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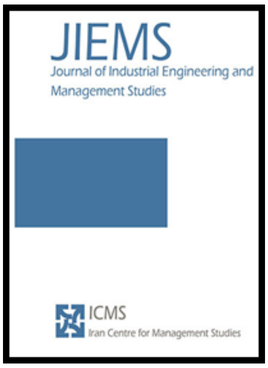

Comparing supply chain risk ranking methods based on fuzzy three-dimensional integration approach

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Abstract

For reducing risk effects in a supply chain, the appropriate risk assessment and ranking by the use of multi-criteria decision-making methods (MCDM) is important. Failure to properly assess and rank the risks makes the supply chain less efficient and competitive. Given the existence of both qualitative and quantitative criteria in a supply chain, the use of verbal preferences, given by authorities for determining the priority of qualitative factors, has higher reliability than that of the Crisp numbers. Fuzzy concept plays an important role in solving the problem of complexity of assigning quantitative fixed numbers to the values of verbal preferences. In the proposed method of this study, a comparison was made among the decision-making methods in the fuzzy environment for selecting a suitable method. To validate the proposed method, we compared it to some case studies from the literature. The results show that the proposed method has high validity and reliability in assessing the risks of a supply chain.

Keywords: risk ranking; supply chain; decision making methods; fuzzy three-dimensional integration mean.

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1. Introduction

Due to the increasing demand for product quality, different factors such as competitive, environmental, economic, social, and political ones contribute to the uncertainty and risks associated with products, services, and organizations. To maintain competitive in such environment, the need for supply chain management becomes more and more revealing. Although assessing and managing supply chain risks are crucial for business success, traditional risk assessment methods are not able to identify intangible criteria as essential factors in risk analysis (Dong and Cooper, 2016; Li, Ren, and Wang, 2016). The inappropriate number of suppliers in a supply chain can create risks, which reduce the strategic performance of an organization. Therefore, managers should consider the role of risks in selecting suppliers (Fang et al., 2013). Features such as high quality, product diversity, cost-effectiveness, and fast services have prompted important issues such as

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selecting the right decision, the effective strategy and the appropriate intra-chain processes to satisfy customers' expectations in the supply chain (Mishra et al., 2016; Abarqhouei, Hosseini Nasab and Fakhrzad, 2012). Recently, advances in computer science and numerology have led to the development of multiple decision making tools, such as linear or dynamic programming, inventory control, hypothesis testing, and operation control. Multi-criteria Decision Making (MCDM) is the most appropriate method to help a decision maker identify a suitable solution among a set of alternatives (Zimmermann, 2011). Over the past 20 years, much attention has been drawn to the structuring decision problems for Multi-criteria Decision Making (MCDM) from a conceptual and practical point of view. This can be inferred from the considerable amount of research arising from the problem-solving approach in combination with the method of multi-criteria analysis (Eslamipoor, Fakhrzad and Zare Mehrjerdi, 2015). The identification of a suitable choice among the available options is a complicated task subject to the priorities of use that should be decided about on a ranking scale. This requires careful attention to all the features of the user options. There are various multi-criteria decision-making techniques to facilitate the ranking of alternatives by the decision maker. Each MCDM method has its own strengths and weaknesses, but the problem of ranking change is observed in almost all the methods using normalization. This problem strongly reduces the reliability of these methods and may yield misleading results in large-scale ranking (Mufazzal and Muzakkir, 2018). Concerning the insufficient accuracy in determining the weight of the criteria, Zadeh and Bellman developed the fuzzy multi criteria decision making method to rank the alternatives based on the criteria assessment. Due to the fact that human minds work with differing logic for making decisions, multi-valued logic methods such as fuzzy logic were developed (Babaee tirkolaee et al., 2020; Rostamzadeh et al., 2018). A fuzzy set deals with uncertainties within the mathematical framework in such a way that phenomena can take continuous values between zero and one. Fuzzy logic provides a useful tool for converting verbal expressions to fuzzy numbers in which uncertain conceptual phenomena are properly examined. Therefore, when decision makers have preferences with respect to a verbal criterion, the fuzzy theory can be applied (Abarqhouei, Hosseini Nasab and Fakhrzad, 2012). Considering the importance of the supply chain and the interdependence of members, the use of a risk rating approach is critical to mitigate the effects of risk on the supply chain. In the real world, different quantitative and qualitative risks affect the supply chain. To rank the quantitative risks, they should be converted to crisp numbers. This process affects the ranking result of the MCDM methods. In addition, different decision-making methods usually provide different rankings for quantitative risks. Accordingly, the probability of choosing the wrong ranking method increases.

In the proposed method, first, various decision-making methods are investigated to determine the reliable ones. A fuzzy interval is then considered for supply chain risks in the different decision-making methods. Finally, to select the most appropriate MCDM method for evaluating and ranking quantitative and qualitative risks in the supply chain, the fuzzy intervals are compared with the proposed average fuzzy triple method.

2. The Literature

We present the literature in three subsections:

2.1. Risk management in the supply chain

The globalization, outsourcing, and the diversification of products and services have led to the complexity in the supply chain. This complexity increases the uncertainty and risks of the supply chain. Therefore, risk management has an important role in the supply chain performance and the companies should manage the risks for having better productivity and dynamism. In addition, disturbances in the supply chain have long-term undesired effects on the financial performance of companies, making risk management essential in the current business environment (Wagner and Neshat, 2010). Nowadays, logistics and supply chain management (SCM) is critical to compete in the current turbulent markets. In addition, in the global context, there are many uncertainties affecting the market (Hajian-Heidary and Aghaie, 2015). The more extended a supply chain is, the more vulnerable it is, and the more risks the companies will take. Supply chain managers must make correct decisions on sustainable resources, communication management, and asset recovery to minimize the risks. Therefore, identifying the risks, assessing their effects, and managing them are important issues for supply chain managers (Hoffman et al., 2014). Generally, the research on supply chain risk management has been excluded from sustainability issues. Moreover, limited research is available on the sustainable risk and supply chain management as well as losses incurred by the companies. The task of risk management in supply chain is to identify and analyze the risks to provide a solution to respond, control, and monitor them in the production cycle (Rostamzadeh et al., 2018; Khalifehzadeh, and Fakhrzad, 2019).

