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Research Article

An Integrated Multiattribute Group Decision-Making Approach for Risk Assessment in Aviation Emergency Rescue

Xia Wang,[1] **Xue-dong Liang**,[1,2] **Xiao-yan Li**,[2] **and Peng Luo**[2]

[1]*Institute for Disaster Management and Reconstruction, Sichuan University-The Hong Kong Polytechnic University, Chengdu 610065, China*
[2]*Business School, Sichuan University, Chengdu 610065, China*

Correspondence should be addressed to Peng Luo; luopeng@scu.edu.cn

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An effective risk assessment approach for assessing the risk level of aviation emergency rescue is essential to aviation emergency management. Therefore, this study is aimed at extending a novel integrated multiattribute group decision-making (MAGDM) approach to conduct risk assessment in aviation emergency rescue. First, a combined improved Swiss cheese model and fault tree analysis method are used to build the index system for risk assessment. Next, the weight vector for risk assessment is calculated using the consensus-based improved analytic hierarchy process (IAHP). Then, based on the traditional technique for order preference by similarity to the ideal solution (TOPSIS) method, we improve the definition express of ideal solution and the standardized formula of indexes, thereby providing a consensus-based improved TOPSIS method to compute the evaluation matrix for risk assessment. Finally, the weight vector and evaluation matrix are combined to estimate the risk level of aviation emergency rescue. As aviation emergency rescue in a sudden natural disaster an example, we illustrate the feasibility of the proposed method and demonstrate its effectiveness by comparative analysis with some similar approaches. The proposed approach can evaluate the safety status of aviation emergency rescue operations, which provides a starting point for the improvement of aviation emergency rescue.

1. Introduction

With the increasingly complex and volatile international environment, deteriorating ecological environment, and greenhouse effect, which have led to various disasters one after another, global human beings are facing increasingly severe disaster pressures. Therefore, the rapid, accurate, and effective implementation of postdisaster emergency rescue is of great significance to the protection of people's lives and properties. Disaster emergency rescue is an essential system engineering, and its risk management provides effective decision supports for the stable operations of this system engineering [1–3]. The unique superiorities of aviation emergency rescue, such as air search capability, rapid response capability, and less restriction by geographic space, become the most effective way for many developed countries to deal with various disasters [4–7]. In addition, in some areas with harsh terrain such as coastlines or mountains, aircraft are often the only rescue equipment that can reach the disaster area. Aviation emergency rescue is a way of using aviation technical means to carry out emergency rescue for all kinds of emergency events. This requires the government and other institutions to establish necessary emergency rescue mechanisms in the process of disaster response and take a series of necessary aviation rescue measures to ensure the safety of the public. At present, aviation emergency rescue, as an important part of the national emergency rescue system, is actively promoting the modernization of emergency management systems and capability and strengthening the construction of aviation emergency rescue capability in many countries. In particular, since the outbreak of the COVID-19 pandemic, aviation has made great positive contributions to disaster emergency response, which has highlighted the importance of aviation emergency rescue.

The primary objective of aviation emergency rescue is to ensure the safety of people's lives and properties. Therefore, an effective risk assessment approach for assessing the risk level of aviation emergency rescue is essential to aviation emergency management. This study is aimed at determining the main risk factors affecting aviation emergency rescue and, moreover, conducting the risk assessment for aviation emergency rescue. The risk assessment of aviation emergency rescue involves multiple conflicting indexes, which can be regarded as a multiattribute group decision-making method (MAGDM) problem. The MAGDM is an effective method to deal with complex problems, which can incorporate the opinions of many decision-makers (DMs) and comprehensively evaluate various indexes [8]. Therefore, the MAGDM can be successfully used in risk assessment for aviation emergency rescue. To identify potential hazards in aviation emergency rescue, we attempt to conduct an objective risk assessment approach based on an improved analytic hierarchy process (IAHP) and the technique for order preference by similarity to an ideal solution (TOPSIS) method. In addition, under a MAGDM environment, the DMs can freely express their preferences for each index and try to find a solution that can be accepted by the group. However, since the decision-making groups come from different professional fields and have different knowledge backgrounds, different DMs may give different evaluation information, and they can only partially understand the goals of other DMs, and their own goals are not fully understood by others as well. As a result, it is very rare for various groups to agree with each other, which requires amendments to the opinions that are too different to achieve the required consensus level, and then proceed to the risk assessment [9–11].

Consequently, the above MAGDM problem must go through two stages: one is the consensus process, and the other is the evaluation process. The consensus process is to promote individuals to move closer to the group opinion through a series of efforts, including an optimization method and an interactive iterative process. In each round of interactions, the current level of group consensus is assessed against a predefined consensus measure. If the consensus level is below a predetermined threshold, further optimization is required. Otherwise, the consensus process terminates and proceeds to the next stage of the risk assessment. Therefore, this paper combines the improved AHP-TOPSIS method with the consensus model and proposes an integrated MAGDM approach. We incorporate the consensus model into the improved AHP-TOPSIS method, which can effectively deal with the inconsistencies of the group, and promote the individual opinions to move closer to the group opinions through optimization and iteration, so the evaluation results are more reasonable.

The proposed approach in this paper is a comprehensive assessment method with multiple attributes, its superiorities are that numerous risk factors can be considered, and emergency rescue data can be used for risk assessment. Meanwhile, index weights of risk assessment in aviation emergency rescue obtained by this approach make the weight assignment more reasonable. As aviation emergency rescue in a sudden natural disaster in 2008 an example, empirical results show that risk assessment of aviation emergency rescue based on the improved AHP-TOPSIS approach is feasible and reasonable with full consideration for the risk factors. The proposed approach offers a new multiattribute group decision-making method for the country to learn the safety status of aviation emergency rescue, which is of great significance to improving the level of aviation emergency rescue.

The next sections consist of the following contents. Section 2 is a literature review where recent studies in the fields of risk assessment of emergency rescue, the Swiss cheese model (SCM), and the AHP-TOPSIS approach are listed. In Section 3, the improved TOPSIS method, improved AHP method, and improved SCM are introduced. A scientific and systematic risk assessment model for aviation emergency rescue is established in Section 4. Empirical analysis using an actual case of aviation emergency rescue in a sudden natural disaster as a sample is conducted in Section 5. Based on this research, the last section summarizes the main conclusions and put forward some safety suggestions to promote the construction of aviation emergency rescue.

