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A Fuzzy Linguistic Multi-Criteria Decision-Making Approach to Assess Emergency Suppliers

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Abstract: Under the influence of COVID-19, various emergency supplies have repeatedly broken links, seriously affecting normal life and hindering the sustainable development of enterprises and society. Therefore, suitable emergency suppliers are crucial. To prioritize and select suitable emergency suppliers, key indicators were determined, and evaluation models were established based on the characteristics of epidemic situations and epidemic prevention materials. The application of the MCDM (multi-criteria decision-making) issue combining fuzzy SWARA (the stepwise weight assessment ratio analysis) and the actor analysis method to emergency supplier selection studies, called the fuzzy SWARA-based actor analysis method, is used to identify appropriate suppliers for optimizing pre-preparation. Results of evaluation system weight computations by the Fuzzy SWARA-based actor analysis method show that the overall prioritization of four non-economic factors in ranking orders are "Delivery Capacity", "Flexible Supply Capacity", "Quality", and "Social Evaluation and Reputation". For the inclusion of conflicting standards and the unquantifiable feature, economic and non-economic factors were discussed separately and evaluated by language variables. Additionally, the fuzzy actor analysis indicated that economic factors and non-economic factors need to be considered comprehensively for emergency supplier selection. This method has good operability and reference value, convenient for the final choice making according to actual situation.

Keywords: emergency supplies; multi-criteria decision making; fuzzy set; actor analysis method; linguistic variables

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1. Introduction

In recent years, the frequent occurrence of various natural disasters and emergencies has caused varying degrees of casualties and property loss. Especially in the past two years under COVID-19 outbreak, the supply chain phenomenon seriously affected the normal life of the masses, hindered the development speed of enterprises and society, and deepened scholars' thinking of the emergency supply chain of logistics management research.

Emergency management operations generally consist of four parts: prevention, preparation, response, and recovery. The process of emergency supply chain system is shown in Figure 1. The main work in the prevention stage is the establishment of relevant emergency mechanisms, laws, and regulations by the main government departments in society, to reduce hidden dangers and strengthen the ability to deal with emergency events. The preparation stage is to advance deployment and arrangement to resist possible emergencies and ensure the effectiveness of rescue after the occurrence of the event to the greatest extent, such as the advance purchase of epidemic prevention materials, the location of emergency supplies reserve centers, the deployment of emergency facilities, and other issues. The response stage is the key element of emergency management. Various rescue methods are needed to reduce the losses and casualties caused by emergencies and reduce the negative impact on society as a whole after the incident, such as the distribution of emergency relief supplies, transportation, and scheduling of emergency relief supplies. The recovery stage involves the reconstruction of disaster areas and the recovery of people's lives after the response stage. Strictly, the prevention stage does not belong to the category of logistics management. In the field of emergency logistics management, the first step should be the preservation of emergency materials, that is, the preparation stage. In the preparation stage, to ensure the best rescue effect after an emergency, reliable suppliers should be selected from numerous emergency suppliers and a good supply system should be established. In disaster relief practices, a good cooperative relationship between relief agencies and suppliers can simplify the procurement process and improve the availability and rapid delivery of supplies. In addition, establishing a close relationship with suppliers can achieve discounts in bulk pricing. Regardless of the scale and importance of procurement in emergency logistics, only a few studies focus on the issue of emergency supply procurement decisions [1].

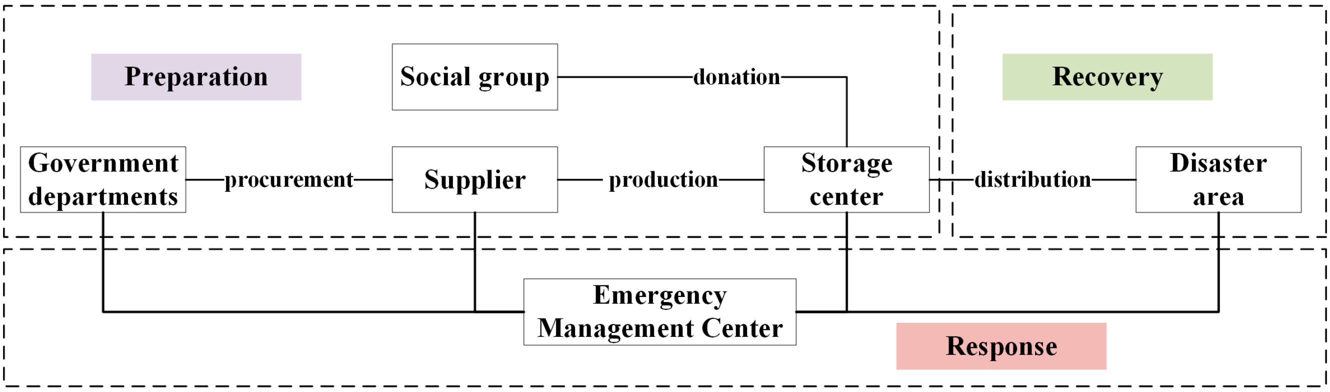

Figure 1. Emergency supply chain system flow chart.

Suppliers are the critical link to any supply chain as an important strategic decision, and supplier selection helps achieve a solid relationship between supply and demand [2,3]. Consequently, the selection of emergency suppliers is an important part of the emergency supply chain management, which is a typical problem. There is a large body of literature on supplier selection decision-making in the commercial supply chain, such as supplier selection criteria [4]. However, not much attention has been paid to these factors in emergency logistics management, because disaster management is more closely related to the relationship between economic and non-economic factors. Previous standards in the commercial supply chain can provide guidance for this study, and the emergency supply chain also uses some of the same indicators, including price, quality, delivery capacity, etc. The contributions of this paper are as follows:

Firstly, the evaluation index system of emergency suppliers for large emergencies was established, and 20 evaluation indicators for emergency suppliers were listed in a relatively comprehensive way, which has targeted and comprehensive coverage, and further improves the evaluation index system of emergency suppliers.

Secondly, different from other fuzzy multi-criteria decision-making methods, this paper focused on the decision preferences of economic factors and non-economic factors and adopted the decision weights of experts to evaluate and select emergency suppliers by the fuzzy SWARA-based actor analysis method. Through the corresponding relationship between triangular fuzzy and decision language variables, the scores of qualitative indicators of different experts were converted into objective values, and the weights of non-economic factors were obtained.