2.2. Multi-criteria decision-making methods

Due to the globalization, customization, innovation, flexibility, sustainability, and uncertainty, the complexity of supply chains is growing, which has negative effects on the cost, customer service, and reputation. Managing the complexity in a supply chain without endangering its profitability is a challenging task. This involves the identification, prioritization, measurement, analysis, control, and elimination of the complexity drivers. These drivers include the number and variety of suppliers, customers, products, processes, and heavily interdependent uncertainties. Therefore, companies need to prioritize these drivers for the purpose of simplification and management. This problem, which is a MCDM one, entails a conceptual approach (Kavilal, Venkatesan and Harsh Kumar, 2017). Long-term planning is a challenging process for dealing with problems in big industries. In such problems, quick and flexible processes of responding to the existing variable requirements are considered. Some of important strategic decisions that should be made in this field are namely the way that the manufacturing facilities should be applied as well as the assignment and design of the orders delivery system. On the other hand, by using the small core and big network viewpoint in planning, such decisions should be made in a concentrated way. A robust multi criteria group decision making model is proposed, which evaluates the requirements of a real case study. In this regard, firstly, the important criteria in such environments should be determined. Secondly, using the experts' opinions and statistical analysis methods, the group multi criteria decision making model should be constructed (Hejazi and Soleimanmeigouni, 2014).The proper method for selecting a supplier can decrease the risks of the supply chain and increase the competitiveness of the company. The selection of the most appropriate supplier by means of a set of quantitative and qualitative criteria transforms the assessment process into an MCDM problem. Although MCDM problems have been flourished, especially over the past two decades, assessing different alternatives and selecting the suitable supplier is a complex problem in which several dimensions should be taken into account (Büyüközkan and Göcer, 2017).

2.3. The Fuzzy System Theory

The fuzzy system theory is suggested for resolving the natural ambiguities (Torkabadi, Pourjavad and Mayorga, 2018). In order to convert verbal variables into numerical ones in decision-making processes, the fuzzy set theory was originally presented by Zadeh (Rostamzadeh et al., 2018). Today, due to population growth, the demand for energy is rising around the world and current conventional resources cannot fulfill this need. Therefore, alternative economic and clean energy resources need to be considered. In this regard, renewable resources can be considered as a solution. Additionally, the choice among the energy alternatives is a multi-criteria decision making (MCDM), requiring an evaluation of several conflicting criteria. The evaluation of criteria by the use of Crisp numbers is not always an easy task. Hence, to have a more proper and flexible assessment, they should be examined using human judgment and verbal terms. In this way, fuzzy sets can resolve the ambiguities in the decision-making process (Çolaka and Kayab, 2017). Risk assessment plays a vital role in determining premium rates in the insurance industry. In this regard, identifying the key risk factors is very crucial. Considering the limitation and inefficiencies the insurance databases, the need for building a general and effective database is felt. However, building such a database requires time and money. Therefore, up to the time this database is build, we can trust the experts' opinions for identifying the most important pieces of information for risk assessment. The crucial factors are identified based on the experts' opinions using Fuzzy Delphi method (Esfandabadi and Esfahani, 2018). Selecting a suitable server based on a set of criteria including quantitative and qualitative parameters is concerned with a multi-criteria decision-making problem. Such decisions are usually made by more than one person from subjective or occasionally vague statements. The theory of fuzzy sets and group decision making approaches are useful tools for addressing these problems. Thus, the combination of MCDM and fuzzy system theory can help companies in selecting a suitable server (Büyüközkan, Karabulutb and Arsenyanc, 2017). Adopting a suitable business partner is a strategic decision in outsourcing problems. This is a complicated process including conflicting goals and demanding complex considerations. Such decision-making processes can be done using MCDM methods. MCDM can help decision-makers to reach a collective agreement based on benchmarking analysis. In this relation, qualitative benchmarks, because of their challenging assessment by the use of Crisp numerical values, can complicate decision-making process. Thus, the ambiguous criteria can be better represented and assessed using fuzzy numbers (Büyüközkan, Güleryüz and Karpak, 2017). Supplier selection is the one of the strategic decision making tasks of each company, which entails several criteria for evaluating and deciding on alternatives. Accordingly, MCDM is an essential approach in this area. For the supplier selection, the qualitative and quantitative criteria need to be simultaneously evaluated. Furthermore, an integrated approach should be employed for finding the internal structure of the criteria. Hence, an MCDM technique can be used in a fuzzy environment (Sarkara, Pratiharb and Sarkarc, 2018). Based on the literature review, most of the available information for evaluating the criteria in MCDM methods is virtual and vague. This requires a technique for converting uncertain and ambiguous data into Crisp numbers. To this end, the fuzzy set is a useful technique. In this paper, to solve the drawbacks in the previous works as much as possible, an appropriate decision-making approach is represented for assessing supply chain risks.

3. Research method

Definition 1 - Figure 1 shows a triangular fuzzy number ($\widetilde{M}$) and parameters (a_1, a_2, a_3), where a_1 is the smallest possible occurrence value, a_2 is the most probable value, and a_3 is the largest possible occurrence value. The left and right sides of each fuzzy number can be linearly determined by the following membership function:

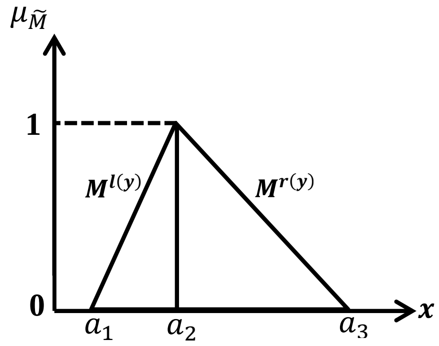

Figure 1. A triangular fuzzy number

(1)

$$\mu_{F(x)} = \begin{cases} 0 & x \leq a_1 \\ \dfrac{x - a_1}{a_2 - a_1} & a_1 < x \leq a_2 \\ \dfrac{a_3 - x}{a_3 - a_2} & a_2 < x \leq a_3 \\ 0 & x > a_3 \end{cases}$$

Definition 2. The following equation shows how a triangular fuzzy number can be represented by the degree of its left and right membership (*l(y)* is the degree of the left membership and *r(y)* is the degree of the right membership).