2. Literature Review

With the rapid development of aviation emergency rescue, safety issues in the rescue process have become increasingly prominent. There are various risks in the aviation emergency rescue process, which may cause loss of life and property. According to the definition of the International Standards Organization, risk is the uncertainty of all types and sizes, which will affect the organization to achieve its goals. The Project Management Institute pointed out that the risk management process needs to be customized for each project. Therefore, the organization reduces risk by identifying, analyzing, and evaluating risk and then taking appropriate actions [12, 13]. In order to reduce the risk of disasters, formulating an emergency rescue plan before the disaster happens is a prerequisite [14–16]. Risk assessment of emergency rescue is the core test of the emergency plan and implementation process to ensure its rationality and preciseness, and many scholars have paid attention to this issue. Chen et al. [17] determined the index weight by AHP and analyzed the decision problem by the fuzzy comprehensive evaluation method in the emergency rescue capability evaluation system. Zhou et al. [18] assess the probability of consequences based on the FTA method and derive the weights of criteria determining the consequence damage applied by the analysis network process. Then, a probabilistic linguistic term set is used to select the plan with the minimum potential damage. Liaropoulos et al. [19] used selective scenarios all along the search and rescue process to analyze the gaps in the search and rescue risk governance of offshore platforms in Greece. Deng et al. [20] used Yunnan and Jiangsu provinces as examples to analyze the importance of cognition of factors affecting earthquake emergency rescue in different regions.

At present, the research on aviation emergency rescue mainly focuses on the effectiveness of helicopter emergency rescue [21–23]. For example, Kaufmann et al. studied the impact of the current trend of mountain sports on the frequency and type of injuries handled by a helicopter-based emergency medical system in mountainous areas [21]. They found that people participating in outdoor leisure activities are increasingly calling for helicopter rescue. Mommsen et al. analyzed a German rescue helicopter base [22]. They found that helicopter emergency medical service can significantly reduce the transportation time for the patient to the nearest rescue center in all diagnosis groups. Liu et al. proposed an assessment framework for helicopters in maritime search and rescue response plans. The emergency assessment indexes of the response plan were extracted by fully analyzing the uncertain factors and the task process [4]. This method can analyze the impact of uncertainty more systematically and optimize the response plan more comprehensively.

Although aviation emergency rescue has attracted much attention from many scholars, there are few studies on the risk assessment in aviation emergency rescue. However, effective risk assessment approaches for assessing the risk level of aviation emergency rescue are essential to achieving safety and efficiency of aviation emergency rescue. Hence, it is necessary to build an effective comprehensive risk assessment model for aviation emergency rescue and then explore the risk factors that lead to the failure of aviation emergency rescue. According to a preceding review of previous researches and the specific features of aviation emergency rescue, the risk assessment in aviation emergency rescue involves multiple conflicting indexes, which can be regarded as a MAGDM problem in essence. The MAGDM is an effective method to deal with complex problems, which can incorporate the opinions of many DMs and comprehensively evaluate various indexes. Hence, the MAGDM has become one of the most widely applicable methods in many fields for decision-making, such as supplier selection, project selection, equipment selection, location selection, investment selection, and risk evaluation. Table 1 presents some relevant studies on MAGDM in different fields.

In contrast with previous studies, we incorporate the consensus model into the improved AHP-TOPSIS method, which can effectively deal with the inconsistencies of the group, and promote the individual opinions to move closer to the group opinions through optimization and iteration, thereby making the evaluation results more reasonable [44]. Therefore, we combine the improved AHP-TOPSIS method with the consensus model to build the risk assessment approach for aviation emergency rescue. The TOPSIS method is a comprehensive assessment approach with multiple attributes. Numerous risk factors can be considered, and emergency rescue data can be used for risk assessment. Meanwhile, index weights of risk assessment in aviation emergency rescue obtained by the IAHP method make the weight distribution more reasonable. At present, the AHP-TOPSIS approach has been used in other fields [45–48]. Nadda et al. [45] conducted experimental research and optimization on cobalt bonded tungsten carbide composite materials through the AHP-TOPSIS method. Ekmekcioğlu et al. [46] assessed the flood risk through the hybrid fuzzy AHP-TOPSIS method to investigate the cognitive differences. Kiracı and Akan [48] used AHP and TOPSIS method in the fuzzy sets of interval type 2 to select aircraft.

According to the overall review of the above literature, the proposed approach for risk assessment of aviation emergency rescue can eliminate the problems of overlapping and subjectivity for risk assessment indexes. In addition, the risk level of aviation emergency rescue is obtained, which can offer decision supports for aviation emergency rescue management.

3. Proposed Integrated Methodology

3.1. SCM and Its Improvement. The SCM was first proposed by Reason in 1990, and the explanation of SCM for accident occurrence is that accident occurrence is a penetrated set of organizational defects. When multiple levels of organizational defects appear simultaneously or successively in the chain of accident-inducing factors, the system will eventually cause accidents. Therefore, it is also called the barrier model. To prevent accidents, it is necessary to set reasonable and effective barriers and constantly provide appropriate maintenance and inspection for these barriers [49–51].

By improving the SCM, the model is not limited to the analysis of human factors, and environmental factors and technical factors are also included in the cause analysis of aviation emergency rescue failure. The improved SCM is combined with the fault tree analysis (FTA) method to analyze the cause mechanism due to barrier failure. The application process of the improved SCM model is as follows:

Step 1. Use improved SCM to analyze the causes of failures from the perspectives of personnel, machines, environment, and management.

Step 2. According to the failure model based on improved SCM, the top event and the middle event are determined. The FTA method is applied to analyze the risk factors.

Step 3. Based on the analysis results of SCM and FTA method, an index system for risk assessment of aviation emergency rescue is constructed.

3.2. IAHP Method and Its Improvement. The AHP method was proposed by Saaty of Pittsburgh University in 1971. After years of development, AHP has derived a variety of methods such as IAHP, fuzzy AHP, and grey AHP [52–55]. Through consulting existing literature, we found that it is more appropriate to use the IAHP method to calculate the index weights for risk assessment of aviation emergency rescue. Its advantage depends on that there is no need to perform consistency checks, and it reduces the number of iterations. We proposed the five-scale method, which has obvious advantages over the nine-scale and three-scale [47]. Because the logic of the five-scale method is reasonable and the form is simple, it is easier for DMs to make judgments about the relative importance of two factors. The steps for using the IAHP method are as follows [55].

Step 1. Build the hierarchical structure for risk assessment of aviation emergency rescue.

Table 1: Some relevant studies on MAGDM.

Literature	Information representation	Multicriteria techniques	Applications
Siraj et al. [24]	Fuzzy numbers	Aggregation operators	Supplier selection
Igoulalene et al. [25]		TOPSIS and goal programming	
Wibowo and Deng [26]		Aggregation operators	
Shen et al. [27]	Intuitionistic fuzzy	ELECTRE III	
Chen et al. [28]	Proportional interval type-2 hesitant fuzzy	TOPSIS approach	
Parreiras et al. [29]	Fuzzy numbers	Aggregation operators	Project selection
Dalal et al. [30]	Crisp numbers	AHP	
Hahn [31]		Kullback-Leibler divergence	
Xu et al. [32]	Fuzzy numbers	Aggregation operators	Equipment selection
Çakır et al. [33]		SMART and FWAD	
Squillante and Ventre [34]	Crisp numbers	Aggregation operators	
Igoulalene and Benyoucef [35]	Fuzzy numbers	TOPSIS	Location selection
Rigopoulos et al. [36]		ELECTRE III	
Wibowo and Deng [37]	Intuitionistic fuzzy numbers	Aggregation operator	
Wu et al. [38]	Crisp numbers	AHP	Investment selection
Meng and An [39]	Hesitant fuzzy	Aggregation operators	
Zhang [40]	Interval-valued hesitant fuzzy	Nonlinear optimization model	
Palomares et al. [41]	Crisp numbers	Aggregation operators	Risk evaluation
Our work		Improved AHP-TOPSIS	
Shen et al. [42]	Intuitionistic fuzzy	ELECTRE III	
Yu et al. [43]	Fuzzy numbers	Aggregation operators	

Step 2. Build comparison matrix $A_{n\times n}$. Each element a_{ij} is assigned according to the five-scale method. When the comparison matrices made by the DMs are inconsistent, the consensus model is used to adjust the decision result made by the DMs and the weight of DMs many times to reach an acceptable consensus, so as to obtain the final group comparison matrix.