Finally, sensitivity analysis was used to verify the influence of economic and non-economic factors on the preference decision of emergency supplier selection, and the priority ranking under different decision preferences was obtained.

In this study, the scientific selection of emergency suppliers is emphasized. The evaluation indicators and evaluation method are two key research points in the evaluation and selection of emergency suppliers. Based on the characteristics of an emergency, by initiating the application of the MCDM issue combining fuzzy stepwise weight assessment ratio analysis (SWARA) and the actor analysis method to emergency supplier selection studies, this study bears significance for it illustratively identifies the evaluation system that is critical to prioritization and selection of alternative suppliers. In the process of supplier selection and evaluation, qualitative indicators need to be quantified because many qualitative indicators are involved. Therefore, linguistic variables are introduced in this method, and the corresponding relationship between linguistic variables and fuzzy sets is established to transform the evaluation of qualitative indicators by experts. Linguistic variables were used to determine standard ratings expressed as fuzzy numbers. The evaluation indicator weights of emergency suppliers were determined using the SWARA method. The ranking of each alternative supplier was determined by the actor analysis method on fuzzy sets, which considers non-economic factors.

The remainder of this paper is organized as follows. Section 2 presents the literature review and outlines the innovative points and contributions of this study. Section 3 puts forward the key evaluation indicators for emergency suppliers. Section 4 describes the methods and processes. Section 5 applies the method to numerical examples of emergency supplier prioritization. Section 6 presents the sensitivity analysis. Section 7 discusses managerial implications. Finally, Section 8 concludes the study and offers future research directions.

2. Literature Review

We focus our attention on the literature on supplier evaluation decision-making methods and evaluation indicators for the criteria.

In the field of emergency logistics management, the first step should be to reserve emergency materials. To ensure the best rescue effect after an emergency, reliable suppliers must be selected. In general, a reliable supplier should follow the principles of right price, right time, right place, right quality, and right quantity. At present, research on the evaluation or selection of commercial suppliers has produced rich results. Several evaluation indicators were proposed, including quantity discounts, transportation costs, carbon taxes, price discounts, delivery times, service levels, supplier capabilities, and delivery times [5–9]. Wang and Su [10] proposed a generic DSS framework based on activity-based costing to evaluate and select suppliers. According to the characteristics of logistics service outsourcing enterprises, Peng [11] established a logistics service outsourcing supplier evaluation and selection index system as measured by cost, operational efficiency, basic quality, and technical level, aiming for the evaluation and selection of logistics outsourcing service suppliers based on the hierarchical analysis method. However, for different industries, the selection basis of suppliers is different; in particular, the selection of emergency material suppliers is more special, and must be considered in terms of the material quality guarantee and timely supply capacity as the main factor. Hu and Dong [12] considered humanitarian assistance extremely important in supplier selection and incorporated it into the selection strategy. The supplier selection criteria include price discounts offered by suppliers based on order quantity, required delivery time, and physical inventory. Ruan et al. [13] built a balanced "helicopter and vehicle" intermodal network by selecting emergency distribution centers (EDCs) and allocating medical assistance points, considering helicopter travel time, transfer time, and vehicle delivery time.

Both quantifiable economic and qualitative non-economic factors are involved in supplier selection decisions; the conflict between the indicators is the existence, which is a typical multi-criteria decision-making problem. The multi-criteria decision-making (MCDM) approach, based on the evaluation of multiple conflict guidelines, provides an effective framework for supplier comparison. Evaluation methods, such as AHP, ANP, TOPSIS, DEA, TCO, and GRA, are widely used in the supplier selection problem [14]. TOPSIS is fully called Technique for Order Preference by Similarity to an Ideal Solution. The basic principle is to rank the distance between the evaluation object and the optimal solution and the worst solution [15–17]. In Boran's [18] study, the TOPSIS method combined with an intuitive fuzzy set is proposed, and it was used in a group decision-making environment to select appropriate suppliers. Based on a set of standards applicable to the Industry 4.0 environment, Kaur and Singh [19] used the fuzzy analytic hierarchy process and the ideal scheme similarity ranking technique (FAHP-TOPSIS) method to evaluate suppliers. Çalık [20] developed a new group decision-making approach based on Industry 4.0 components for selecting the best green supplier by integrating AHP and TOPSIS methods under the Pythagorean fuzzy environment. Chen [21] proposed a novel decision-making model of TOPSIS integrated entropy-AHP weights to select the appropriate supplier. Zhang et al. [22] solved the uncertain attribute values and weights in MCDM problems by combining the ER approach and stochastic multi-criteria acceptability analysis-2 (SMAA-2). Bai et al. [23] used the gray-BWM-TODIM method to evaluate and select socially sustainable suppliers. Social sustainability attribute weights were determined using the gray-BWM approach, and then the gray-TODIM method was used to rank suppliers. Nekooie et al. [24] proposed a fuzzy objective planning method with soft priority between the objectives. Wang and Cai [25] built a distance-based VIKOR multi-criteria group decision-making (MCGDM) model for processing heterogeneous information to appropriately and flexibly solve the problem of emergency supplier selection with a compromise solution, which is more acceptable and suitable in practice. Badi [26] used a hybrid grey theory-MARCOS method for decision-making regarding the selection of suppliers in the Libyan Iron and Steel Company (LISCO) to help it compete. Tavana [27] proposed an integrated approach for supplier selection by combining the fuzzy AHP method with the fuzzy multiplicative multi-objective optimization based on ratio analysis. Giannakis [28] developed a sustainability performance measurement framework for supplier evaluation and selection by the Analytic Network Process (ANP) method. Chou and Chang [29] used linguistic values to evaluate the ratings and weights of selection factors and proposed a strategy alignment fuzzy simple multiple attribute rating (SMART) technique to solve the supplier selection problem. Weng [30] presented the analytic hierarchy process (AHP) and grey relational analysis (GRA) as potential multi-criteria decision-making (MCDM) methods for spare parts planning (SPP) software selection. Bakeshlou et al. [31] established a multi-objective fuzzy linear planning model with 17 criteria and divided it into five clusters, solved by a mixed fuzzy multi-objective decision model (MODM). Fallahpour et al. [32] improved the existing DEA-AI model, introduced a new artificial intelligence method for supplier selection, and integrated the Kourosh and Arash methods into a robust DEA model obtained by genetic programming (GP).

