable to show data using fuzzy numbers rather than definite numbers and to assess expert views using fuzzy sets. The steps necessary to perform the study are shown in Figure 1.

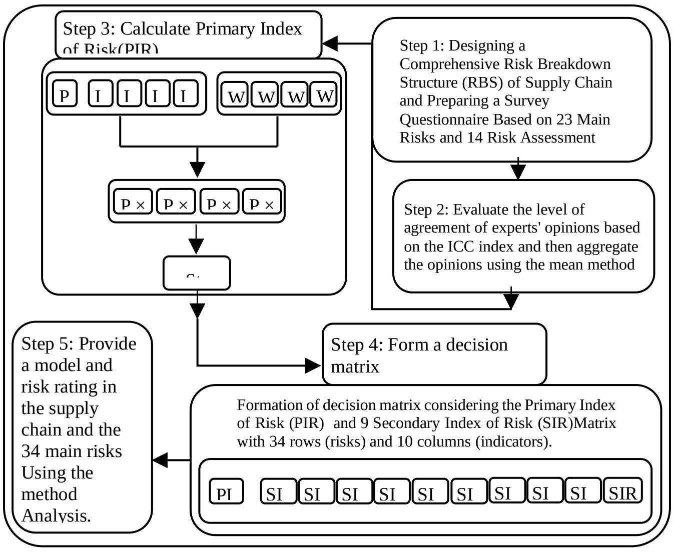

FIGURE I
COMBINED RESEARCH APPROACH

- *Delphi Fuzzy*

Implementation steps of this method are a mix of the Delphi method implementation and information analysis utilizing unclear set theory definitions, as follows:

- Choosing experts and explaining the issue to them
- Provide the questionnaire for sending the experts
- Collecting expert opinions: At this step, a questionnaire is provided to the expert group members to ascertain their agreement with each component and to summarize the suggested and corrected points of view. The fuzzy mean of each component is determined using the questionnaire questions and the linguistic factors provided in the questionnaire (Lin and Cheng, 2002).

Equation 1:

$$A_i = \left(a_1{}^{(i)}, a_2{}^{(i)}, a_3{}^{(i)}\right), i = 1,2,3, \dots, \text{n}$$

Equation 2:

$$A_{ave} = (m_1, m_2, m_3) = \left(\frac{1}{n}\sum_{i=1}^{n} a_1{}^{(i)}, \frac{1}{n}\sum_{i=1}^{n} a_2{}^{(i)}, \frac{1}{n}\sum_{i=1}^{n} a_3{}^{(i)}\right)$$

In equation 1, A_i expresses the opinion of the expert and equation 2 A_{ave} says the average views of the experts. $a_1{}^{(i)}, a_2{}^{(i)}, a_3{}^{(i)}$ also represent a fuzzy number. The prior point of view for each instance, the amount it differs from the average point of view for the others, and the questionnaire for the following round are sent to the experts in this stage. After performing a fresh round of polls and comparing them to the results of the current round, the poll process will halt. The following equation is used to determine the difference limit:

Equation 3:

$$s(A_{m2}, A_{m1}) = \left|\frac{1}{3}[(a_{m21} + a_{m22} + a_{m23}) - (a_{m11} + a_{m12} + a_{m13})]\right|$$

- *FAHP method*

In this strategy, fuzzy triangular values are used to substitute unclear data and a matrix of pairwise comparisons is created for a certain level of hierarchy depending on the responses provided by decision-makers. For selecting the criteria, a questionnaire is created to ascertain their relative relevance. Individuals choose just the applicable descriptive criteria while evaluating the questions, and then the preferred alternatives are translated to scales comprising triangular fuzzy values (Chang, 1996). Additionally, they are generalized to conduct computations and analyse the findings. Weighing using Chen's approach of extended analysis: Chang developed a relatively straightforward way for extending the hierarchical analysis process to fuzzy space in 1992. This strategy, which was created using fuzzy triangular numbers and was based on the arithmetic mean of expert judgments and the hourly normalization procedure, was well received by researchers. This procedure is as follows:

Step 1: Drawing the Hierarchical Tree: In this step, draw the structure of the decision hierarchy by applying the target, criterion, and option levels.