Step 3. Define importance ranking index r_i as

$$r_i = \sum_{j=1}^{n} a_{ij} \; (i = 1, 2, \cdots, n). \tag{1}$$

Step 4. Calculate judgment matrix $B_{n\times n}$, and define b_{ij} as

$$b_{ij} = \begin{cases} \dfrac{r_i - r_j}{r_{\max} - r_{\min}} \times (k_m - 1) + 1, & r_i \geq r_j \\ \left[\dfrac{|r_i - r_j|}{r_{\max} - r_{\min}} \times (k_m - 1) + 1 \right]^{-1}, & r_i < r_j \end{cases} \quad (i, j = 1, 2, \cdots, n), \tag{2}$$

where $r_{\max}$ is the maximum value of r_i and $r_{\min}$ is the minimum value of r_i. k_m is defined as

$$k_m = \frac{\max\{r_i\}}{\min\{r_i\}} (i = 1, 2, \cdots, n). \tag{3}$$

Step 5. Calculate optimal transfer matrix $C_{n\times n}$, and define c_{ij} as

$$c_{ij} = \frac{1}{n} \sum_{k=1}^{n} \left(\lg \frac{b_{ik}}{b_{jk}} \right) \; (i, j = 1, 2, \cdots, n). \tag{4}$$

Step 6. Calculate quasioptimal consistent matrix $D_{n\times n}$, and define d_{ij} as

$$d_{ij} = 10^{c_{ij}} \; (i, j = 1, 2, \cdots, n). \tag{5}$$

Step 7. Calculate the eigenvector of the maximum eigenvalue of $D_{n\times n}$ and normalize it to obtain weight ω_i. Define weight vector ω as

$$\omega = (\omega_1, \omega_2, \cdots, \omega_n)^T. \tag{6}$$

3.3. TOPSIS Method and Its Improvement. The TOPSIS method was proposed by Hwang and Yoon in 1981 to solve multivariate optimization problems in multiattribute decision-making. Assuming that i $(i = 1, 2, \cdots, m)$ decision-making unit and j $(j = 1, 2, \cdots, n)$ assessment index exist. The steps for the use of the improved TOPSIS method are as follows [32, 56–58].

Step 1. Establish initial judgment matrix $P_{m\times n}$, and element is p_{ij}.

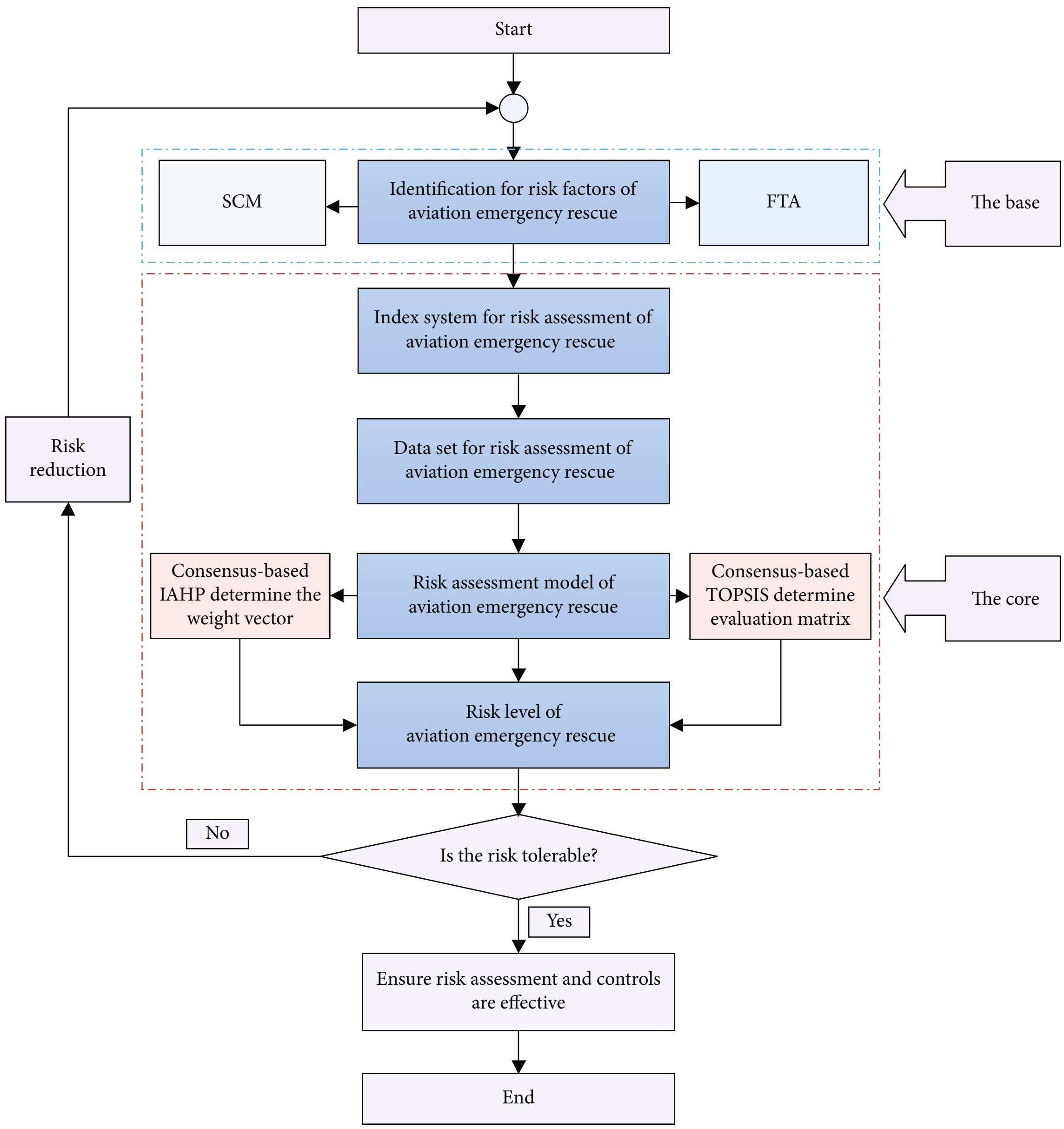

Figure 1: The flowchart of risk assessment framework using the integrated MAGDM approach.