This is a sophisticated problem because supplier selection is often a multi-standard group decision-making problem involving conflicting standards. Fuzzy set theory has been widely used in management decision making. The fuzzy set theory proposed by Zadeh [33] provides an effective method for addressing fuzzy problems. The judgment of decision makers is represented by fuzzy numbers, thereby quantifying the evaluation level. Muneeb [34] proposed a decentralized bi-level VSP where demand and supply are normal random variables and objectives are fuzzy in nature. Many others have solved evaluation and selection problems using fuzzy set theory [35–38]. Based on this, aiming at the fuzzy concepts that often appear in decision-making problems, a new multi-criteria decision-making method is proposed to solve the supplier selection problem.

In summary, most previous studies have focused on the evaluation or selection of suppliers, and the fields of application are mostly in commercial supply areas, using classic evaluation methods. A comparison of supplier selection methods is shown in Table 1. Additionally, many scholars have made innovations from the perspective of fuzzy theory, and a variety of fuzzy multi-criteria decision-making methods have been formed. Meanwhile, the emergency supplier selection decision issues as a multi-standard group decision-making problem involving conflicting standards and unquantifiable features. There are many non-economic factors to be considered, economic and non-economic factors should be discussed separately. In order to fully demonstrate the importance of non-economic factors and their mutual comparison, the fuzzy SWARA-based actor analysis method is used to evaluate emergency suppliers. Meanwhile, the lack of research on emergency supply evaluation fields thus makes it necessary to conduct an emergency suppliers' criteria system and method, and fuzzy set theory is suitable for this issue. Therefore, the actor analysis method combined with the fuzzy SWARA method is proposed to solve the multiple-criteria decision-making (MCDM) problem, which evaluates unquantifiable indicators using language variables.

Table 1. Comparison of supplier selection methods.

Method	Features	References
TOPSIS method	Simple calculation, full use of original data, and less information loss, but strong subjectivity.	[15–19]
Analytic hierarchy process (AHP)	Comprehensive consideration of qualitative and quantitative. However, when there are too many indicators, the data statistics are large. The weight of the indicators is difficult to determine.	[20,21,27]
Grey relation analysis (GRA)	The computation amount is small, low data requirements, less workload, but it must be a gray system, and the optimal value of some indicators is difficult to determine.	[23,26,30]
Analytic network process (ANP)	Reflects the dependence between the hierarchical structure but needs to study the relationship between the factors; the workload is relatively large.	[28]
Fuzzy comprehensive evaluation (FCE) method	According to the membership degree theory of fuzzy mathematics, the qualitative evaluation is transformed into a quantitative evaluation method. The result is clear and systematic, suitable for solving nondeterministic problems, but the calculation is complex and subjective.	[24,33,34]
DEA method	Not affected by the dimensional and subjective factors, the results obtained are the relative evaluation values.	[31,32]

3. Evaluation Indicators Analysis

Compared with ordinary materials, epidemic prevention materials are highly irreplaceable, with more uncertainties and high timeliness in the delivery process, that need more reliable channels [39–42]. If the quality of supplies is not guaranteed, insufficient quantity, or a low qualified rate, it may cause problems in the subsequent rescue response stage. As the supplier of emergency supplies, it should have a better supply capacity and a higher response capacity in both delivery time and quantity. In addition, a high response level in the supply chain ensures the effectiveness and supply of emergency supplies. The emergency suppliers' evaluation and selection criteria system established in this study is shown in Figure 2, which includes five main indicators: flexible supply capacity, delivery capacity, price, quality, social evaluation, and reputation. The following is an explanation of these indicators.

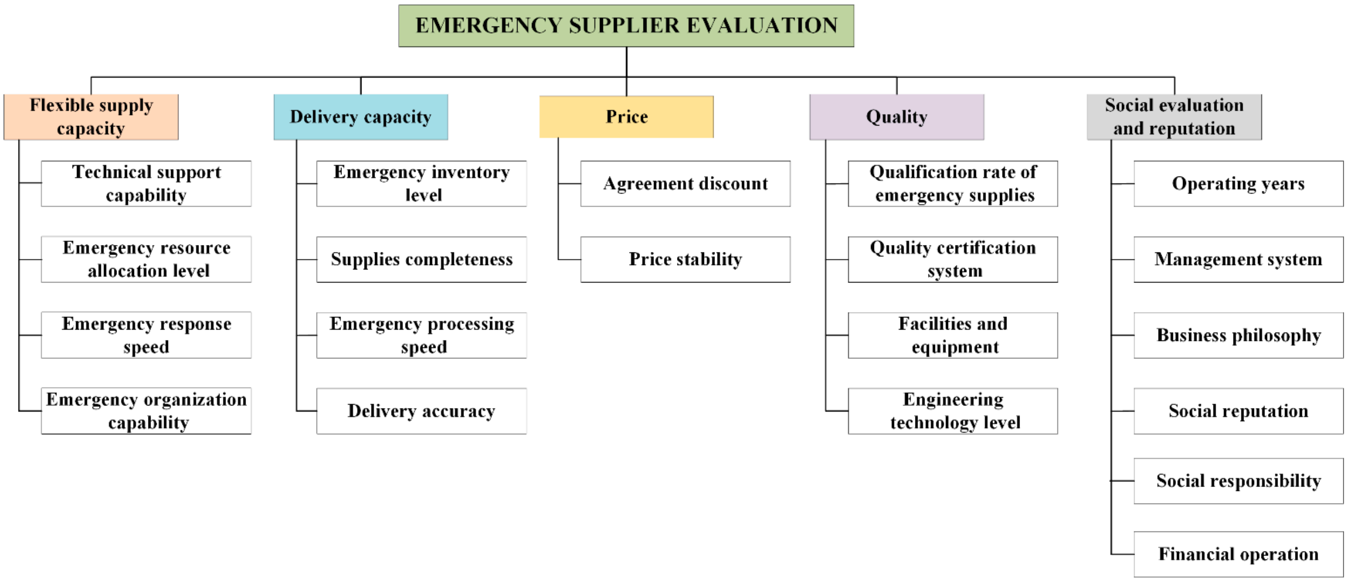

Figure 2. The emergency suppliers' evaluation and selection criteria.