Step 2: Forming a pairwise comparison matrix: Applying a decision maker, form a matrix of comparisons using triangular fuzzy numbers $\tilde{t}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ due to the opinions of several decision makers.

$$\tilde{A} = \begin{bmatrix} (1,1,1) & \begin{Bmatrix} \tilde{a}_{121} \\ \tilde{a}_{122} \\ \vdots \\ \tilde{a}_{12p_{12}} \end{Bmatrix} & \cdots & \cdots & \begin{Bmatrix} \tilde{a}_{1n1} \\ \tilde{a}_{1n2} \\ \vdots \\ \tilde{a}_{1np_{1n}} \end{Bmatrix} \\ \begin{Bmatrix} \tilde{a}_{211} \\ \tilde{a}_{212} \\ \vdots \\ \tilde{a}_{21p_{21}} \end{Bmatrix} & (1,1,1) & \cdots & \cdots & \begin{Bmatrix} \tilde{a}_{2n1} \\ \tilde{a}_{2n2} \\ \vdots \\ \tilde{a}_{2np_{2n}} \end{Bmatrix} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \begin{Bmatrix} \tilde{a}_{n11} \\ \tilde{a}_{n12} \\ \vdots \\ \tilde{a}_{n1p_{n1}} \end{Bmatrix} & \begin{Bmatrix} \tilde{a}_{n21} \\ \tilde{a}_{n22} \\ \vdots \\ \tilde{a}_{n2p_{n2}} \end{Bmatrix} & \cdots & \cdots & (1,1,1) \end{bmatrix}$$

In this matrix P_{ij} is the number of people commenting on the priority of drive i over j.

Step 3; Arithmetic mean of opinions: Calculate the arithmetic mean of views of decision makers as the following matrix:

$$\tilde{A} = \begin{bmatrix} (1,1,1) & \tilde{a}_{12} & \tilde{a}_{1n} \\ \tilde{a}_{21} & (1,1,1) & \tilde{a}_{2n} \\ \vdots & \vdots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & (1,1,1) \end{bmatrix} \qquad \tilde{a}_{ij} = \frac{\sum_{k=1}^{p_{ij}} a_{ijk}}{P_{ij}} \quad i,j = 1,2,\dots,n \quad (4)$$

Step 4: Calculate the sum of line elements: Calculate the sum of line elements:

$$\tilde{s}_i = \sum_{i=1}^{n} \tilde{a}_{ij} \qquad i = 1,2,\dots,n \qquad (5)$$

Step 5: Normalizing: Normalize the sum of the lines as follows.

$$\tilde{M}_i = \tilde{s}_i [\textstyle\sum_{i=1}^{n} \tilde{s}_i]^{-1} \qquad i = 1,2,\dots,n \qquad (6)$$

The above equation is calculated in the following order if we indicate as (li, mi, ui)

$$\tilde{M}_i = \left(\frac{l_i}{\sum_{i=1}^{n} u_i}, \frac{m_i}{\sum_{i=1}^{n} m_i}, \frac{u_i}{\sum_{i=1}^{n} l_i}\right) \qquad (7)$$

Step 6: Identifying the degree of being larger: We calculate the probability that every iµ is larger than the other µi and call it d '(Ai).

The degree of probability of a fuzzy triangular number is µ2= (l2,m2,u2) than the fuzzy triangular number µ1=(l1,m1,u1) is as:

$$V(M_2 > M_1) = Sub_{y \geq x}\left[min\left(\mu_{M_1}(x), \mu_{M_2}(y)\right)\right] \qquad (8)$$

This equation can be synonymously expressed as follows:

$$V(M_2 > M_1) = hgt(M_2 \cap M_1) = \mu_{M_2}(d) = \begin{cases} 1 & m_2 \geq m_2 \\ 0 & l_2 \geq u_1 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \end{cases} \qquad (9)$$

Where d is the coordinate of the highest point in the area of collision and collision of the two membership functions μ_{M_1} and μ_{M_2}.

To compare M1 and M2, it is required to calculate both V(M2 ≥ M1) and V(M1≥M2) values. The greater probability of a convex fuzzy number (M) is separated from the K of another convex fuzzy number (Mi; i = 1,2,...,k).

Step 7: Normalization: By normalizing the weight vector, normalized weights are obtained.

$$W = \left[\frac{d'(A_1)}{\sum_{i=1}^{n} d'(A_i)}, \frac{d'(A_2)}{\sum_{i=1}^{n} d'(A_i)}, \dots, \frac{d'(A_n)}{\sum_{i=1}^{n} d'(A_i)}\right]^T \qquad (10)$$

The above weights are definite (non-fuzzy) weights. With the repetition of this process, the weights of all matrices are provided. By performing these calculations, the results are provided in the following order.