(2)

$$\widetilde{M} = \left(M^{l(y)}, M^{r(y)}\right) = [\, a_1 + (a_2 - a_1)y \,, a_3 - (a_3 - a_2)y \,] \;, y \in [0,1]$$

Definition 3. The following relation transforms a fuzzy number to a Crisp number:

(3)

$$Crisp\left(\widetilde{M}\right) = \frac{a_1 + 2\,a_2 + a_3}{4}$$

Definition 4: To transform verbal preferences of factor (risk rank) *i* given by the authorities (decision-making methods) *j* i.e. (c_{ij}) into fuzzy numbers (a_{1i}, a_{2i}, a_{3i}), the following relationships can be used:

First method: For each factor/ risk *i* (*i* = 1, 2... *n*), we have:

(4)

$$\left(a_{1i} = min\, c_{ij} \;\; , a_{2i} = \frac{\sum c_{ij}}{m} \; , a_{3i} = max\, c_{ij} \right) \quad j \in [1,2, \ldots \;, m]$$

m = the number of the authorities or decision making methods

In this method, a vast data domain is concerned so there will be outliers and low precision of data.

Second method: For each factor/ risk *i* (*i* = 1, 2... *n*), we have:

(5)

$$\left(\left\{a_{1i} = \frac{\sum c_{ij'}}{m'} \mid j' \in (\forall c_{ij} < a_{2i})\right\} \quad , a_{2i} = \frac{\sum c_{ij}}{m} , \left\{a_{3i} = \frac{\sum c_{ij''}}{m''} \mid j'' \in (\forall c_{ij} > a_{2i})\right\}\right) \quad j \in [1,2, \dots ,m]$$

Where m' is the number of authorities or decision-making methods, so that the values of c_{ij} is less than a_{2i}, and m'' is the number of authorities or decision-making methods, so that the value of c_{ij} is more than a_{2i}. In this method, the outliers are omitted due to the narrower domain and the higher precision.

Third method: For each factor/ risk i (i = 1, 2... n), we have:

$$\left(a_{1i} = \frac{\sum c_{ij}}{m} - 3S_i \ , a_{2i} = \frac{\sum c_{ij}}{m} \ , a_{3i} = \frac{\sum c_{ij}}{m} + 3S_i\right) \quad j = 1,2, \dots ,m \qquad S_i^2 = \frac{\sum\left(c_{ij} - a_{2i}\right)^2}{m-1} , \tag{6}$$

This approach, which is generally agreed upon, covers 99% of the comments. In the third step of the proposed method of this article, the third method has been used.

Definition 5: Three-sequential criteria method has been used to rank fuzzy numbers. The following relationships show this:

The first criterion: Fuzzy numbers will be arranged according to their size or Crisp value:

$$S(A_i) = Crisp\ (A_i) = \frac{a_{1i} + 2\,a_{2i} + a_{3i}}{4} \qquad i \in [1,2, \dots ,n]\ \&\ j \in [1,2, \dots ,m] \tag{7}$$

If fuzzy numbers are of the same size, the second criterion will be used.

Second criterion: The fuzzy numbers will be ordered based on the mode value.

$$M(A_i) = a_{2i} \qquad i \in [1,2, \dots ,n] \tag{8}$$

In the case of fuzzy numbers with equal mode values, the third criterion will be used.

Third criterion: Fuzzy numbers will be ordered using domain relation:

$$R(A_i) = a_{3i} - a_{1i} \qquad i \in [1,2, \dots ,n] \tag{9}$$

Note: According to the third step in this study, the first and second criteria values will be equal to:

$$S(A_i) = \frac{a_{1i} + 2\,a_{2i} + a_{3i}}{4} = \frac{\frac{\sum c_{ij}}{m} - 3S_i + 2\,\frac{\sum c_{ij}}{m} + \frac{\sum c_{ij}}{m} + 3S_i}{4} = \frac{\sum c_{ij}}{m} = a_{2i} = M(A_i) , \quad i \in [1,2, \dots ,n]\ \&\ j \in [1,2, \dots ,m] \tag{10}$$

Therefore, in this research, the size and fuzzy domain criteria have been used for mutual comparison and ranking of risk factors.

4. The proposed method

Generally, different results are obtained from the decision-making methods used for risk assessment and ranking, so it is necessary to compare these methods and select the preferred one. To make a more appropriate comparison of the decision making methods, a ranking domain should be defined for each risk factor since it may have different ranks in different decision making methods. Consequently, the fuzzy system theory must be suitable for this purpose. The following steps illustrate how to make a comparison of the risk assessment methods by means of the proposed fuzzy three-dimensional integration method, which uses statistical relationships.

4.1. Steps of the proposed method

Step 1: Take decision-making methods simultaneously such as AHP[1], Topsis[2], Electre[3], Linmap[4] (at least two of them). If their ranking results are the same, a suitable situation will happen and the calculations will end. Otherwise, go to the second step.

Step 2: Normally, in a real case, decision making methods do not provide a single ranking for a particular problem. In this case, proceed as follows:

First, determine the degree of convergence for the rankings of the decision-making methods. In other words, the significance of the proposed rankings should be measured. It also should be made clear whether there is a causal relationship between the rankings, or the correlation coefficient is randomly obtained. To determine the convergence of the rankings, correlation coefficient test can be used. For this purpose, according to the type of data, which is ranked data, Spearman correlation coefficient is used to calculate the relationship between each pairs of decision-making methods. To obtain the result of the Spearman test, the hypotheses of zero and one are defined as follows:

$$\begin{cases} H_0 = \text{ There is no correlation between the pair of decision making methods} \\ H_1 = \text{ There is correlation between the pair of decision making methods} \end{cases}$$

If the significance level of Spearman test is smaller than 0.05, the H1 assumption is confirmed. It means that the ranking of this pair of the decision-making methods is not random and a significant relationship exists between the ranking methods. Therefore, the ranking can be trusted.

If there is no significant relationship between all the pairs of the decision-making methods, it shows that the decision-making methods are not reliable and the alternatives should be re-ranked. If there is a significant relationship between the decision-making methods, go to the step three.

Step 3. For the decision-making methods that have a meaningful relationship with each other in step 2, the fuzzy number values (a_{1i}, a_{2i}, a_{3i}) of risk factor *i* are calculated by the decision-making method *j* as follows:

$$\left(a_{1i} = \frac{\sum c_{ij}}{m} - 3S_i \ , a_{2i} = \frac{\sum c_{ij}}{m} \ , a_{3i} = \frac{\sum c_{ij}}{m} + 3S_i \right) \quad j = 1,2,\dots \ , m \qquad S_i^2 = \frac{\sum (c_{ij} - a_{2i})^2}{m-1} \tag{11}$$

Step 4: Perform the ranking by the use of fuzzy three-dimensional integration method (the mean of the three methods: Crisp ranking of the decision-making methods, fuzzy Borda method, and fuzzy Copland method).