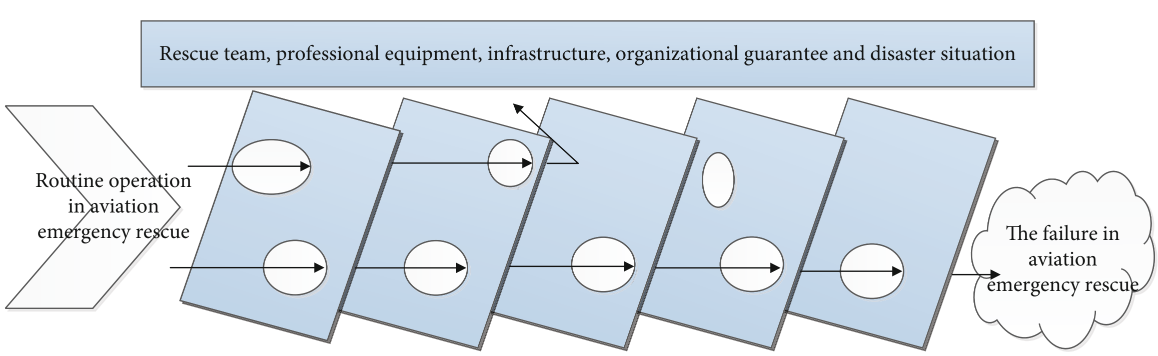

Figure 2: The failure model of aviation emergency rescue based on improved SCM.

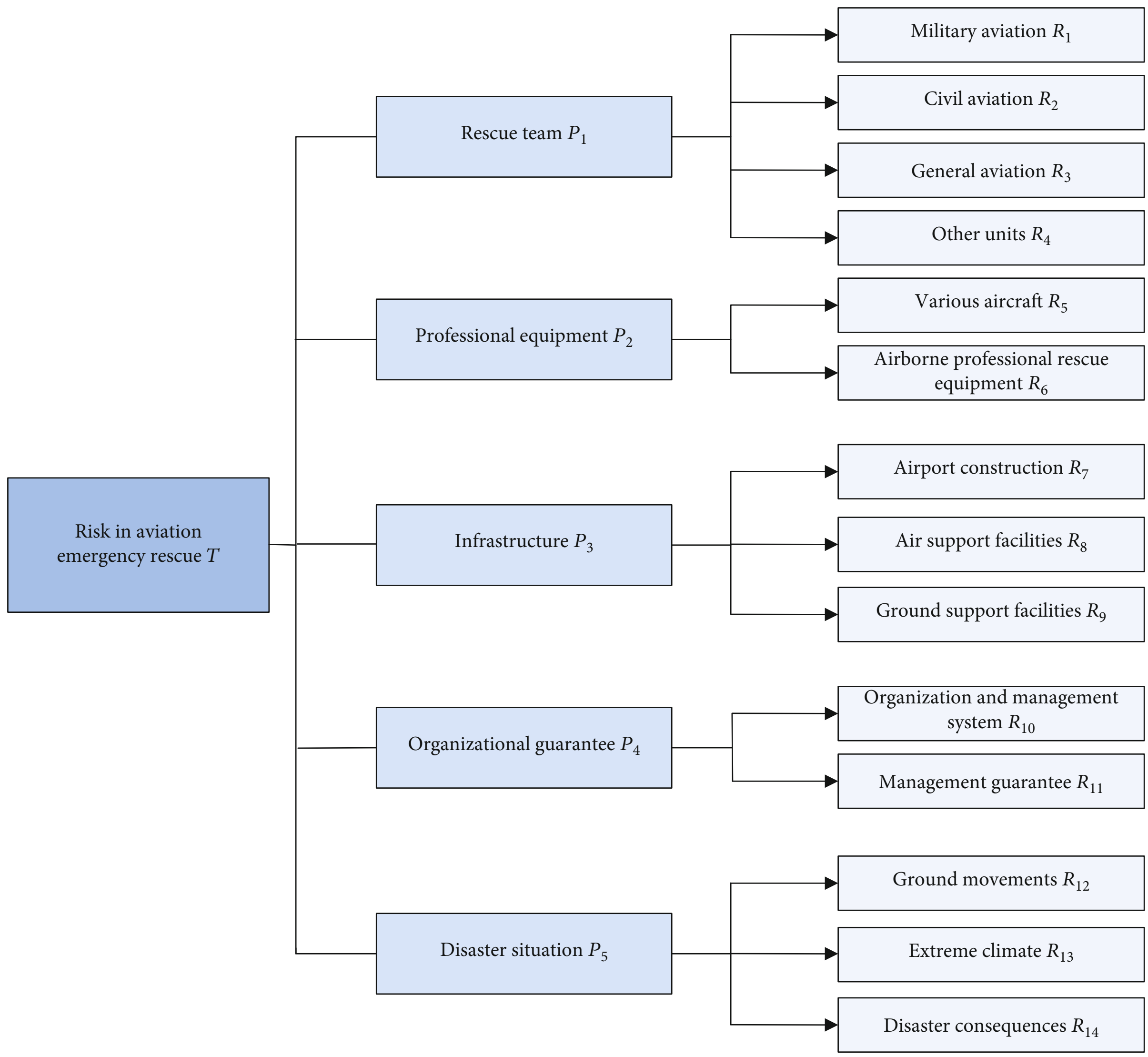

Figure 3: The index system for risk assessment of aviation emergency rescue.

Step 2. Calculate normalized decision matrix $N_{m\times n}$, and define element n_{ij} as

$$n_{ij} = \frac{p_{ij}}{\sqrt{\sum_{i=1}^{m} p_{ij}^2}} \quad (i = 1, 2, \cdots, m, \;\; j = 1, 2, \cdots, n). \tag{7}$$

We have improved the normalization equation for the index to render it applicable in risk assessment of aviation emergency rescue. Equation (7) is difficult to find the normalized value. In addition, Equation (7) shows that there is no distinction between the normalization of the income index and the cost index. Thus, the type of the normalized value is not uniform. Therefore, when the TOPSIS method is applied for risk assessment of aviation emergency rescue, the benefit index and the cost index are processed by different normalization equations, which are unified into the benefit index, so as to obtain a standardized decision matrix. Define the normalized value n_{ij} of the benefit index and the normalized value n_{ij}^* of the cost index as

$$\begin{aligned} n_{ij} &= \frac{p_{ij} - p_j^b}{p_j^a - p_j^b} \quad (i = 1, 2, \cdots, m, \;\; j = 1, 2, \cdots, n), \\ n_{ij}^* &= \frac{p_j^b - p_{ij}}{p_j^b - p_j^a} \quad (i = 1, 2, \cdots, m, \;\; j = 1, 2, \cdots, n). \end{aligned} \tag{8}$$

When aviation emergency rescue of a sudden natural disaster is in the best state, $p_j = p_j^a$; when aviation emergency rescue of a sudden natural disaster is in the worst state, $p_j = p_j^b$.