Step 8: Weight Composition: The final weights are obtained by combining option weights and criteria.

$$\tilde{U}_i = \sum_{j=1}^{n} \tilde{w}_i \, \tilde{r}_{ij} \qquad \forall I \qquad (11)$$

Gogus and Boucher (1998) investigated the compatibility of decision matrices by regenerating 400 random matrices from the set of random indices for the pairwise comparison matrix, producing a hazy image, which entails the following procedures:

Step 1: Divide the fuzzy triangular matrix into the following two matrices:
Intermediate numbers of triangular judgments

Am=[aijm]

Geometric mean of upper and lower triangular numbers

Step 2: Calculating the weight vector of each matrix applying the hourly method:

$$W_i^m = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ijm}}{\sum_{i=1}^{n} a_{ijm}} \; ; W^m = [W_i^m] \quad , \quad W_i^g = \frac{1}{n}\sum_{j=1}^{n}\frac{\sqrt{a_{iju}a_{ij1}}}{\sum_{i=1}^{n}\sqrt{a_{iju}a_{ij1}}}, \; ; W^g = [W_i^g] \qquad (12)$$

Step 3: Calculating the largest eigenvalue for each matrix:

$$\lambda_{max}^m = \frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{n} a_{ijm}\left(\frac{W_j^m}{W_i^m}\right) \quad , \quad \lambda_{max}^g = \frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{n}\sqrt{a_{iju}a_{ij1}}\left(\frac{W_j^g}{W_i^g}\right) \qquad (13)$$

Step 4: Calculating the compatibility index applying the following equations

$$CI^m = \frac{(\lambda_{max}^m - n)}{n-1} \quad , \quad CI^g = \frac{(\lambda_{max}^g - n)}{n-1} \qquad (14)$$

Step 5: Calculating the Compatibility Rate (IR)

$$CR^m = \frac{CI^m}{RI^m} \text{ and } CR^g = \frac{CI^g}{RI^g} \qquad (15)$$

The fuzzy matrix is compatible if both indices are less than 0.1. Suppose both are greater than 1. The decision maker is asked to regard the priorities presented, and if only CRg and CRm was greater than 0.1. The decision maker will revise the intermediate values of the fuzzy judgments.

- *Fuzzy TOPSIS*

The TOPSIS approach was created and is used to discover the optimal alternative based on the composite solution's notions. The composite solution chooses the solution that is closest to the ideal solution and the solution that is farthest from the negative perfect solution. Given that reference rankings often include subjective ambiguity; it is logical for TOPSIS to consider the location of fuzzy numbers. In this work, we use Chen's FTOPSIS technique (2000). This technique is defined as follows:

Step 1: Regarding the decision group with expert K, the following formula calculates the scores of the alternatives for each criterion:

$$\tilde{x}_{ij} = \frac{1}{K}\left[\tilde{x}_{ij}^1 + \tilde{x}_{ij}^2 + \cdots + \tilde{x}_{ij}^K\right] \qquad (16)$$

$= \{A_i | i = 1,2, \dots, m\}$ shows the sum of alternatives and $C = \{C_j | j = 1,2, \dots, m\}$ the sum of criteria.
$X = \{X_{ij} | i = 1, \dots, m, \; j = 1, \dots, n\}$ shows the sum of fuzzy ranking and $\widetilde{w} = \{\widetilde{w}_j | j = 1, \dots, n\}$ the sum of fuzzy weights. Linguistic variables are described with triangular fuzzy numbers:

Step 2: Normal rankings are identified by the following equation.

$$\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}) \qquad (17)$$

Step 3: Normal weighted rankings are identified by the following equation.

$$\tilde{v}_{ij} = \widetilde{w}_j(x)\tilde{r}_{ij} \qquad (18)$$

Step 4: The following equations obtain the fuzzy positive ideal point (FPIS, A *) and the negative perfect point (FNIS, A-). Here, J1 and J2 indicate the benefit and cost characteristics.

$$FPIS = A^* = \{\tilde{v}_1^*, \tilde{v}_2^*, \dots, \tilde{v}_n^*\} where \tilde{v}_1^* = (1,1,1) \qquad (19)$$

$$FNIS = A^- = \{\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^-\} where \tilde{v}_1^- = (0,0,0) \qquad (20)$$

Step 5: Similar to the crisp position, the next step is calculating the separation of FPIS and FNIS between the alternatives. Separation values are provided by applying the Euclidean distance such as equations (10-11):

$$\tilde{S}_i^* = \sqrt{\sum_{j=1}^{n} \left[\tilde{v}_{ij} - \tilde{v}_j^*\right]^2}, \qquad i = 1,2,\dots,m \qquad (21)$$

$$\tilde{S}_i^- = \sqrt{\sum_{j=1}^{n} \left[\tilde{v}_{ij} - \tilde{v}_j^-\right]^2}, \qquad i = 1,2,\dots,m \qquad (22)$$

Step 6: Then, the de-fuzzy separation values are provided by applying the CoA (area center) fuzzy decoupling method, such as calculating the similarities to the perfect solution. The following are similarities to the ideal solution in the following equation.

$$C_i^* = \frac{\tilde{S}_j^-}{(\tilde{S}_j^* + \tilde{S}_j^-)}, \qquad i = 1,2,\dots,m \qquad (23)$$

Then, the preferred arrangements C_i^* are ranked in descending order and the best alternative is selected. Finally, based on the determined alternative, the supply chain risk model is identified.