١ – Analytic Hierarchy Process

٢ – Technique for Order of Preference by Similarity to Ideal Solution

٣ – Elimination et Choice Translating Reality

۴ - Linear programming for Multidimensional Analysis of Preference

Generally, the number of the used methods for ranking purpose can be related to the available time and the validity of a research. That is, the greater the number of used methods, the complexity and the time of calculation will increase, but the research will be more accurate. So, a fuzzy three-dimensional integration method has been used in this research.

A summary of these three methods is described below:

- Crisp ranking of the decision making methods: In this method, according to step 3, for each risk factor r_i, the Crisp value is obtained:

$$Crisp\ (\widetilde{r_i}) = \frac{a_{1i} + 2\ a_{2i} + \ a_{3i}}{4} \quad , \ \ i \in [1,2, \dots \ , n] \tag{12}$$

Risks are ranked from the lowest to the highest Crisp value.

- Fuzzy Borda method: Consider the two risk factors r1 and r3. Based on the first criterion for ordering fuzzy numbers, if *S(r1) < S(r3)* , then this comparison is shown with M. If *S(r1) = S(r3)*, regarding the third criterion of ordering fuzzy numbers, it is coded with M when *R(r1) <R(r3)*, otherwise it is coded with X. M implies that the row is prior to the column, and X indicates that the column is prior to the row. It should be noted that each pair comparison should be drawn independently. The number of comparisons is equal to $\frac{n(n-1)}{2}$ where n shows the number of risk factors. Therefore, the ranking criterion in this method is such that the number of wins in a row (*ΣC*= the number of M in the raw) has the majority on several occasions.

- Fuzzy Copland method: This method starts by the end of the Fuzzy Borda method. This method calculates not only the number of wins but also the number of losses (*ΣR*= the number of M in the column) for each alternative. The score that this method gives to each alternative is calculated by reducing the number of losses from the number of wins (*ΣC*-*ΣR*). The ranking criterion in this method is from the highest to the lowest score.

In this step, after determining the rankings of the three methods, they will be averaged, and finally, the fuzzy three-dimensional integration mean ranking is performed. If the ranking of the fuzzy three- dimensional integration mean method is in accordance with one of the decision making methods (AHP, Topsis, Electere, Linmap, etc.), that decision-making method will be considered as the basis for the final ranking. Otherwise, go to step five.

Step 5: Calculate Spearman correlation coefficient between the fuzzy three-dimensional integration mean method and each decision-making method from step 4. The decision making method with the highest correlation coefficient determines the final ranking. Figure 2 shows steps 1 to 5 of the proposed method.

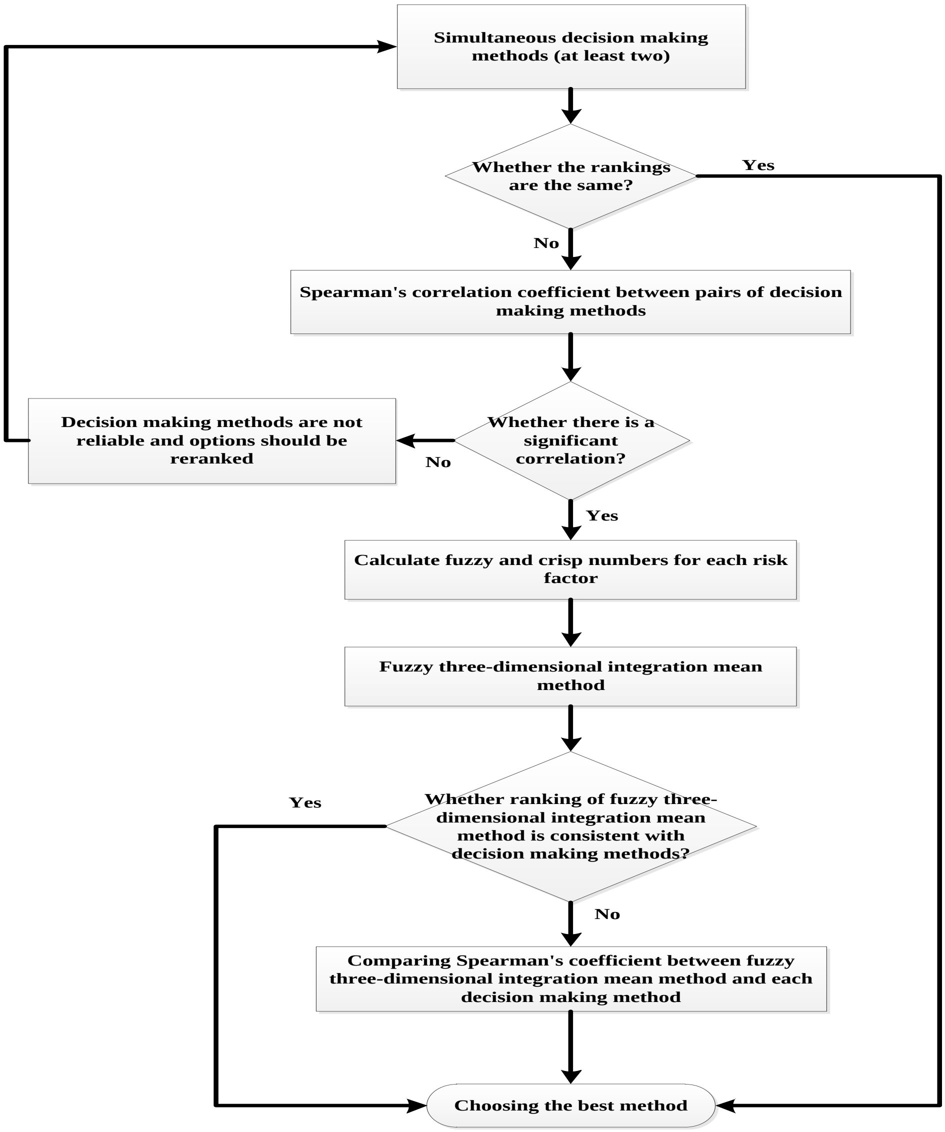

Figure 2. The algorithm of the proposed method

4.2. Advantage and disadvantage of the proposed method

Each proposed method can have its own advantages and limitations. For the proposed approach, the following advantages and limitations are indicated.