1. Flexible supply capacity.

After the replenishment demand for emergency materials is issued, different enterprises have different emergency response speeds and resource allocation capabilities. In addition, when encountering material damage or other technical problems, the response capabilities of different companies also differ. Therefore, it is necessary to choose suppliers with more flexible supply capabilities.

2. Delivery capacity.

Priority is given to suppliers with strong delivery capacity due to differences in delivery quantity, timeliness, completion rate, and accuracy.

3. Price.

This indicator is used to measure the economic factors in the procurement cost of emergency material reserves. Even if the emergency work itself is weakly economical, the more efficient the rescue, the higher the economic cost, but the price and cost factors must be comprehensively considered. This includes price stability, bulk agreement preferential price, etc. Here, refers to the unit cost of the material allocated to the distribution center.

4. Quality.

The quality of emergency materials determines the quality of the rescue after emergencies. This includes the product qualification rate, quality certification system, engineering technology level, etc.

5. Social evaluation and reputation.

The evaluation and reputation of enterprises in society must be considered, including whether they have a good image in the hearts of the people and a high social reputation. The difference is that disaster relief has a strong public welfare nature. If the social evaluation degree of the suppliers is not high, it may cause unfair doubts in the public.

In general, the evaluation and selection indicators of the emergency materials suppliers should closely focus on the characteristics of the emergency rescue work, consider the connection between the indicators and the working process, and highlight the emergency ability of the supplier enterprises, so as to choose. At the same time, the above analysis shows that the indicators selected by emergency materials suppliers can be basically divided into two categories; one is economical indicators, where the smaller the evaluation value, the better. Price is an economic indicator. The other is the non-economical indicator; the greater the evaluation value, the better. Flexible supply capacity, delivery capacity, quality, social evaluation, and reputation are non-economical indicators.

4. Methodology

4.1. Fuzzy Set Theory

Definition 1. *R is a real number set, $F(R)$ represents all the fuzzy sets, and a fuzzy set $M \in F(R)$ on R is called a fuzzy number [43].*

① *$x_0 \in R$, such that $\mu_M(x_0) = 1$.*
② *For any $\alpha \in [0, 1]$, $A_\alpha = [x, \mu_{A_\alpha} \geq \alpha]$ is the closed interval.*

Definition 2. *In fuzzy mathematics, the membership function of fuzzy sets can be represented by a triangular distribution:*

$$\mu_M(x) = \begin{cases} \frac{x}{m-l} - \frac{l}{m-l} & x \in [l, m] \\ \frac{x}{m-u} - \frac{u}{m-u} & x \in [m, u] \\ 0 & others \end{cases} \tag{1}$$

where, $l \leq m \leq u$, l and u represent the lower limit and upper limit of M, respectively, and m is the most likely value.

The triangular fuzzy number can be defined by $(l < x < u)$, and represents the non-fuzzy number when l, m, and u are equal. $M = \{x \in R | l \leq m \leq u\}$.

Its image is shown in Figure 3.

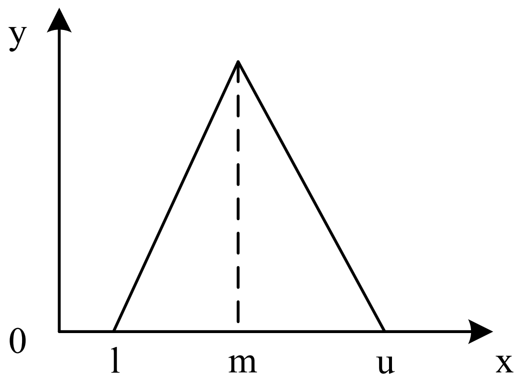

Figure 3. Triangular distribution function.

The fuzzy number of the triangular distribution is represented as $M = [l, m, u](l \leq m \leq u)$. If the size of the fuzzy number is compared, it needs to be de-fuzzy, and the average comprehensive representation method is selected to de-fuzzy. According to the Equation (2), the defuzzification value $P(M)$ is as follows.

$$P(M) = (l + m + u)/3 \tag{2}$$

Definition 3. *Set up triangular fuzzy numbers M_1 and M_2, $M_1 = (l_1, m_1, u_1)$, $M_2 = (l_2, m_2, u_2)$, $M_1 + M_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2)$, $M_1 - M_2 = (l_1 - l_2, m_1 - m_2, u_1 - u_2)$, $M_1 * M_2 = (l_1 l_2, m_1 m_2, u_1 u_2)$, $\gamma * M_1 = (\gamma l_1, \gamma m_1, \gamma u_1)$.*

4.2. Fuzzy SWARA Method

The stepwise weight assessment ratio analysis (SWARA) method is a new multi-criteria decision-making method proposed by Kersuliene et al. [44] to determine standard weights [45]. An important feature of SWARA is the ability to assess the accuracy of experts regarding the weighting criteria in the methodological process. Experts play a crucial role in the process of judging the criteria and weights. Each expert sets the priority of each criterion, and then considers the total results to rank all factors. In this method, the highest priority will be assigned to the most valuable indicator, and the lowest priority will be assigned to the lowest value evaluation indicator.

Considering that the knowledge, experience, and information of experts are different, their scores directly affect the accuracy of the final results in the evaluation process. In order to weaken the decisive role of subjective factors in the traditional SWARA method and reduce the influence of a single decision maker's preference, the fuzzy SWARA method is adopted in this paper. According to the level of knowledge and experience of experts, combined with the fuzzy set, different experts are given the weight and the indicators weight are obtained. Here, is a description of fuzzy SWARA.

Step 1. Relative importance of different indicators and the corresponding order of defuzzification values. Each decision expert expresses the relative importance of each indicator. The triangular fuzzy number for each indicator can be obtained according to the corresponding linguistic variable. The defuzzification value of each indicator is then obtained [46–49]. The defuzzification values of the different indicators are arranged in descending order [50,51].

Step 2. The correlation parameter s_j $(j \geq 2)$ between two adjacent indicators before and after is determined. The correlation parameter s_j $(j \geq 2)$ can be determined according to different rules. In this study, the difference between the defuzzification values of two adjacent indicators is used to calculate the correlation parameter.