DATA ANALYSIS

This part analyzes the information. Objective 1: To ascertain the steel industry's risk: The fuzzy Delphi approach is utilized to ascertain steel industry's risk in the supply chain. Using the fuzzy Delphi technique, data gathered from theoretical and information sources were first transformed into a collection of primary and secondary dangers. After extracting the risks, which was accomplished by sending a questionnaire and getting responses and summarizing, the study was continued until the desired result (model) was obtained; Table 1 summarizes the hazards associated with the steel industry's supply chain. The following section examines expert viewpoints. The fuzzy Delphi technique began with distributing a two-part questionnaire to panel members. The first section of the questionnaire used a 5-point Likert scale. The second section of the questionnaire included open-ended questions to elicit panel members' creativity in identifying the steel industry's supply chain concerns, which resulted in clarifying unclear terminology and including a component. Table 2 summarizes the general outcome of the first Delphi stage.

TABLE I
MAIN AND SECONDARY RISKS

Sub-risk	Main Risk
Financial risks of suppliers	Supply and suppliers' risks
Existing sanctions risk	External risks of organization
Risk of possible sanctions	
Risk of natural factors	
Risk of rules and regulations	
Industrial risks	
Risk management	Internal risks of organization
Production technical risks	Production risk
Design change risk	
Risk of environmental problems	
Safety risk and safe equipment of all production processes up to distribution	
Production quality risk	
Technology transfer risk	
Procurement risk	Risk of support and logistics and information
Risk of product price change	Demand risk
Risk of change in demand	

In an open questionnaire, experts were asked their opinion on the practical risks in the steel industry's supply chain. The experts raised many risks, which have progressed to the second phase, the fuzzy jump letter, and 22 experts have expressed their opinion that the announced risks are related to the steel industry. Second round was built with the adjustments above in mind. A five-choice Likert scale was utilized in the second round of the questionnaire. The second step included informing the statistical sample (experts) of the risk adjustments determined during the first Delphi stage. Table 4 summarizes the supply chain hazards in the steel sector as a consequence of the fuzzy Delphi method's second phase. The first section of the questionnaire used a five-point Likert scale (shallow to extremely high).

The second section is included open-ended questions to elicit panel members' creativity in identifying supply chain concerns in the steel sector, which resulted in unanimous agreement among experts during the first round of changes. As shown in Table 5, some of the expert group members' risks have achieved consensus, and the degree of disagreement in the first and second phases was less than the 0.2 thresholds, so the survey on the above risks was halted. Among the dangers stated, those with a non-fuzzy average of expert views less than 8 (as determined by the Pareto rule) were excluded from the research's conceptual model, which will continue the survey in the third stage. The following table summarizes the outcome of the second Delphi phase.

TABLE 2
GENERAL RESULT OF THE FIRST PHASE OF FUZZY DELPHI

	Added component
Sub-risk	**Main Risk**
Production risk of suppliers	Supply and suppliers' risks
Supply performance risk and Raw material suppliers	
Risk of mines supplying raw materials	
Risk of rising raw material prices	
Political risks	External Risks of organization
Economic risks by introducing the tax laws	
Economic risks with the introduction of new protection and subsidy laws	
Risk of foreign competitors in the international arena	
Organizational culture risk	Internal risks of organization
Administrative bureaucratic risk	
Risks of organizational agility	
Risk of supply chain organizational relationships	
Production planning risk	Production risk
Human resource risk	
Internal barriers to production	
External barriers to production	
Operation risk of equipment, devices and production lines	
Supplier Dependency Risk	
Raw material quality risk	
supply and inventory supply and raw materials required for production risk	Risk of support and logistics and information
Raw material warehouse risk	
storage risk of materials extracted from mines	
Final product warehouse risk	
Transportation risk of imported raw materials	
transportation risk of materials extracted from mines	
Information flow risk	
Information integration risk	
Information system security risk	
Risk of information accessibility	
Risk of information systems inconsistency	
International demand risk	Demand risk
Domestic market demand risk	
Demand forecasting risk	
Risk of receiving financials claims	
Risk of internal customer expectations	
Risk of external customer expectations	
Risk of environmental factors affecting the demand function	
Risk of domestic investors	Capital Risk
Risk of foreign investors	
Stock market risk and shareholders	
Capital risk	
Risk of return of capital from foreign buyers	
Risk of government economic policies in the field of stock exchange and economy	
Risk of inability to provide currency	
Risk of not communicating with foreign banks	
Risk of blocking part of the company's capital in other countries	