Step 3. Define weighted normalized decision matrix $V_{m\times n}$ as

$$\mathbf{V}_{m\times n} = \mathbf{N}_{m\times n} \mathbf{W}_{n\times n}, \tag{9}$$

where $\mathbf{W}_{n\times n}$ is a weight matrix composed of ω_j.

Table 2: The data sets for risk assessment of aviation emergency rescue.

Factor	Data variable
Rescue team P_1	Military aviation: number of rescue aircraft (aircraft), rescue aircraft movements (movements), cargo throughput (tonnes), passenger throughput (passengers), supply-to-demand ratio for rescuers (%), emergency skill level of rescuers (%), physical condition of rescuers (%), psychological condition of rescuers (%) Civil aviation: number of rescue aircraft (aircrafts), rescue aircraft movements (movements), cargo throughput (tonnes), passenger throughput (passengers), supply-to-demand ratio for rescuers (%), emergency skill level of rescuers (%), physical condition of rescuers (%), psychological condition of rescuers (%) General aviation: number of rescue aircraft (aircrafts), rescue aircraft movements (movements), cargo throughput (tonnes), passenger throughput (passengers), supply-to-demand ratio for rescuers (%), emergency skill level of rescuers (%), physical condition of rescuers (%), psychological condition of rescuers (%) Other units: number of rescue aircraft (aircrafts), rescue aircraft movements (movements), cargo throughput (tonnes), passenger throughput (passengers), supply-to-demand ratio for rescuers (%), emergency skill level of rescuers (%), physical condition of rescuers (%), psychological condition of rescuers (%)
Professional equipment P_2	Various aircraft: supply-to-demand ratio for rescue helicopter (%), supply-to-demand ratio for fixed-wing rescue aircraft (%), supply-to-demand ratio for rescue UAV (%) Airborne professional rescue equipment: supply-to-demand ratio for airborne powerful searchlight (%), supply-to-demand ratio for airborne rescue winch (%), supply-to-demand ratio for airborne rescue spreader (%), supply-to-demand ratio for airborne life guarantee system (%), supply-to-demand ratio for aviation medical stretcher (%), supply-to-demand ratio for other equipment (%)
Infrastructure P_3	Airport construction: supply-to-demand ratio for general airport (%), supply-to-demand ratio for civil airport (%), supply-to-demand ratio for military airport (%) Air support facilities: communication status (%), navigation status (%), information transmission status (%) Ground support facilities: supply-demand ratio for aviation fuel (%), aircraft maintenance capacity (%)
Organizational guarantee P_4	Organization and management system: national aviation rescue management system level (%), military aviation rescue management system level (%), social aviation rescue management system level (%) Management guarantee: initiation status of emergency plan (%), emergency response status (%), completeness of aviation rescue laws and regulations (%), emergency safety training status (%)
Disaster situation P_5	Ground movement: ground movement susceptibility (%), ground movement precautions (%) Extreme climate: extreme climate susceptibility (%), extreme weather precautions (%) Disaster consequences: casualty status (%), property loss status (%)

Table 3: Aviation emergency rescue risk level according to the quantitative value.

Quantitative value	$(0, 0.45]$	$(45, 0.60]$	$(0.60, 0.75]$	$(0.75, 0.90]$	$(0.90, 1.00]$
Risk level	Extremely high	High	Medium	Low	Extremely low

Step 4. Define positive ideal solution V^+ and the negative ideal solution V^- as

$$\begin{aligned} V^+ &= \{v_1^+, v_2^+, \cdots, v_n^+\} = \left\{ \left(\max v_{ij} \mid j \in I\right), \left(\min v_{ij} \mid j \in I^*\right) \right\} \\ &\quad \cdot (i = 1, 2, \cdots, m,\ \ j = 1, 2, \cdots, n), \\ V^- &= \{v_1^-, v_2^-, \cdots, v_n^-\} = \left\{ \left(\min v_{ij} \mid j \in I\right), \left(\max v_{ij} \mid j \in I^*\right) \right\} \\ &\quad \cdot (i = 1, 2, \cdots, m,\ \ j = 1, 2, \cdots, n), \end{aligned} \tag{10}$$

where I is the benefit index and I^* is the cost index.

Here, Equation (10) is not suitable for directly computing the ideal solution in the risk assessment of aviation emergency rescue, which may lead to relative deviation in the assessment result. Therefore, we have improved the method for determining the ideal solution. When the TOPSIS method is used to evaluate the risk of aviation emergency rescue, the positive ideal solution should correspond to the best state value of aviation emergency rescue, and the negative ideal solution should correspond to the worst state value of aviation emergency rescue. For instance, for the number of military rescue aircraft, the value when the number of military rescue aircraft meets the rescue demand in the process of aviation emergency rescue is the best value of the number of military rescue aircraft, and the number of military rescue aircraft is far lower than the value of demand; that is, 0 is the worst value of the number of military rescue aircraft. The best value is generally decided by the DMs. When the best/worst values made by the DMs are inconsistent, the decision results made by DMs and the weight of DMs are adjusted several times to reach an acceptable consensus. So, the final best/worst value is obtained.

Step 5. Define separation degree d_i^+ between the target value and the positive ideal solution, and the separation degree d_i^-

Table 4: The detail description of the sudden natural disaster.

Basic parameters	Condition description
Type of disaster	Earthquake
Magnitude	8.0
Rescue team	Air force dispatched 94 aircraft, flew 1,800 aircraft movements, and transported 4,734.96 tonnes of cargo and 17,497 passengers. Army aviation dispatched 96 aircraft, flew 4,085 aircraft movements, and transported 2,026.45 tonnes of cargo and 8932 passengers. Civil aviation dispatched more than 200 aircraft, flew 1,200 aircraft movements, and transported more than 15,000 tonnes of cargo and 37,000 passengers. General aviation dispatched 38 aircraft, flew 1,032 aircraft movements, and transported 781.4 tonnes of cargo and 3,299 passengers. Other units dispatched 20 aircraft and flew 160 aircraft movements
Professional equipment	Rescue helicopter, fixed-wing rescue aircraft, rescue UAV, and aerial remote sensing aircraft participate in the rescue. Equipped with 3 aviation medical stretchers, airborne high-power broadcasting system
Infrastructure	There are Guanghan airport in Civil Aviation Flight University of China and military airport in Chengdu Military Region. Disasters caused destruction of communication base stations and damage to communication equipment. In the disaster area, the climatic conditions are poor, making it difficult to implement airborne. The airborne troops had no ground guidance, no ground signs, and no meteorological data during the initial rescue
Organizational guarantee	The State Council's General Headquarters for Earthquake Relief was established quickly, and the command structure was operating efficiently. The Central Military Commission established an army earthquake relief command group to organize and command the army's earthquake relief operations. The four general headquarters of the People's Liberation Army, military regions, services and arms, and armed police units have all established command organizations to implement the central decision-making and deployment. The Provincial Party Committee and the Provincial Government immediately established the Sichuan Provincial "5·12" Earthquake Relief Headquarters, with unified leadership and unified command. Sichuan Red Cross, Sichuan Lawyers Association and law firms, and the province's construction, aviation, petrochemical, and other industries quickly organize ambulance teams, service teams, and wounded transfer teams and provide strong support in disaster relief. All departments of the central state organs fully activated the emergency response mechanism and launched the national emergency response plan. The army activates the emergency mechanism. The provincial government quickly initiated the emergency level I response, and the Wenchuan County Party Committee and the county government immediately launched the first level emergency response plan
Disaster situation	As of September 25, 2008, 69,227 people died, 17,923 people are missing, 374,643 people are injured to varying degrees, 19,930,300 people lost their homes, and the number of people affected by the disaster reached 46.256 million. The direct economic loss caused was 852.309 billion yuan
Rescue statue	As of July 15, 2008, a total of 83,988 people were rescued from the rubble in the Sichuan disaster area, more than 15 million people were evacuated urgently, 55,000 trapped tourists were rescued, and a total of 1,336,621 wounded and sick in the quake-stricken area were received and treated by Sichuan medical and health institutions