Step 3. Calculate the comparison coefficient k_j according to Equation (3).

$$k_j = \begin{cases} 1, & j = 1 \\ s_j + 1, & j > 1 \end{cases} \quad (3)$$

Step 4. Calculate the relative weight q_j according to Equation (4).

$$q_j = \begin{cases} 1, & j = 1 \\ \frac{q_{j-1}}{k_j}, & j > 1 \end{cases} \quad (4)$$

Step 5. Calculate the final weight ω_j according to Equation (5).

$$\omega_j = \frac{q_j}{\sum_{k=1}^{n} q_k} \quad (5)$$

4.3. Actor Analysis Method

Actor analysis is a comprehensive factor evaluation method. The economic and non-economic factors are unified according to their relative importance, and the factors are comprehensively analyzed from different degrees [52]. In this study, the fuzzy SWARA method was combined with the actor analysis method to determine the priority of the alternatives.

Step 1: Calculation of the importance value of economic factors T_j.

$$T_j = \frac{\frac{1}{c_j}}{\sum_{j=1}^{n} \frac{1}{c_j}} \quad (6)$$

There are n alternatives, and c_j is the cost value reflected by the economic factors of the alternative, which is the economic cost. The higher the cost, the worse the economy; therefore, taking the reciprocal for comparison, the larger the result, the better is the economy.

Step 2: Calculation of the importance value of non-economic factors T_f.

(1) The pairs of alternatives are compared using a single factor. According to the importance evaluation value given by the experts, the proportion value of the better one is

1 point, and the worst one is 0. Therefore, the relative importance value T_{di} of every single non-economic factor for different alternatives is obtained. *Gi* is the specific gravity value of the alternatives for a single factor.

$$T_{di} = \frac{G_i}{\sum_{j=1}^{n} G_i} \tag{7}$$

(2) The relative importance value T_{di} of every single non-economic factor is multiplied by its weight value W_i and accumulated to obtain the importance factor T_f. The number of non-economic factors is m.

$$T_f = \sum_{i=1}^{m} W_i T_{di} \tag{8}$$

Step 3: Calculation of the importance values F_i.

The importance values of the alternatives are superimposed according to economic and non-economic factors to obtain the ranking of alternatives. M, N are the relative importance of economic factors (objective factors) and non-economic factors (subjective factors) respectively, $M + N = 1$.

$$F_i = MT_j + NT_f \tag{9}$$

5. Case Analysis

A schematic of the research methodology is shown in Figure 4. First, the weights of the experts were determined according to the triangular fuzzy set method. The SWARA method of triangular fuzzy sets was then used to determine the weights of the evaluation indicators. Finally, the actor analysis method was used to determine the priority of each alternative enterprise.

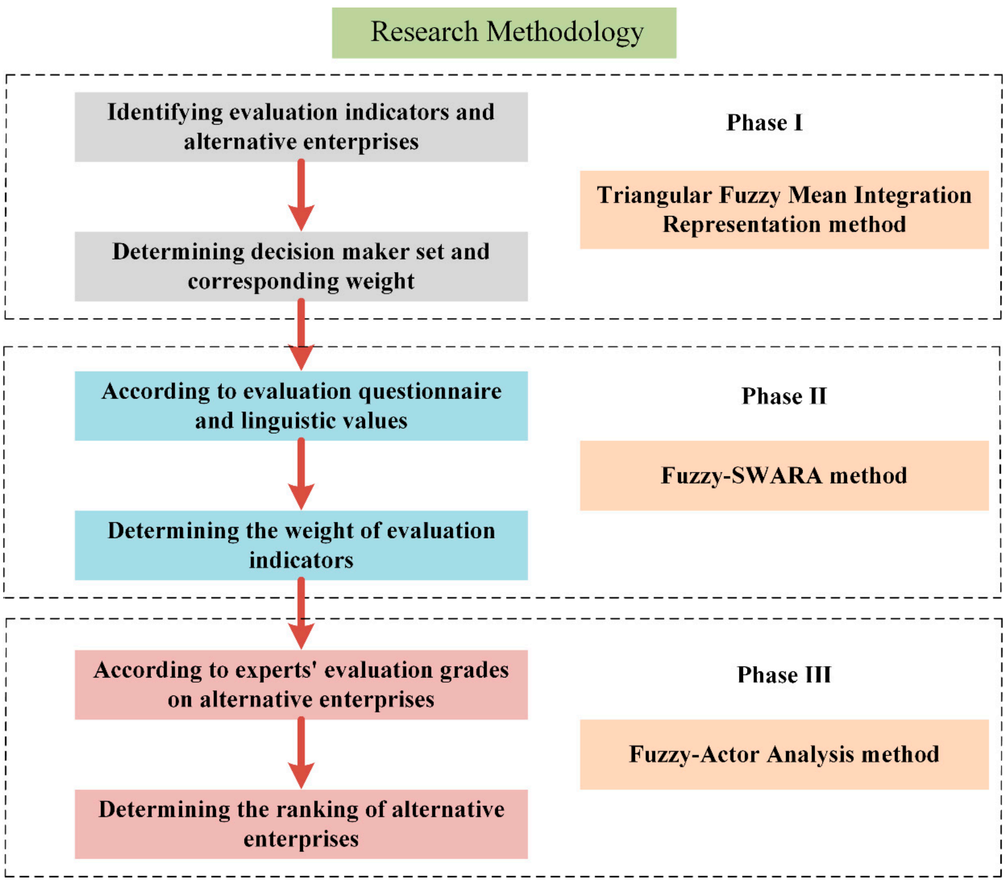

Figure 4. The schematic diagram of the research methodology.

It is assumed that city J needed to carry out reserve work of emergency relief materials, and the cooperative emergency suppliers needed to be determined. Originally, ten companies are selected. After a preliminary judgment and evaluation by three experienced experts in the emergency industry, the remaining five enterprises served as alternatives.

The indicator set was determined as $C = \{C_1, C_2, C_3, C_4, C_5\}$, C_1 corresponding to flexible supply capacity, C_2 to delivery capacity, C_3 to price, C_4 to quality, and C_5 to social evaluation and reputation, respectively. Here, C_3 is the economic indicator, C_1, C_2, C_4, and C_5 are non-economic indicators. The unit prices of the five alternatives are 18, 22, 30, 15, and 20. A questionnaire for the evaluation of indicators was established and sent to three experienced experts. The evaluation values in the questionnaire were designed according to the importance scale tables in Tables 2 and 3 [53].