Advantages:

1- In the proposed method, the problem of dedicating numbers to qualitative criteria is solved by applying the fuzzy interval.

2- In this study, a larger range of expert opinions could be applied for decision-making using the fuzzy method.

3. There is more confidence in comparing the ranking due to their fuzzy range in this study.

Limitations:

1- If all of the decision-making methods have the same ranking for a particular problem, the proposed method cannot be used because the fuzzy numbers are equal in all cases. *(a_{3i} = a_{2i} = a_{1i})*

2. If a decision-making method has a very large ranking difference compared to other methods, then the fuzzy range of that alternative is affected by its fuzzy range. Thus, comparing that alternative with the others may not be accurate enough.

5. Case study

To evaluate the risks by the proposed method, several examples from the literature are used.

Example 1

Liu et al. have considered the supply chain of a telecommunication equipment manufacturer for risk assessment. Due to increased competition, lack of resources, strict rules, and stakeholder requirements, this company has decided to invest resources in a sustainable supply chain. However, there are potential risks to the company owing to the uncertainty of the global economy, increased outsourcing activities, etc. In addition, there are disagreements among managers about the importance of risk factors (Liu, Song and Ming, 2017). Their proposed approach to assess the risk factors of the company has been compared to other methods, as shown in Table 1.

Table 1. Risk factor ranking for the telecommunication equipment manufacturer (Liu, Song and Ming, 2017)

Risk Factor / Decision making method	RF1	RF2	RF3	RF4	RF5	RF6	RF7	RF8	RF9	RF10	RF11	RF12	RF13	RF14	RF15	RF16	RF17	RF18	RF19	RF20
AHP	11	2	10	12	1	17	18	4	5	19	13	9	6	14	7	15	8	3	20	16
DEMATEL	4	1	12	3	6	11	15	7	2	18	8	5	10	9	14	16	13	17	20	19
Fuzzy DEMATEL	7	1	12	5	6	11	16	4	2	19	8	3	10	9	14	15	13	17	18	20
Liu et al.	7	1	10	3	5	14	17	6	2	20	9	4	11	8	13	16	12	15	18	19

They believe that their assessment method provides more detailed information for risk decision making and more accurate results for risk ranking. Liu et al.' method is evaluated by the proposed method and the results are illustrated in Table 2.

Table 2. Assessment of the ranking methods of example 1 by the proposed method

														The fuzzy three-dimensional integration mean method																															
Risk Factor	**Rank**				significance level of the test						risk rank fuzzy numbers			**1- Crisp Size**	**2-Fuzzy BORDA**																						**3- Fuzzy COPLAND**		**Triple average (1, 2 and 3)**		Correlation coefficient between the fuzzy three-dimensional integration mean method and decision-making				**Final Ranking**
	AHP (1)	DEMATEL (2)	Fuzzy DEMATEL (3)	Liu et al. Method (4)	**(1) – (2)**	**(1) – (3)**	**(1) – (4)**	**(2) – (3)**	**(2) – (4)**	**(3) – (4)**	**a1**	**a2**	**a3**	**Rank**	RF1	RF2	RF3	RF4	RF5	RF6	RF7	RF8	RF9	RF10	RF11	RF12	RF13	RF14	RF15	RF16	RF17	RF18	RF19	RF20	∑C	**Rank**	∑C - ∑R	**Rank**	Average	Rank	**With (1)**	**With (2)**	**With (3)**	**With (4)**	
RF1	11	4	7	7							**-1.37**	**7.25**	**15.87**	**6**	-	X	M	X	X	M	M	X	X	M	M	X	M	M	M	M	M	M	M	M	**13**	**7**	7	**7**	6.67	**7**					
RF2	2	1	1	1							**-0.25**	**1.25**	**2.75**	**1**	M	-	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	**19**	**1**	19	**1**	1.00	**1**					
RF3	10	12	12	10							**7.54**	**11.00**	**14.46**	**10**	X	X	-	X	X	M	M	X	X	M	X	X	X	X	M	M	M	M	M	M	**9**	**11**	-1	**11**	10.67	**11**					
RF4	12	3	5	3							**-7.07**	**5.75**	**18.57**	**5**	M	X	M	-	X	M	M	X	X	M	M	X	M	M	M	M	M	M	M	M	**14**	**6**	9	**6**	5.67	**6**					
RF5	1	6	6	5							**-2.64**	**4.50**	**11.64**	**3**	M	X	M	M	-	M	M	M	X	M	M	M	M	M	M	M	M	M	M	M	**17**	**3**	15	**3**	3.00	**3**					
RF6	17	11	11	14							**4.63**	**13.25**	**21.87**	**14**	X	X	X	X	X	-	M	X	X	M	X	X	X	X	X	M	X	X	M	M	**5**	**15**	-9	**15**	14.67	**15**					
RF7	18	15	16	17							**12.63**	**16.50**	**20.37**	**16**	X	X	X	X	X	X	-	X	X	M	X	X	X	X	X	X	X	X	M	M	**3**	**17**	-13	**17**	16.67	**17**					
RF8	4	7	4	6							**0.75**	**5.25**	**9.75**	**4**	M	X	M	M	X	M	M	-	X	M	M	M	M	M	M	M	M	M	M	M	**16**	**4**	13	**4**	4.00	**4**					
RF9	5	2	2	2	0.010	0.005	0.001	0.000	0.000	0.000	**-1.75**	**2.75**	**7.25**	**2**	M	X	M	M	M	M	M	M	-	M	M	M	M	M	M	M	M	M	M	M	**18**	**2**	17	**2**	2.00	**2**	**0.7730**	**0.9430**	**0.9560**	**0.9700**	**On base of Liu et al. method**
RF10	19	18	19	20							**16.55**	**19.00**	**21.45**	**18**	X	X	X	X	X	X	X	X	X	-	X	X	X	X	X	X	X	X	M	X	**1**	**19**	-17	**19**	18.67	**19**					
RF11	13	8	8	9							**2.36**	**9.50**	**16.64**	**8**	X	X	M	X	X	M	M	X	X	M	-	X	X	M	M	M	M	M	M	M	**11**	**9**	3	**9**	8.67	**9**					
RF12	9	5	3	4							**-2.64**	**5.25**	**13.14**	**4**	M	X	M	M	X	M	M	X	X	M	M	-	M	M	M	M	M	M	M	M	**15**	**5**	11	**5**	4.67	**5**					
RF13	6	10	10	11							**2.60**	**9.25**	**15.90**	**7**	X	X	M	X	X	M	M	X	X	M	M	X	-	M	M	M	M	M	M	M	**12**	**8**	5	**8**	7.67	**8**					
RF14	14	9	9	8							**1.88**	**10.00**	**18.12**	**9**	X	X	M	X	X	M	M	X	X	M	X	X	X	-	M	M	M	M	M	M	**10**	**10**	1	**10**	9.67	**10**					
RF15	7	14	14	13							**1.90**	**12.00**	**22.10**	**12**	X	X	X	X	X	M	M	X	X	M	X	X	X	X	-	M	X	M	M	M	**7**	**13**	-5	**13**	12.67	**13**					
RF16	15	16	15	16							**13.77**	**15.50**	**17.23**	**15**	X	X	X	X	X	X	M	X	X	M	X	X	X	X	X	-	X	X	M	M	**4**	**16**	-11	**16**	15.67	**16**					
RF17	8	13	13	12							**4.36**	**11.50**	**18.64**	**11**	X	X	X	X	X	M	M	X	X	M	X	X	X	X	M	M	-	M	M	M	**8**	**12**	-3	**12**	11.67	**12**					