TABLE 3
GENERAL RESULT OF THE SECOND PHASE OF FUZZY DELPHI

Deleted components
Financial risks of suppliers
Risk of possible sanctions
Industrial risks
Production technical risks
Safety risk and safe equipment of all production processes up to distribution
Production quality risk
Procurement risk
Risk of product price change

The third round of the Delphi questionnaire on risks was constructed in light of the above. A five-choice Likert scale was utilized in the third round of the questionnaire. Additionally, the questionnaire contains open-ended questions. The third stage informed the statistical sample (experts) of the experts' average views due to the second Delphi stage. Table 6 summarizes the risks to the steel industry's supply chain as a consequence of the third phase of the fuzzy Delphi technique. The second section of the questionnaire included open-ended questions to encourage panel members' creativity in identifying risks of supply chain in the steel sector, which resulted in rectification and integration during the second round of corrections. As shown in Table 7, some of the expert group members' risks have achieved consensus, and the level of disagreement in the second and third phases was less than the 0.2 thresholds, so the survey on the risks above was halted. Among the dangers stated, those with a non-fuzzy average of expert views less than 8 (as determined by the Pareto rule) were excluded from the research's conceptual model, which will continue the survey in the third stage. The fourth stage informed the statistical sample (experts) of the experts' average views as a consequence of the third Delphi stage. Table 8 illustrates the supply chain hazards in the steel sector as a consequence of the fuzzy Delphi method's fourth phase. Amount of disagreement among experts in the third and fourth phases is less than the 0.2 threshold, and hence the poll is halted at this point. As a result, over the three rounds of the survey, 28 hazards were eliminated from the conceptual model of the study, and the final risks associated with the steel supply chain were reduced to 30, as indicated in Table 4:

TABLE 4
RISKS OF SUPPLY CHAIN IN THE STEEL INDUSTRY

Code	Sub-risk	Main risk
A1	Suppliers planning risk	Supply and suppliers' risks
A2	Performance risk of raw material suppliers	
A3	Mines of raw materials suppliers	
A4	Risk of rising raw material prices	
A5	Existing sanctions risk	External risks of organization
A6	Political risks	
A7	Economic risks with new laws	
A8	Risk of foreign competitors in the international arena	
A9	Risk of rules and regulations	
A10	Risk management and leadership	Internal risks of organization
A11	Risks of organizational agility	
A12	Risk of supply chain organizational relationships	
A13	Production planning risk	Production risk
A14	Design change risk	
A15	Risk of environmental problems	
A16	Operation risk of equipment, devices and production lines	
A17	Technology transfer risk	
A18	Inventory risk	Risk of support and logistics and information
A19	Information flow risk	
A20	Information integration risk	
A21	Risk of information accessibility	
A22	Risk of information systems inconsistency	
A23	Demand forecasting risk	Demand risk
A24	Risk of change in demand	
A25	Risk of receiving financials claims	
A26	Risk of external customer expectations	
A27	Risk of foreign investors	Capital risk
A28	Risk of stock market and shareholders	
A29	Capital risk	
A30	Risk of not doing Swift by foreign banks	

- *Weighting of criteria using fuzzy AHP method*

FMEA criteria were used in this research to rank risks of supply chain in the steel sector. Three factors comprise the FMEA criterion: risk intensity, risk likelihood, and probability of detecting risk. The risk assessment factors were weighted using the fuzzy AHP approach. As a result, Figure 2 depicts the model with a hierarchical structure:

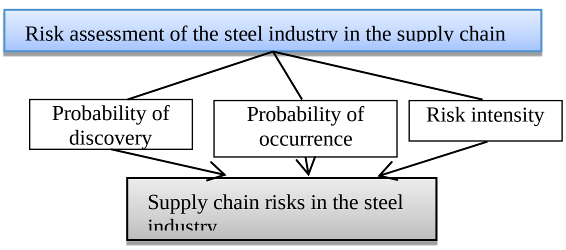

FIGURE 2
MODEL WITH HIERARCHICAL STRUCTURE OF RESEARCH

For this objective, even comparison matrices are made, and then the elements of even comparison matrices (Table 5):

TABLE 5
TRIANGULAR FUZZY NUMBERS TO CALCULATE RELATIVE IMPORTANCE

Triangular fuzzy scale		**Definition**
(7,9,9)	9	Extreme
(5,7,9)	7	Very strong
(3,5,7)	5	Strong
(1,3,5)	3	Relative
(1,1,1)	1	Same

After establishing pairwise comparison matrices and converting the decision matrix's linguistic variables to triangular fuzzy integers, the weights for the FMEA criterion were generated using the fuzzy hierarchical technique (F. AHP). The incompatibility rate is also determined using the Gogus and Boucher (1998) approach, with the findings in Table 6.