between the target value and the negative ideal solution as

$$d_i^+ = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^+\right)^2}\ (i = 1, 2, \cdots, m,\ j = 1, 2, \cdots, n),$$
$$d_i^- = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^-\right)^2}\ (i = 1, 2, \cdots, m,\ j = 1, 2, \cdots, n). \tag{11}$$

Step 6. The closeness coefficient r_i^* is defined as

$$r_i^* = \frac{d_i^-}{d_i^+ + d_i^-}\ (i = 1, 2, \cdots, m). \tag{12}$$

4. Research Framework on Risk Assessment in Aviation Emergency Rescue

A single method cannot establish either a realistic assessment model or a risk assessment process in emergency locations, so future views should focus on the combined approach. Therefore, our proposed method integrates the TOPSIS method, IAHP method, SCM, and consensus model. As shown in Figure 1, we describe the flowchart of the newly proposed risk assessment framework for aviation emergency rescue using the integrated MAGDM approach.

4.1. Index System for Risk Assessment. We use improved SCM to analyze the causes of aviation emergency rescue failures from the perspectives of personnel, machines, environment, and management. Meanwhile, by analyzing and comparing the connotation, characteristic, and influencing factor of aviation emergency rescue [4–7, 59], a failure model of aviation emergency rescue based on improved SCM is established as shown in Figure 2.

The failure model of aviation emergency rescue based on SCM shows that rescue team, professional equipment, infrastructure, organizational guarantee, and disaster situation are the main inducing factors that lead to aviation emergency rescue failure. Although these inducing factors exist in the aviation emergency rescue system for a long time, they do not necessarily lead to the failure of aviation emergency

Table 5: Group comparison matrix $A_{5\times5}$.

$A_{5\times5}$	P_1	P_2	P_3	P_4	P_5
P_1	1	0.91	2.00	0.50	3.00
P_2	1.10	1	2.00	0.50	4.00
P_3	0.50	0.50	1	0.25	2.00
P_4	2.00	2	4	1	5.00
P_5	0.33	0.25	0.50	0.20	1

Table 6: Judgment matrix $B_{5\times5}$.

$B_{5\times5}$	P_1	P_2	P_3	P_4	P_5
P_1	1	0.6954	2.4234	0.2600	3.2847
P_2	1.4380	1	2.8613	0.2934	3.7227
P_3	0.4126	0.3495	1	0.1897	1.8613
P_4	3.8468	3.4088	5.2702	1	6.1315
P_5	0.3044	0.2686	0.5372	0.1631	1

Table 7: Optimal transfer matrix $C_{5\times5}$.

$C_{5\times5}$	P_1	P_2	P_3	P_4	P_5
P_1	0	-0.0989	0.2902	-0.4938	0.4606
P_2	0.0989	0	0.3891	-0.3949	0.5595
P_3	-0.2902	-0.3891	0	-0.7840	0.1704
P_4	0.4938	0.3949	0.7840	0	0.9544
P_5	-0.4606	-0.5595	-0.1704	-0.9544	0

Table 8: Quasioptimal consistent matrix $D_{5\times5}$.

$D_{5\times5}$	P_1	P_2	P_3	P_4	P_5
P_1	1	0.7963	1.9508	0.3208	2.8878
P_2	1.2557	1	2.4497	0.4028	3.6263
P_3	0.5126	0.4082	1	0.1644	1.4803
P_4	3.1175	2.4826	6.0816	1	9.0026
P_5	0.3463	0.2758	0.6755	0.1111	1

rescue. Aviation emergency rescue failure is caused when the organizational flaws of multiple levels in an accident-causing factor simultaneously or successively occur. Therefore, only risk assessment of aviation emergency rescue based on multiple risk factor indexes can ensure the rationality of the result.

According to the failure model of aviation emergency rescue based on improved SCM, the top event and the middle event are determined. The FTA method is applied to analyze the risk factors. Based on the analysis results of SCM and FTA method, an index system for risk assessment of aviation emergency rescue is constructed, as shown in Figure 3. The aviation emergency rescue failure is the objective layer, the first-layer index of risk assessment of aviation emergency rescue is the criterion layer, and the second-layer index of risk assessment of aviation emergency rescue is the subcriterion layer.

4.2. Data Sets for Risk Assessment. The quantitative value of the secondary index in the calculation of the risk assessment of aviation emergency rescue model is unreliable, and the data used for quantitative risk assessment of aviation emergency rescue shall include the most important specific data among the five risk factors: rescue team, professional equipment, infrastructure, organizational guarantee, and disaster situation. We combine these three methods to screen the index data set. First, through frequency analysis, we select the index data set that is frequently used from research literature on aviation emergency rescue. At the same time, we analyze and compare the connotation, characteristics, and influencing factors of aviation emergency rescue and select the index data set with strong pertinence. Finally, the expert consultation method is used to further obtain the index data set as shown in Table 2.

4.3. Compute the Risk Assessment Results. The actual state for aviation emergency rescue of a sudden disaster, the best state, and the worst state constitute i $(i = 1, 2, \cdots, m)$ decision-making units. Rescue team, professional equipment, infrastructure, organizational guarantee, and disaster situation compose j $(j = 1, 2, \cdots, 5)$ index set [17, 59, 60].

Step 1. The consensus-based IAHP method is used to calculate the index weight of risk assessment in aviation emergency rescue, and the index weight of the criterion layer composes weight vector ω.

Step 2. Using the consensus-based TOPSIS method, the initial judgment matrix $P_{m\times n}$ for the index of the criterion layer is built according to the actual state of aviation emergency rescue in a sudden natural disaster, the best state, and the worst state. Perform normalization processing according to Equation (8) to get a normalized decision matrix $N_{m\times n}$. Equations (10)–(12) are used to calculate the closeness coefficient of the criterion layer index of the actual situation of aviation emergency rescue in sudden natural disasters. The closeness coefficient of the criterion layer index of aviation emergency rescue situation constitutes the evaluation matrix $R_{3\times5}$ for risk assessment of aviation emergency rescue.