Table 2. Importance scales for evaluating decision makers.

Linguistic Variable Value	Fuzzy Number	Linguistic Variable Value	Fuzzy Number
Extremely important (EI)	(0.8, 0.9, 1.0)	Middle (M)	(0.4, 0.5, 0.6)
Very important (VI)	(0.7, 0.8, 0.9)	Unimportant (U)	(0.3, 0.4, 0.5)
Important (I)	(0.6, 0.7, 0.8)	Very unimportant (VU)	(0.1, 0.2, 0.3)

Table 3. Correspondence of linguistic variable values.

Linguistic Variable Value	Triangular Fuzzy Number
Extremely Good (EG)/Extremely High (EH)	(0.8, 0.9, 1.0)
Very Very Good (VVG)/Very Very High (VVH)	(0.7, 0.8, 0.9)
Very Good (VG)/Very High (VH)	(0.6, 0.7, 0.8)
Good (G)/High (H)	(0.5, 0.6, 0.7)
Medium Good (MG)/Medium-High (MH)	(0.4, 0.5, 0.6)
Fair (F)/Medium (M)	(0.3, 0.4, 0.5)
Medium Bad (MB)/Medium Low (ML)	(0.2, 0.3, 0.4)
Bad (B)/Low (L)	(0.1, 0.2, 0.3)

Phase 1: Determining decision maker set and corresponding weight, alternative enterprise set, and evaluation indicators set.

The alternative enterprise set is $E = \{E_1, E_2, E_3, E_4, E_5\}$. The evaluation indicators set is $C = \{C_1, C_2, C_3, C_4, C_5\}$. The set of decision-makers is represented by $A = \{A_1, A_2, A_3\}$, and the relative importance value of decision-makers are calculated according to the importance scale of Table 2. The order $\varepsilon = (\varepsilon_1, \varepsilon_2, \varepsilon_3)^T$ as the importance weight of the expert group. The weight of the three decision makers can be obtained according to Table 2 and Equation (10). The results are presented in Table 4.

$$\varepsilon_k = \frac{P(M_k)}{\sum_{k=1}^{p} P(M_k)},\ k = 1, 2, \ldots, p \tag{10}$$

$$\varepsilon = (\varepsilon_1, \varepsilon_2, \varepsilon_3)^T = (0.3750, 0.2917, 0.3333) \tag{11}$$

Table 4. Weight of decision makers.

Decision-Maker	A1	A2	A3
Linguistic variable	EI	I	VI
Triangular fuzzy number	(0.80, 0.90, 1.00)	(0.60, 0.70, 0.80)	(0.70, 0.80, 0.90)
Weight	0.3750	0.2917	0.3333

Phase 2: Determine the weight of non-economic factors.

Decision makers assigned the importance of the indicators based on the linguistic variable values in Table 3. The aggregation triangular fuzzy number was obtained using Equation (11). The defuzzification value was calculated using Equation (2). The obtained defuzzification value P(C_j) was sorted in descending order, according to Equations (3)–(5), as shown in Table 5. The weights of four non-economic indicators were obtained as follows:

$$W = (W_1, W_2, W_4, W_5) = (0.2604, 0.2767, 0.2583, 0.2046) \tag{12}$$

Table 5. Significance of the evaluation indicators.

Indicators	A1	A2	A3	Aggregated Fuzzy Number	Crisp Values P (C_j)	W_j
C1	EG	VVG	VVG	(0.7375, 0.8375, 0.9375)	0.8375	0.2604
C2	EG	EG	EG	(0.8000, 0.9000, 1.0000)	0.9000	0.2767
C4	VVG	VG	VVG	(0.7292, 0.8292, 0.9292)	0.8292	0.2583
C5	MG	MG	VG	(0.4667, 0.5667, 0.6667)	0.5667	0.2046

Phase 3: Calculate the importance values.

According to the Equations (6)–(8), Tables 6–8, and the price, the importance values of economic and non-economic factors were calculated.

$$T_{jE1}, T_{jE2}, T_{jE3}, T_{jE4}, T_{jE5} = (0.2214, 0.1812, 0.1326, 0.2656, 0.1991) \tag{13}$$

$$T_{fE1}, T_{fE2}, T_{fE3}, T_{fE4}, T_{fE5} = (0.2981, 0.0928, 0.2912, 0.1351, 0.1828) \tag{14}$$

Table 6. Decision makers' evaluation grades of alternative enterprises.

Enterprises	E1			E2			E3			E4			E5		
Decision-Maker	**A1**	**A2**	**A3**	**A1**	**A2**	**A3**	**A1**	**A2**	**A3**	**A1**	**A2**	**A3**	**A1**	**A2**	**A3**
C1	G	VG	G	MG	G	MG	VG	VVG	VG	MG	G	G	M	MG	MG
C2	VG	G	G	M	MG	M	G	MG	G	VG	VG	G	VVG	VG	G
C3	VH	H	VH	H	H	MH	VH	VH	H	VH	H	H	VH	H	MH
C4	G	MG	M	MB	M	MB	MG	M	M	B	MB	MB	M	MG	MG
C5	MG	G	MG	M	MG	G	VG	G	VG	MG	M	MG	MG	MG	M

Table 7. Comparison results on non-economic factors.

Comparison Results on C1								Comparison Results on C2							
Enterprises	**E1**	**E2**	**E3**	**E4**	**E5**	G_i	T_{dC1}	**Enterprises**	**E1**	**E2**	**E3**	**E4**	**E5**	G_i	T_{dC2}
E1	\	1	0	1	1	3	0.3	E1	\	1	1	0	0	2	0.2
E2	0	\	0	0	1	1	0.1	E2	0	\	0	0	0	0	0
E3	1	1	\	1	1	4	0.4	E3	0	1	\	0	0	1	0.1
E4	0	1	0	\	1	2	0.2	E4	1	1	1	\	0	3	0.3
E5	0	0	0	0	\	0	0	E5	1	1	1	1	\	4	0.4
Comparison Results on C4								**Comparison Results on C5**							
Enterprises	**E1**	**E2**	**E3**	**E4**	**E5**	G_i	T_{dC4}	**Enterprises**	**E1**	**E2**	**E3**	**E4**	**E5**	G_i	T_{dC5}
E1	\	1	1	1	1	4	0.4	E1	\	1	0	1	1	3	0.3
E2	0	\	0	1	0	1	0.1	E2	0	\	0	1	1	2	0.2
E3	0	1	\	1	1	3	0.3	E3	1	1	\	1	1	4	0.4
E4	0	0	0	\	0	0	0	E4	0	0	0	\	0	0	0
E5	0	1	0	1	\	2	0.2	E5	0	0	0	1	\	1	0.1

Table 8. Comparison results summary.