TABLE 6
MATRIX COMPATIBILITY TEST

Matrix	N	λ^{m}_{max}	CIm	CRm	λ^{g}_{max}	CIg	CRg	Result
FMEA Criteria	3	3	0.0017	0.0034	3	0.0168	0.0937	< 0.1

Because the value of CRm and CRg is less than 0.1 in all matrices, the matrix is fuzzy compatible. Thus, the work can be continued and the matrix of the pairwise comparisons can be solved. Based on the information provided by 10 research experts, and by calculating the aggregation of their opinions on each of the items of the fuzzy pairwise comparison questionnaire and placing them in the desired range due to the proximity of the score, Table 6 is due to calculating the overall score of the case study (Table 7).

TABLE 7
PARALLEL COMPARISONS OF RISKS OF SUPPLY CHAIN IN THE STEEL INDUSTRY

	C1			**C2**			**C3**		
C1	1	1	1	0.333	0.66	1	0.25	0.361	1
C2	1	1.516	3	1	1	1	0.25	0.461	1
C3	1	2.766	4	1	2.169	4	1	1	1

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M = (6.83, 10.93, 17) \quad [\sum_{i=1}^{n}\sum_{j=1}^{m} M]^{-1} = (0.059, 0.091, 0.146) \qquad (24)$$

The magnitude of each of the Si values relative to the other

TABLE 8
RELATIVE IMPORTANCE OF FMEA CRITERIA

Normalized weight	**Abnormal weight**	**FMEA Criteria**	
0.202	0.423	C1	Risk intensity
0.321	0.672	C2	Probability of risk
0.477	1.000	C3	Probability of risk detection

As shown in Table 8, the criterion of "probability of discovery" with the highest weight equal to 48% of the total weights is the most essential criterion of FMEA when assessing risks of supply chain in the steel industry. In comparison, the criterion of "risk intensity" with the lowest weight equal to 2% of the total weights, is the second most important criterion of FMEA. A weight of 32% is assigned to the second priority, while a minimum weight of 20% is assigned to the last and third priority criteria of "probability of occurrence." Option ranking using the fuzzy TOPSIS technique type 2: In this part, a fuzzy TOPSIS type 2 technique based on weights derived from FMEA criteria is utilized to analyze and prioritize risks of supply chain in the steel sector. The steel sector faces 30 risks of supply chain outlined in Table 9.

TABLE 9
RISKS OF SUPPLY CHAIN

Code	Risks of supply chain in the steel industry
A1	Supplier planning risk
A2	Performance risk of raw material suppliers
A3	Mines of raw materials suppliers
A4	Risk of rising raw material prices
A5	Existing sanctions risk
A6	Political risks
A7	Economic risks with new laws
A8	Risk of foreign competitors in the international arena
A9	Risk of rules and regulations
A10	Risk management and leadership
A11	Risks of organizational agility
A12	Risk of supply chain organizational relationships
A13	Production planning risk
A14	Design change risk
A15	Risk of environmental problems
A16	Operation risk of equipment, devices and production lines.
A17	Technology transfer risk
A18	Inventory risk
A19	Information flow risk
A20	Information integration risk
A21	Risk of information accessibility
A22	Risk of information systems inconsistency
A23	Demand forecasting risk
A24	Risk of change in demand
A25	Risk of receiving financials claims
A26	Risk of external customer expectations
A27	Risk of foreign investors
A28	Risk of stock market and shareholders
A29	Capital risk
A30	Risk of not doing Swift by foreign banks

The following is the solution of fuzzy TOPSIS type 2 distance:

The first step is to create a decision matrix. To determine each risk using FMEA criteria, a pairwise comparison matrix was developed and completed by ten experts. Decision makers decided on the relevance of the linguistic characteristics in Table 10.