Step 3. The result vector Q for risk assessment of aviation emergency rescue is calculated as

$$Q = R_{m\times5} \times \omega. \quad (13)$$

4.4. Determine the Risk Level of Aviation Emergency Rescue. We interval the quantitative interval $(0, 1)$ of the assessment object, and correspondingly divide the aviation emergency rescue risk level into five levels as shown in Table 3 [17]. The quantitative value of aviation emergency rescue risk determines the aviation emergency rescue risk level.

Table 9: Weight of risk assessment index.

First-layer index	Weight	Second-layer index	Weight	Second total weight
Rescue team P_1	0.1605	Military aviation R_1	0.4001	0.0642
		Civil aviation R_2	0.3097	0.0497
		General aviation R_3	0.1910	0.0307
		Other units R_4	0.0992	0.0159
Professional equipment P_2	0.2015	Various aircraft R_5	0.6280	0.1265
		Airborne professional rescue equipment R_6	0.3720	0.0750
Infrastructure P_3	0.0822	Airport construction R_7	0.3812	0.0313
		Air support facilities R_8	0.3291	0.0271
		Ground support facilities R_9	0.2897	0.0238
Organizational guarantee P_4	0.5002	Organization and management system R_{10}	0.3927	0.1964
		Management support R_{11}	0.6073	0.3038
Disaster situation P_5	0.0556	Ground movement R_{12}	0.3650	0.0203
		Extreme climate R_{13}	0.5246	0.0292
		Disaster consequences R_{14}	0.1104	0.0061

5. Case Study

We conduct an empirical analysis using an actual case of aviation emergency rescue in a sudden natural disaster in 2008 as a sample. The details of this aviation emergency rescue are shown in Table 4. The raw data mainly come from the book *Aviation Emergency Rescue* [59] and *Disaster Relief Records of Wenchuan Earthquake* (published by the Compilation Committee of Disaster Relief Records of Wenchuan Earthquake in 2015) [61].

5.1. Calculate the Weight Vector for Risk Assessment in Aviation Emergency Rescue. We use the consensus-based IAHP method and consult experts to compute the weight vector of risk assessment of aviation emergency rescue for the sudden natural disaster in 2008. Take the criterion layer as an example to illustrate the weight determination process.

Step 1. We invited 5 experts in emergency management and 5 professional rescuers to obtain the group comparison matrix. First, experts and professional rescuers use the five-scale method to judge the importance of each factor in the case study of aviation emergency rescue risk. Then, a consensus model is used to adjust the decision result made by the DMs and the weight of DMs many times to reach an acceptable consensus. Finally, the group comparison matrix $A_{5\times5}$ of the criterion layer indexes of aviation emergency rescue risk evaluation is obtained, as shown in Table 5.

Step 2. Calculate r_i according to Equation (1). $r_1 = 7.5000$, $r_2 = 8.5000$, $r_3 = 4.2500$, $r_4 = 14.0000$, $r_5 = 2.2833$, $r_{\max} = 14.0000$, $r_{\min} = 2.2833$.

Step 3. According to Equation (2), the judgment matrix $B_{5\times5}$ is calculated, as shown in Table 6.

Step 4. According to Equation (4), the optimal transfer matrix $C_{5\times5}$ is calculated, as shown in Table 7.

Step 5. According to Equation (5), the quasioptimal consistent matrix $D_{5\times5}$ is calculated, as shown in Table 8.

Step 6. The maximum eigenvalue of $D_{5\times5}$ is 5.0000, and the corresponding eigenvector is $(0.2808, 0.3527, 0.1440, 0.8755, 0.0973)^T$. Get the first-layer index weight value through normalization: $(0.1605, 0.2015, 0.0822, 0.5002, 0.0556)^T$. Similarly, according to the index system for risk assessment of aviation emergency rescue (Figure 3), we can obtain the index weight of rescue team, professional equipment, infrastructure, organizational guarantee, and disaster situation. Finally, the weight of the risk assessment index of aviation emergency rescue for sudden natural disaster is calculated, as shown in Table 9.

5.2. Determine the Evaluation Matrix for Risk Assessment in Aviation Emergency Rescue. To determine the evaluation matrix for risk assessment in aviation emergency rescue, we take the rescue team as an example for conducting the index assessment as follows.

Step 1. We collect the actual values corresponding to the actual state in the data set for risk assessment of aviation emergency rescue in natural disaster. The raw data mainly come from the book *Aviation Emergency Rescue* [59] and *Disaster Relief Records of Wenchuan Earthquake* (published by the Compilation Committee of Disaster Relief Records of Wenchuan Earthquake in 2015). We invited 5 experts in emergency management and 5 professional rescuers to obtain the best/worst values for risk assessment of aviation emergency rescue. First, experts and professional rescuers

Table 10: Data set of rescue team factor.

Rescue team factor	Rescue team factor	The actual state	The best state	The worst state
Military aviation	Number of rescue aircraft (aircraft)	190	300	0
	Rescue aircraft movements (movements)	5,885	7,000	0
	Cargo throughput (tonnes)	6,761.21	8,000	0
	Passenger throughput (passengers)	26,429	30,000	0
	Supply-to-demand ratio for rescuers (%)	90	100	0
	Emergency skill level of rescuers (%)	90	100	0
	Physical condition of rescuers (%)	90	100	0
	Psychological condition of rescuers (%)	90	100	0
Civil aviation	Number of rescue aircraft (aircraft)	200	400	0
	Rescue aircraft movements (movements)	1,200	2,000	0
	Cargo throughput (tonnes)	15,000	20,000	0
	Passenger throughput (passengers)	37,000	50,000	0
	Supply-to-demand ratio for rescuers (%)	70	100	0
	Emergency skill level of rescuers (%)	70	100	0
	Physical condition of rescuers (%)	80	100	0
	Psychological condition of rescuers (%)	80	100	0
General aviation	Number of rescue aircraft (aircraft)	38	100	0
	Rescue aircraft movements (movements)	1,032	2,000	0
	Cargo throughput (tonnes)	781.4	2,000	0
	Passenger throughput (passengers)	3,299	5,000	0
	Supply-to-demand ratio for rescuers (%)	50	100	0
	Emergency skill level of rescuers (%)	60	100	0
	Physical condition of rescuers (%)	80	100	0
	Psychological condition of rescuers (%)	80	100	0
Other units	Number of rescue aircraft (aircraft)	20	100	0
	Rescue aircraft movements (movements)	160	400	0
	Supply-to-demand ratio for rescuers (%)	50	100	0
	Emergency skill level of rescuers (%)	60	100	0
	Physical condition of rescuers (%)	80	100	0
	Psychological condition of rescuers (%)	80	100	0

judge the best/worst values based on the actual state. Then, the consensus model is used to adjust the decision result made by the DMs and the weight of DMs many times to reach an acceptable consensus. Finally, the final best/worst value of aviation emergency rescue risk evaluation is obtained. For instance, for the number of military rescue aircraft, the value when the number of military rescue aircraft meets the rescue demand in the process of aviation emergency rescue is the best value; that is, 300 is the best value of the number of military rescue aircraft. The number of military rescue aircraft is far lower than the value of demand; that is, 0 is the worst value of the number of military rescue aircraft. The data set of rescue team factor P_1 is shown in Table 10.