Enterprises	E1	E2	E3	E4	E5	W_i
C1	0.3	0.1	0.4	0.2	0	0.2604
C2	0.2	0	0.1	0.3	0.4	0.2767
C4	0.4	0.1	0.3	0	0.2	0.2583
C5	0.3	0.2	0.4	0	0.1	0.2046

Let $M = N = 0.5$. The importance values of the alternatives were obtained. and the order of importance was $E_1 > E_3 > E_4 > E_5 > E_2$. Therefore, E_1 is the best choice.

$$F_{E1}, F_{E2}, F_{E3}, F_{E4}, F_{E5} = (0.2598, 0.1370, 0.2119, 0.2003, 0.1910) \tag{15}$$

6. Sensitivity Analysis

To verify the effectiveness of the method, sensitivity analysis is carried out in this section. The relative importance of economic factors and non-economic factors are adjusted, and the remaining indicators are kept unchanged to test the stability of the fuzzy linguistic multi-criteria decision-making method. Make the scenario S1 = Tj:Tf = (0.1, 0.9), the relative importance weights of the economic factor indicators Tj and Tf are set to 0.1, 0.9, respectively. There are nine scenarios, S1 = Tj:Tf = (0.1, 0.9), S2 = Tj:Tf = (0.2, 0.8), S3 = Tj:Tf = (0.3, 0.7), S4 = Tj:Tf = (0.4, 0.6), S5 = Tj:Tf = (0.5, 0.5),S6 = Tj:Tf = (0.6, 0.4),S7 = Tj:Tf = (0.7, 0.3), S8 = Tj:Tf = (0.8, 0.2), S9 = Tj:Tf = (0.9, 0.1).

In each scenario, the importance values of alternative emergency suppliers were calculated respectively, which are shown in Table 9 and Figure 5. As can be seen from the results, the obtained enterprise priorities are not exactly the same in the nine different scenarios. When the important values of economic factors and non-economic factors are the same, $E_1 > E_3 > E_4 > E_5 > E_2$ can be obtained. When the importance value of economic factors is higher and decision-making preference is toward economic factors, 1 and 4 have higher priority. When the importance value of non-economic factors is higher and the decision preference is toward non-economic factors, the priority of 1 and 3 is high.

Table 9. Sensitivity analysis of rankings by F_{Ei}.

Scenarios	Tj	Tf	F_{E1}	F_{E2}	F_{E3}	F_{E4}	F_{E5}	Rankings
S1	0.1	0.9	0.2904	0.1016	0.2753	0.1482	0.1845	$E_1 > E_3 > E_5 > E_4 > E_2$
S2	0.2	0.8	0.2827	0.1105	0.2595	0.1612	0.1861	$E_1 > E_3 > E_5 > E_4 > E_2$
S3	0.3	0.7	0.2751	0.1193	0.2436	0.1743	0.1877	$E_1 > E_3 > E_5 > E_4 > E_2$
S4	0.4	0.6	0.2674	0.1282	0.2278	0.1873	0.1893	$E_1 > E_3 > E_5 > E_4 > E_2$
S5	0.5	0.5	0.2598	0.1370	0.2119	0.2003	0.1910	$E_1 > E_3 > E_4 > E_5 > E_2$
S6	0.6	0.4	0.2522	0.1458	0.1960	0.2134	0.1926	$E_1 > E_4 > E_3 > E_5 > E_2$
S7	0.7	0.3	0.2444	0.1547	0.1802	0.2265	0.1942	$E_1 > E_4 > E_5 > E_3 > E_2$
S8	0.8	0.2	0.2368	0.1636	0.1643	0.2395	0.1958	$E_4 > E_1 > E_5 > E_3 > E_2$
S9	0.9	0.1	0.2291	0.1724	0.1485	0.2525	0.1975	$E_4 > E_1 > E_5 > E_2 > E_3$

It can be concluded that the triangle fuzzy SWARA factor analysis method used in emergency supplies supplier selection is reliable, can not only reflect the importance weights of different experts themselves and the ratings of the target enterprise, more can adjust the economic factors and non-economic factors to reflect the decision-making preference in practical application. It is convenient for decision-making departments to make final decisions, which has good operability and reference value.

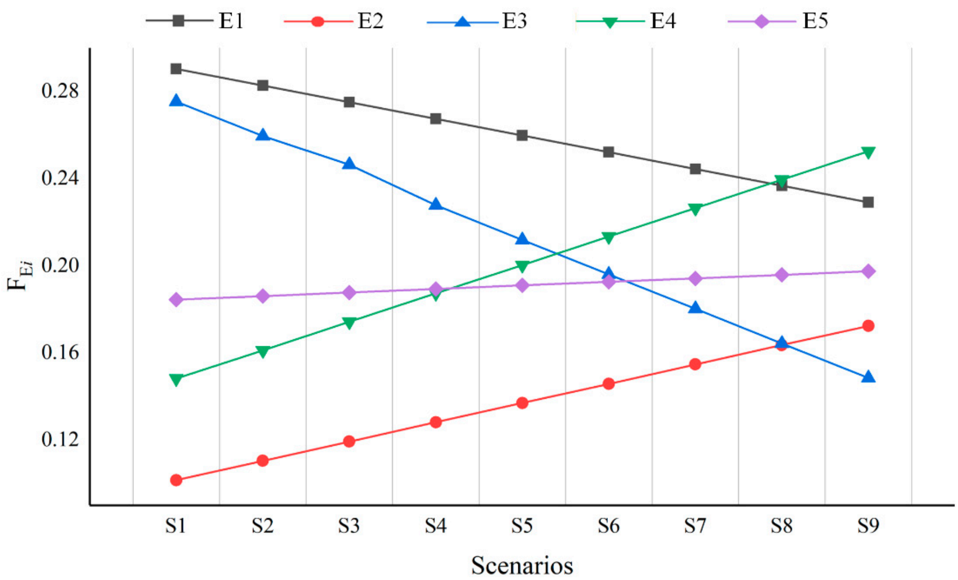

Figure 5. Sensitivity analysis of rankings by F_{Ei}.