TABLE 10
LANGUAGE VARIABLES FOR RANKING OPTIONS

interval type fuzzy set-۲	Language variables
((0, 0, 0, 1; 1, 1), (0, 0, 0, 0.5; 0.9, 0.9))	Very low
((0, 1, 1, 3; 1, 1), (0.5, 1, 1, 2; 0.9, 0.9))	low
((1, 3, 3, 5; 1, 1), (2, 3, 3, 4; 0.9, 0.9))	Relatively low
((3, 5, 5, 7; 1, 1), (4, 5, 5, 6; 0.9, 0.9))	medium
((5, 7, 7, 9; 1, 1), (6, 7, 7, 8; 0.9, 0.9))	Relatively much
((7, 9, 9, 10; 1, 1), (8, 9, 9, 9.5; 0.9, 0.9))	much
((9, 10, 10, 10; 1, 1), (9.5, 10, 10, 10; 0.9, 0.9))	very much

After consulting with experts, a matrix of fuzzy decision was created. In Table 16, matrix of fuzzy decision is generated using variables received from the assessment of criteria in terms of choices. This aggregated matrix represents the perspectives of ten experts.

Step 2: Normalizing matrix of fuzzy decision

The normalized matrix of fuzzy decision was created by multiplying the matrix of fuzzy decision in Table 17 by ten. Risk severity and likelihood of occurrence criteria have a positive aspect, which indicates that the greater their values, the more hazardous the risk. However, the probability of detection criteria has a negative connotation, implying that the situation is improved if the chance of danger detection is increased. The following example illustrates the fuzzy average value of option A1 for the criteria C1 (risk intensity) with a positive aspect:

$$C_j^+ = \max(10,\ 10, 10, 10) \quad (25)$$

$$\tilde{r}_{ij} = \left(\frac{8.333}{10}, \frac{9.667}{10}, \frac{9.667}{10}, \frac{10}{10}; 1, 1\right), \left(\frac{9}{10}, \frac{9.667}{10}, \frac{9.667}{10}, \frac{9.833}{10}; 1, 1\right) \quad (26)$$

= (0.833, 0.967, 0.967, 1; 1, 1), (0.915, 0.983, 0.983, 1; 0.9, 0.9)

Step 3: Identify the weighted matrix of fuzzy decision

It is indicated in Table 18. Then, the ranking value values are calculated according to the criteria for each option. For instance, for option A1 relative to criterion C1, the following was provided:

RankV11=(0.182+0.192+0.195+0.199+0.199+0.2)-(011)+(0.202+0.202+0.182+0.182)=1.922

Finally, the weighted matrix of decision is obtained, which is shown in Table 11. Step 4: Identify the ideal solution and the fuzzy counter-ideal solution. That is described in Table 12.

Step 5: Calculate the distance from the ideal solution and the fuzzy counter-ideal

The distance of every option from ideal solution and the fuzzy counter-ideal is calculated. Applying the weight of criteria and matrix of pairwise comparisons of options and indicators by Excel software, the final TOPSIS ranking design and the distance of each option from the ideal and anti-ideal solution (S_i^-, S_i^*)and similarity index (CC_i)The options are extracted and the results are indicated in Table13 (Appendix 1), which is calculated for the first option as follows:

A1=1.273 / (0.415+1.273)= 0.754 (27)

TABLE 11
DECISION WEIGHT AND RANKING MATRIX

Criteria	C1	C2	C3
	Risk intensity	Probability of risk	Probability of risk detection
A1	1.922	1.922	0.862
A2	1.922	1.922	0.989
A3	1.596	1.354	0.901
A4	1.922	1.922	0.901
A5	1.922	1.922	0.901
A6	1.922	1.922	0.862
A7	1.596	1.922	0.862
A8	1.922	1.922	0.862
A9	1.922	1.8	0.901
A10	1.354	1.124	0.989
A11	1.354	1.354	0.989
A12	1.596	1.596	0.989
A13	1.922	1.922	0.989
A14	1.124	0.931	0.989
A15	1.922	1.922	0.901
A16	1.354	1.354	0.901
A17	1.596	1.596	0.901
A18	1.922	1.922	0.862
A19	1.596	1.596	0.901
A20	1.596	1.596	0.989
A21	1.596	1.596	1.277
A22	1.922	1.922	0.989
A23	1.922	1.922	0.862
A24	1.922	1.922	0.901
A25	1.922	1.8	0.901
A26	1.922	1.922	0.989
A27	1.922	1.922	0.989
A28	1.922	1.922	0.901
A29	1.596	1.596	0.989
A30	1.922	1.922	0.862