RF18	3	17	17	15							**-7.20**	**13.00**	**33.20**	**13**	X	X	X	X	X	M	M	X	X	M	X	X	X	X	X	M	X	-	M	M	**6**	**14**	-7	**14**	13.667	**14**					
RF19	20	20	18	18							**15.54**	**19.00**	**22.46**	**18**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	X	**0**	**20**	-19	**20**	19.333	**20**					
RF20	16	19	20	19							**13.30**	**18.50**	**23.70**	**17**	X	X	X	X	X	X	X	X	X	M	X	X	X	X	X	X	X	X	M	-	**2**	**18**	-15	**18**	17.667	**18**					
															6	**0**	**10**	**5**	**2**	**14**	**16**	**3**	**1**	**18**	**8**	**4**	**7**	**9**	**12**	**15**	**11**	**13**	**19**	**17**	∑R										

According to the results of Table 2, Liu et al. method is considered better than other mentioned methods in risk ranking.

Example 2

Assessing the credit risks of supplier companies due to their communication is very complicated. XU et al. classified the risks of suppliers into spontaneous and contagious credit risks and assessed them. To this end, they considered a Chinese drinking company in the fourth place of revenue among the manufacturers of this product in China. This company has many suppliers. The credit risks for the supply chain of this company have been investigated based on their proposed research method and ranking of the suppliers has been carried out based on the risk assessment. Their ranking is compared with that of the Fang and Marle (2013) method and the results are shown in Table 3 (Xu et al., 2017).

Table 3. Ranking of Suppliers (XU et al., 2017)

Supplier / **Decision making method**	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**E9**
Fang and Marle Method	1	5	9	6	7	3	4	2	8
XU et al. Method	1	4	8	5	7	3	6	2	9

They concluded that the ranking of suppliers with regard to risk assessment is more targeted in their proposed scientific approach. XU et al. approach is assessed by the proposed method in this paper, as shown in Table 4. The results indicate that, contrary to their claims, Fang and Marle method has the same precision to their proposed method in the ranking of suppliers.

Table 4. Assessment of the decision-making methods of example 2 by the proposed method of this paper

							The fuzzy three-dimensional integration mean method																		
Supplier	**Rank**		significance level of the test	risk rank fuzzy numbers			**1- Crisp Size**	**2-Fuzzy BORDA**											**3- Fuzzy COPLAND**		**Triple average (1, 2 and 3)**		Correlation coefficient between the fuzzy three-dimensional integration mean method and decision-making methods		**Final Ranking**
	Fang and Marle Method (1)	**XU et al. Method (2)**	**(1) – (2)**	**a1**	**a2**	**a3**	**Rank**	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**E9**	**∑C**	**Rank**	**∑C - ∑R**	**Rank**	**Average**	**Rank**	**With (1)**	**With (2)**	
E1	1	1	0.000	**1.00**	**1.00**	**1.00**	**1**	-	M	M	M	M	M	M	M	M	**8**	**1**	8	**1**	1.00	**1**	**0.979**	**0.979**	**On base of Fang and Marle method or XU et al. Method**
E2	5	4		**2.38**	**4.50**	**6.62**	**4**	X	-	M	M	M	X	M	X	M	**5**	**4**	2	**4**	4.00	**4**			
E3	9	8		**6.38**	**8.50**	**10.62**	**8**	X	X	-	X	X	X	X	X	X	**0**	**8**	-7	**8**	8.00	**8**			
E4	6	5		**3.38**	**5.50**	**7.62**	**6**	X	X	M	-	M	X	X	X	M	**3**	**6**	-2	**6**	6.00	**6**			
E5	7	7		**7.00**	**7.00**	**7.00**	**7**	X	X	M	X	-	X	X	X	M	**2**	**7**	-4	**7**	7.00	**7**			
E6	3	3		**3.00**	**3.00**	**3.00**	**3**	X	M	M	M	M	-	M	X	M	**6**	**3**	4	**3**	3.00	**3**			
E7	4	6		**0.76**	**5.00**	**9.24**	**5**	X	X	M	M	M	X	-	X	M	**4**	**5**	0	**5**	5.00	**5**			
E8	2	2		**2.00**	**2.00**	**2.00**	**2**	X	M	M	M	M	M	M	-	M	**7**	**2**	6	**2**	2.00	**2**			
E9	8	9		**6.38**	**8.50**	**10.62**	**8**	X	X	X	X	X	X	X	X	-	**0**	**8**	-7	**8**	8.00	**8**			
								0	**3**	**7**	**5**	**6**	**2**	**4**	**1**	**7**	∑R								

Example 3

Liou and Lo claimed that the goal of risk assessment is to identify and eliminate the potential failures to quality improvement (Liou and Lo, 2018). They suggested a combination of the FMEA and MCDM techniques to improve the deficiencies of the FMEA method. In their case study, they considered a smartphone manufacturer. In the production of these phones, a high interaction is required between hardware and radio frequency. This process involves possible failures due to hardware design based on frequency design. Accordingly, they made a comparison between their proposed method and other decision making methods, as presented in Table 5.