7. Discussion

Various natural disasters and emergencies occurred frequently in recent years; after the disaster, to minimize adverse effects, we must attach importance to disaster relief work. Therefore, it is necessary to establish an effective emergency supply chain, among which a reasonable selection of emergency suppliers is an important link for all departments to cope with new challenges and build a modern emergency support mode. Based on the analysis of the evaluation indicators of emergency suppliers, the fuzzy SWARA method was used to give the indicators' weights, and the fuzzy SWARA-based actor analysis method was used to establish the evaluation model of emergency suppliers considering the final decision preference. Thus, the best choice under different decision-making preferences can be obtained, which provides a scientific theoretical basis for decision-making departments to make final decisions, and to ensure the smooth development of emergency rescue work. This study has the following management implications:

(1) The evaluation index system of emergency suppliers proposed in this paper is developed from five aspects of flexible supply capacity, delivery capacity, price, quality, social evaluation, and reputation. The quantifiable economic factors and non-quantifiable non-economic factors are fully considered, which can provide more comprehensive reference for management decision makers. Among them, the flexible supply capacity, emergency delivery capacity, and quality factors are closely related to the timeliness, stability, and reliability of supplies delivery. The acceptable price level is determined by the financial expenditure capacity of the management department, and the social evaluation and reputation will involve the public's view on the fairness and credibility of the management department. That means there are antinomic relationships among some indicators. In the decision-making process, it should be fully considered and relatively appropriate suppliers should be chosen to avoid some disadvantages of suppliers, which can not only guarantee the rescue work, but also maintain a good social image of the emergency management department.

(2) Since January 2020, novel coronavirus pneumonia has been spreading worldwide. Novel coronavirus pneumonia is a new type of public health emergency. It needs comprehensive emergency management and needs a coordinated response from different countries and regions. It is necessary to strengthen international macroeconomic policy coordination, maintain a stable and smooth supply chain of the global industrial chain, and jointly cope with the new crown pneumonia epidemic. At the same time, in the process of emergency management, reserve inventory, emergency demand, and supplier supply capacity should be deeply analyzed, and the uncertain impact of emergency inventory management should

be considered. In order to maximize the efficiency of emergency resource allocation, strong unified organization and implementation are needed in terms of material sources, material distribution, social security, and other measures. Emergency supplier evaluation and selection is an important link affecting the efficiency of emergency resource allocation, which has an important impact on the response and efficiency of the whole emergency supply chain.

(3) Under uncertain conditions, the total cost input of emergency rescue will increase with the improvement of the requirements on service level and reliability. Therefore, in the practical decision making of emergency supplier selection, the final decision maker should give certain decision-making preferences and fully consider the financial expenditure ability, so as to achieve the ideal decision-making goal within the reasonable total cost budget.

8. Conclusions

Due to the uncertainty and abruptness of natural disasters and emergencies, coupled with the complexity and changeability of the rescue process, the emergency rescue management has put forward high requirements. In order to respond quickly and effectively, emergency suppliers can be determined in advance, and the emergency material supply plan can be arranged to ensure emergency supply.

(1) This paper combined the fuzzy theory and the actor analysis method; fuzzy numbers are used to represent uncertainty and fuzziness, which improves the scientific and feasibility of decision making. Fuzzy numbers were used to convert the evaluation language of experts and establish a triangular fuzzy actor analysis method using the constraint nature of triangular fuzzy numbers. To get closer to the actual decision-making situation, the weight of each indicator was determined according to the situation of the experts. The weight of each indicator is determined using the fuzzy SWARA method. The triangle fuzzy actor analysis method determined the priority ranking of different emergency suppliers, which fully considered the decision preference for economic and non-economic factors.

Additionally, the specific application process of the method is given through a numerical example in this paper, and the optimal selection strategy of emergency supplies suppliers under different decision preferences is obtained by combining the sensitivity analysis of economic and non-economic factors. This method provides an evaluation method for emergency suppliers selection, which has reference value in practice. The results show that when the preferences of economic factors and non-economic factors are different, the optimal choice is different. When the important values of economic factors and non-economic factors are the same, we can obtain $E_1 > E_3 > E_4 > E_5 > E_2$. When the decision preference is toward economic factors, E_1 and E_4 have higher priority. When the decision preference is toward non-economic factors, E_1 and E_3 have higher priority. This also indicates that in practical decision-making, disaster needs and financial situation need to be closely linked to achieve the best supply of materials within the range of reasonable economic expenditure.

Different from other qualitative or quantitative evaluation methods, the results of AHP, COPRAS, SWARA, and TOPSIS are mainly determined by the subjective evaluation of external experts, but they cannot directly reflect the antinomic relationship between economic and non-economic factors, which is not conducive to the reference and choice of the final decision-making departments. The method proposed in this paper can not only reflect the importance weights of different experts themselves and the ratings of the target enterprise, but it can also adjust the important value of the economic factors and economy factors to reflect the actual application of the decision preference. This method has good operability and reference value, which is convenient for the decision-making departments to make the final choice according to their own actual situation.

(2) The evaluation scope of emergency supplies suppliers has a wide range, especially for different types of suppliers involved in different indicators. This paper mainly puts forward a single supplier selection scheme from the perspective of epidemic prevention

supplies, and there is still a lot of research space. In future research, the following aspects should be studied. First, it can be considered to increase the evaluation and analysis of specific materials, to solve the problem of supplier selection of emergency materials in a more targeted manner. Second, considering the impact scope of large emergencies, a single supplier may not be able to meet the actual demand, so the selection and configuration of emergency suppliers can be carried out from the perspective of multi-supplier collaborative supply. Third, it can study the emergency supply chain of multi-product, multi-level, and multi-inventory, considering the existing inventory and the supply guarantee ability of suppliers. The dynamic demand can be expressed by appropriate random function, which fully reflects the behavior of multi-level supply chain and completes the allocation of emergency materials. Finally, in the future, it can be considered to further extend the research from trapezoidal fuzzy sets, intuitionistic fuzzy sets, interval intuitionistic fuzzy sets, Z-number theory, and other fuzzy sets, so as to express uncertainty and fuzziness more precisely [54–56].

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