TABLE 12
DETERMINATION OF FUZZY IDEAL AND COUNTER-IDEAL SOLUTION

Criteria	C1	C2	C3
	Risk intensity	Probability of risk	Probability of risk detection
A1	1.922	1.922	0.862
A2	1.922	1.922	0.989
A3	1.596	1.354	0.901
A4	1.922	1.922	0.901
A5	1.922	1.922	0.901
A6	1.922	1.922	0.862
A7	1.596	1.922	0.862
A8	1.922	1.922	0.862
A9	1.922	1.8	0.901
A10	1.354	1.124	0.989
A11	1.354	1.354	0.989
A12	1.596	1.596	0.989
A13	1.922	1.922	0.989
A14	1.124	0.931	0.989
A15	1.922	1.922	0.901
A16	1.354	1.354	0.901
A17	1.596	1.596	0.901
A18	1.922	1.922	0.862
A19	1.596	1.596	0.901
A20	1.596	1.596	0.989
A21	1.596	1.596	1.277
A22	1.922	1.922	0.989
A23	1.922	1.922	0.862
A24	1.922	1.922	0.901
A25	1.922	1.8	0.901
A26	1.922	1.922	0.989
A27	1.922	1.922	0.989
A28	1.922	1.922	0.901
A29	1.596	1.596	0.989
A30	1.922	1.922	0.862
Positive idea*(MAX)	1.922	1.922	1.277
Negative idea A-(MIN)	1.124	0.931	0.862

At this point, the alternatives are sorted according to their similarity index, with the ones with the highest similarity index being favoured. According to the TOPSIS method's findings, the top three risk categories in the steel industry's supply chain are "performance risk of raw material suppliers," "production planning risk," and "information systems inconsistency risk."

CONCLUSION

This research aims to evaluate the steel industry's risks of supply chain. Findings shown the five most significant risks in this business are, in order, raw material supplier performance risk, production planning risk, information system inconsistency risk, foreign customer expectations risk, and foreign investor risk. According to the proposed model for evaluating and ranking risks based on the weight of criteria, it is suggested that this model be used for ranking in other areas or organizational processes (for example, personnel selection in the workforce process, project ranking, or other items) because the proposed model enables managers to make the best choices. Additionally, it is recommended that the sectors above get acquainted with the strategic viewpoint and begin using the balanced scorecard, a relatively new form of strategic management, to extract the primary aspects of customer risk. In future studies, a combined strategy of Delphi and balanced scorecard may be employed to prioritize risks.

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APPENDIX 1:

TABLE 13
DISTANCE BETWEEN EVERY OPTION OF FUZZY IDEAL AND COUNTER-IDEAL SOLUTION AND RANKING OF OPTIONS

Options (Steel industry risks of supply chain)		Distance from positive idea	Distance from negative idea	Similarity index	Ranking options
Suppliers planning risk	A1	0.415	1.273	0.754	11
Performance risk of raw material suppliers	A2	0.288	1.279	0.816	1
Mines of raw materials suppliers	A3	0.755	0.635	0.457	26
Risk of rising raw material prices	A4	0.376	1.274	0.772	6
Existing sanctions risk	A5	0.376	1.274	0.772	7
Political risks	A6	0.415	1.273	0.754	12
Economic risks with new laws	A7	0.528	1.098	0.675	19
Risk of foreign competitors in the international arena	A8	0.415	1.273	0.754	13
Risk of rules and regulations	A9	0.395	1.181	0.749	17
Risk management and leadership	A10	1.021	0.326	0.242	29
Risks of organizational agility	A11	0.853	0.498	0.369	27
Risk of supply chain organizational relationships	A12	0.544	0.825	0.602	21
Production planning risk	A13	0.288	1.279	0.816	2
Design change risk	A14	1.305	0.127	0.089	30
Risk of environmental problems	A15	0.376	1.274	0.772	8
Operation risk of equipment, devices and production lines	A16	0.887	0.484	0.353	28
Technology transfer risk	A17	0.596	0.816	0.578	24
Inventory risk	A18	0.415	1.273	0.754	14
Information flow risk	A19	0.596	0.816	0.578	25
Information integration risk	A20	0.544	0.825	0.602	22
Risk of information accessibility	A21	0.462	0.915	0.664	20
Risk of information systems inconsistency	A22	0.288	1.279	0.816	3
Demand forecasting risk	A23	0.415	1.273	0.754	15
Risk of change in demand	A24	0.376	1.274	0.772	9
Risk of receiving financials claims	A25	0.395	1.181	0.749	18
Risk of external customer expectations	A26	0.288	1.279	0.816	4
Risk of foreign investors	A27	0.288	1.279	0.816	5
Risk of stock market and shareholders	A28	0.376	1.274	0.772	10
Capital risk	A29	0.544	0.825	0.602	23
Risk of external customer expectations	A30	0.415	1.273	0.754	16