Table 5. Ranking of the alternatives (Liou and Lo, 2018)

Decision making method \ Failure Mode	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15
Traditional FMEA	9	1	12	9	8	13	14	15	5	2	2	5	4	9	7
GRA+FMEA	5	1	13	13	13	4	12	3	8	6	6	10	2	9	11
Liou and Lo method	6	1	11	9	15	7	12	14	3	2	4	13	5	8	10

They conducted the sensitivity analysis and claimed that their suggested method is more practical and effective than the two other methods. Their suggested method is evaluated here by our proposed method, whose results are presented in Table 6. Based on the method of this research, Liou and Lo method is superior to two other mentioned methods in risk assessment.

Table 6. Assessment of decision making methods in example 3 by the proposed method of this paper

Failure Modes	Rank			significance level of the test			risk rank fuzzy numbers			The fuzzy three-dimensional integration mean method: 1- Crisp Size	2-Fuzzy BORDA																	3- Fuzzy COPLAND		Triple average (1, 2 and 3)		Correlation coefficient between the fuzzy three-dimensional integration mean method and decision-making methods			Final Ranking
	Traditional FMEA (1)	GRA+FMEA (2)	Liou and Lo Method (3)	(1) – (2)	(1) – (3)	(2) – (3)	a1	a2	a3	Rank	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	∑C	Rank	∑C - ∑R	Rank	Average	Rank	With (1)	With (2)	With (3)	
M1	9	5	6	0.281	0.007	0.025	**0.42**	**6.67**	**12.91**	**6**	-	X	M	M	M	M	M	M	X	X	X	M	X	M	M	**9**	**6**	4	**6**	6.00	**6**	**0.763**	**0.728**	**0.929**	**On base of Liou and Lo method**
M2	1	1	1				**1.00**	**1.00**	**1.00**	**1**	M	-	M	M	M	M	M	M	M	M	M	M	M	M	M	**14**	**1**	14	**1**	1.00	**1**				
M3	12	13	11				**9.00**	**12.00**	**15.00**	**12**	X	X	-	X	M	X	M	X	X	X	X	X	X	X	X	**2**	**13**	-10	**13**	12.67	**13**				
M4	9	13	9				**3.41**	**10.33**	**17.26**	**10**	X	X	M	-	M	X	M	M	X	X	X	X	X	X	X	**4**	**11**	-6	**11**	10.67	**11**				
M5	8	13	15				**1.18**	**12.00**	**22.82**	**12**	X	X	X	X	-	X	M	X	X	X	X	X	X	X	X	**1**	**14**	-12	**14**	13.33	**14**				
M6	13	4	7				**-5.75**	**8.00**	**21.75**	**7**	X	X	M	M	M	-	M	M	X	X	X	M	X	M	M	**8**	**7**	2	**7**	7.00	**7**				
M7	14	12	12				**9.20**	**12.67**	**16.13**	**13**	X	X	X	X	X	X	-	X	X	X	X	X	X	X	X	**0**	**15**	-14	**15**	14.33	**15**				
M8	15	3	14				**-9.31**	**10.67**	**30.64**	**11**	X	X	M	X	M	X	M	-	X	X	X	X	X	X	X	**3**	**12**	-8	**12**	11.67	**12**				
M9	5	8	3				**-2.22**	**5.33**	**12.88**	**5**	M	X	M	M	M	M	M	M	-	X	X	M	X	M	M	**10**	**5**	6	**5**	5.00	**5**				
M10	2	6	2				**-3.59**	**3.33**	**10.26**	**2**	M	X	M	M	M	M	M	M	M	-	M	M	M	M	M	**13**	**2**	12	**2**	2.00	**2**				
M11	2	6	4				**-2.00**	**4.00**	**10.00**	**4**	M	X	M	M	M	M	M	M	M	X	-	M	X	M	M	**11**	**4**	8	**4**	4.00	**4**				
M12	5	10	13				**-2.79**	**9.33**	**21.46**	**9**	X	X	M	M	M	X	M	M	X	X	X	-	X	X	X	**5**	**10**	-4	**10**	9.67	**10**				
M13	4	2	5				**-0.92**	**3.67**	**8.25**	**3**	M	X	M	M	M	M	M	M	M	X	M	M	-	M	M	**12**	**3**	10	**3**	3.00	**3**				
M14	9	9	8				**6.93**	**8.67**	**10.40**	**8**	X	X	M	M	M	X	M	M	X	X	X	M	X	-	M	**7**	**8**	0	**8**	8.00	**8**				
M15	7	11	10				**3.09**	**9.33**	**15.58**	**9**	X	X	M	M	M	X	M	M	X	X	X	M	X	X	-	**6**	**9**	-2	**9**	9.00	**9**				
											5	**0**	**12**	**10**	**13**	**6**	**14**	**11**	**4**	**1**	**3**	**9**	**2**	**7**	**8**	∑R									

Example 4

Senthi et al. investigated the ranking of reverse logistics risks. Due to the lack of information on reverse logistics, many companies do not or cannot enter the reverse logistics market since they cannot ignore the involved risks. They have offered a method for assessing reverse logistics risks so that senior executives can have a proper ranking of them. Hence, they can make decisions with high reliability for minimizing risks (Senthil, Murugananthan and Ramesh, 2018). Their recommended method involves combining some MCDM methods together. They considered a plastic recycling company in India as their case study. The assessment of reverse logistics risks for the company is shown in Table 7.

Table 7. Reverse Logistics Risk Ranking (Senthil, Murugananthan and Ramesh, 2018)

Risk / **Decision making method**	A1	A2	A3	A4	A5	A6	A7	A8	A9
AHP + Fuzzy TOPSIS	2	1	7	9	6	8	4	5	3
AHP + PROMETHEE	2	1	7	9	6	8	4	5	3
AHP + Digraph and Matrix	2	1	9	8	6	7	4	5	3

In their research, they identified that each three combinations of the methods are suitable for risk assessment in reverse logistics. They made no comment on the suitable one because the third method provides different rankings for some risks. Their recommended method is evaluated by the proposed method of this paper as illustrated in Table 8. Based on the results, all three combinations of the methods are the suitable method for assessing reverse logistics risks.

Table 8. Assessment of decision making methods in example 4 by the method of this paper

Risk	Rank			significance level of the test			risk rank fuzzy numbers			The fuzzy three-dimensional integration mean method: 1- Crisp Size	2-Fuzzy BORDA											3- Fuzzy COPLAND		Triple average (1, 2 and 3)		Correlation coefficient between the fuzzy three-dimensional integration mean method and decision-making			Final Ranking
	AHP+Fuzzy TOPSIS(1)	AHP + PROMETHEE(2)	AHP + Digraph and Matrix(3)	(1) -(2)	(1) - (3)	(2) - (3)	a1	a2	a3	Rank	A1	A2	A3	A4	A5	A6	A7	A8	A9	∑C	Rank	∑C - ∑R	Rank	Average	Rank	With (1)	With (2)	with (3)	
A1	2	2	2	0.000	0.000	0.000	2.00	2.00	2.00	2	-	X	M	M	M	M	M	M	M	7	2	6	2	2.00	2	0.983	0.983	0.983	On base of three methods
A2	1	1	1				1.00	1.00	1.00	1	M	-	M	M	M	M	M	M	M	8	1	8	1	1.00	1				
A3	7	7	9				4.20	7.67	11.13	7	X	X	-	M	X	X	X	X	X	1	8	-6	8	7.67	8				
A4	9	9	8				6.93	8.67	10.40	8	X	X	X	-	X	X	X	X	X	0	9	-8	9	8.67	9				
A5	6	6	6				6.00	6.00	6.00	6	X	X	M	M	-	M	X	X	X	3	6	-2	6	6.00	6				
A6	8	8	7				5.93	7.67	9.40	7	X	X	M	M	X	-	X	X	X	2	7	-4	7	7.00	7				
A7	4	4	4				4.00	4.00	4.00	4	X	X	M	M	M	M	-	M	X	5	4	2	4	4.00	4				
A8	5	5	5				5.00	5.00	5.00	5	X	X	M	M	M	M	X	-	X	4	5	0	5	5.00	5				
A9	3	3	3				3.00	3.00	3.00	3	X	X	M	M	M	M	M	M	-	6	3	4	3	3.00	3				
											1	0	7	8	5	6	3	4	2	∑R									

Table 9 summarizes all examples extracted from the literature.

Table 9. The given examples extracted from the literature

Reference	Compared MCDM's methods	Appropriate approach from the author's / authors' perspective	Appropriate approach from the proposed perspective
Liu et al., (2017)	- AHP - DEMATEL - Fuzzy DEMATEL - Proposed with Authors	- Proposed with Authors	- Proposed with Authors
XU et al., (2017)	- Fang and Marle Method, (2013) - Proposed with Authors	- Proposed with Authors	- All methods have a same precision in ranking of suppliers
Liou, and Lo, (2018)	-Traditional FMEA -GRA+FMEA - Proposed with Authors	- Proposed with Authors	- Proposed with Authors
Senthil, et al., (2018)	- AHP + Fuzzy TOPSIS - AHP + PROMETHEE - AHP + Digraph and Matrix	The authors did not comment on these methods	- All three combination methods, alike, are the suitable method
Büyüközkan and Göcer, (2017)	- TOPSIS - AHP and TOPSIS - AHP and VIKOR - Proposed with Authors	- Proposed with Authors	- Proposed with Authors
Zarbakhshnia et al., (2018)	- COPRAS - COPRAS-G - Proposed with Authors	- Proposed with Authors	The proposed method is not comparable to other methods, because the significant numbers of the test are in the zero assumption acceptance area, and other claims are rejected.
Mufazzal and Muzakkir, (2018) Case study (VI)	- ELECTRE III - Proposed with Authors	- Proposed with Authors	- Proposed with Authors
Moradian et al., (2018)	-MOORA - TOPSIS -VIKOR	-MOORA and TOPSIS	-MOORA

6. Validation of the proposed method

In order to verify the validity of the obtained information, the proposed method of this study and those of case studies in this research (25 related subject from the literature have been examined by the proposed method) were given to 65 people from different industries. The experts were asked to comment on the proposed method of the study as: 1 = fully agree, 2 = agree, 3 = fairly agree, 4 = no comment, 5 = fairly opposed, 6 = opposed, 7 = totally opposed. Out of these experts, 51 ones expressed their opinion. The comments were coded and run into SPSS software. Table 10 presents the obtained results.

Table 10. The experts' comments on the proposed method

Experts' Comment	Frequency	Percent	Cumulative Percent	Median	Mode	Mean	95% Confidence Interval for Mean	
							Lower Bound	Upper Bound
Fully agree	13	25.5	25.5	2= agree	2= agree	2.33	1.97	2.70
Agree	23	45.1	70.6					
Fairly agree	6	11.8	82.4					
No comment	5	9.8	92.2					
Fairly opposed	2	3.9	96.1					
opposed	2	3.9	100					
Totally opposed	0	0	100					
Total	51	100	100					

Table 10 shows that 82.4% of the experts' opinions were in line with the results obtained from the proposed method of this paper, and only 7.8% of the opinions were in the opposite direction. Therefore, with a confidence level of 95%, the average opinions of the experts are consistent with the proposed method.

7. Conclusion

Most decision-making methods of risk assessment and ranking utilize lingual preferences and qualitative expressions for comparing the alternatives. This is the cause of different supply chain risk rankings via different decision-making methods. Therefore, it is necessary to specify different ranks of a risk in a numerical range for which the theory of fuzzy system is well qualified. After the specification of risk fuzzy numbers, risk ranking should be carried out in a fuzzy environment. In this paper, we proposed a method to rank the risks according to their fuzzy numbers and compare the results with the ranking results from other decision-making methods. Accordingly, we provided a suitable way to rank supply chain risks. In order to validate the proposed method, we chose and solved few examples from the literature, and gave their results have to a group of experts. The statistical analysis of their feedback indicates the validity of the proposed approach. The proposed method needs as its input a ranking of risks in the first step. This ranking is normally done by different decision-making methods, which could be a limitation for the proposed method. It can be suggested for future research to separately determine the fuzzy ranks given to each risk by each decision-making method and examine them with the method proposed in this paper.

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