Step 2. According to Equation (8), the actual date of the rescue team factor is normalized to obtain matrix $N_{3\times 4}$ of the rescue team factor, as shown in Table 11.

Step 3. According to Equation (8), the matrix $N_{3\times 4}$ of the rescue team factor is multiplied by matrix $W_{4\times 4}$ of the rescue team factor, where $W_{4\times 4}$ is shown in Table 12, to obtain matrix $V_{3\times 4}$ of the rescue team factor, as shown in Table 13.

Step 4. According to Equations (11) and (12), we calculate the distance and the closeness coefficient of the rescue team factor with the ideal solution (the values of the ideal solution as shown in Table 14). Similarly, according to the index system for risk assessment of aviation emergency rescue (Figure 3), we obtain the distance and the closeness coefficient of the remaining four factors as shown in Table 15.

According to Equations (11) and (12), we calculated the distance and closeness coefficient of the rescue team factor with the ideal solution (the values of the ideal solution are shown in Table 13). Similarly, according to the index system for risk assessment of aviation emergency rescue (Figure 3), we obtain the distance and closeness coefficient of the remaining four factors as shown in Table 15.

Table 11: Matrix $N_{3\times4}$ of rescue team factor.

$N_{3\times4}$	R_1	R_2	R_3	R_4
The actual state	0.8500	0.6988	0.5808	0.5500
The best state	1	1	1	1
The worst state	0	0	0	0

Table 12: Matrix $W_{4\times4}$ of rescue team factor.

$W_{4\times4}$	R_1	R_2	R_3	R_4
R_1	0.0642	0	0	0
R_2	0	0.0497	0	0
R_3	0	0	0.0307	0
R_4	0	0	0	0.0159

Table 13: Matrix $V_{3\times4}$ of the rescue team factor.

$V_{3\times4}$	R_1	R_2	R_3	R_4
The actual state	0.0546	0.0347	0.0178	0.0087
The best state	0.0642	0.0497	0.0307	0.0159
The worst state	0	0	0	0

5.3. Results of Risk Assessment in Aviation Emergency Rescue. The index weight of the criterion layer constitutes the weight vector $\omega = (0.1605, 0.2015, 0.0822, 0.5002, 0.0556)^T$. The evaluation matrix $\mathbf{R}_{3\times5}$ constructed by using the closeness coefficient of the criterion layer is shown in Table 16.

According to Equation (13), the evaluation result vector Q of assessment objects is obtained, and the quantitative value of the natural disaster emergency rescue is 0.7011. According to the corresponding table of quantified value and aviation emergency rescue risk level (Table 2), it can be known that the risk level of natural disaster aviation emergency rescue in 2008 is medium risk. The result obtained through the proposed approach is consistent with the actual situation, indicating that the risk assessment model of aviation emergency rescue based on the improved AHP-TOPSIS approach is feasible. The model fully considers the risk factors of aviation emergency rescue, and the assessment results are reasonable and scientific. The proposed approach offers a new MAGDM method for the country to learn the safety status of aviation emergency rescue.

5.4. Comparison Analysis. In this section, we verify the rationality of the improved AHP-TOPSIS approach. This method is compared with the traditional AHP-TOPSIS approach and the TOPSIS approach without considering the index weight; the influence of different decision-making methods on the assessment results is discussed. We calculate that the quantitative values of the natural disaster emergency rescue by these three approaches, respectively, are 0.7011, 0.6520, and 0.7278. However, all three decision-making methods determine that the risk level of natural disaster aviation emergency rescue in 2008 is medium risk, which verifies the effectiveness of the proposed approach to a certain extent.

Table 14: Ideal solution of criterion layer index.

Risk factor	V^+	V^-
Rescue team P_1	(0.0642, 0.0497, 0.0307, 0.0159)	(0, 0, 0, 0)
Professional equipment P_2	(0.1265, 0.0750)	(0, 0)
Infrastructure P_3	(0.0313, 0.0271, 0.0238)	(0, 0, 0)
Organizational guarantee P_4	(0.1964, 0.3038)	(0, 0)
Disaster situation P_5	(0.0203, 0.0292, 0.0061)	(0, 0, 0)

Table 15: Result of criterion layer indexes.

Risk factors		The actual state	The best state	The worst state
Rescue team P_1	d^+	0.0231	0	0.0882
	d^-	0.0677	0.0882	0
	r^*	0.7452	1	0
Professional equipment P_2	d^+	0.0763	0.0000	0.1471
	d^-	0.0734	0.1471	0
	r^*	0.4901	1	0
Infrastructure P_3	d^+	0.0242	0	0.0478
	d^-	0.0240	0.0478	0
	r^*	0.4975	1	0
Organizational guarantee P_4	d^+	0.0611	0	0.3618
	d^-	0.3033	0.3618	0
	r^*	0.8323	1	0
Disaster situation P_5	d^+	0.0195	0	0.0361
	d^-	0.0166	0.0361	0
	r^*	0.4599	1	0

Table 16: Evaluation matrix $R_{3\times5}$ of the criterion layer.

$R_{4\times5}$	P_1	P_2	P_3	P_4	P_5
The actual state	0.7452	0.4901	0.4975	0.8323	0.4599
The best state	1	1	1	1	1
The worst state	0	0	0	0	0

There are certain differences based on different approaches, and the reasons for the differences can be discussed from two aspects:

(1) Compared with the traditional AHP method, the improved AHP method has stronger operability, and the result of index weight for risk assessment in aviation emergency rescue calculated by this method is more accurate and reasonable. At the same time, the five-scale method has obvious advantages over the nine-scale method and the three-scale method. Because the logic is reasonable and the form

is simple, it is easier for experts to make judgments about the relative importance of the two factors

(2) We have improved the TOPSIS method to render it more applicable in risk assessment of aviation emergency rescue. The weight vector and evaluation matrix are combined to obtain the risk level of aviation emergency rescue

6. Conclusions and Suggestions

In this paper, based on the IAHP and TOPSIS method, we proposed an objective risk assessment approach to identify potential hazards in aviation emergency rescue. The proposed approach offers a new MAGDM method for the country to learn the safety status of aviation emergency rescue, which is of great significance to improving the level of aviation emergency rescue. As aviation emergency rescue in a sudden natural disaster an example, empirical results show that the risk assessment of aviation emergency rescue based on the improved AHP-TOPSIS approach is feasible and reasonable with full consideration of the risk factors. In this way, the problem of low reliability of the evaluation results caused by the use of a single index can be avoided. What is more, the result of index weight for risk assessment in aviation emergency rescue calculated by improved AHP is more accurate and reasonable. Meanwhile, we improve the determination method of ideal solution and the standardized formula of indexes, thereby providing an improved TOPSIS method to calculate the evaluation matrix of aviation emergency rescue.

The integrated MAGDM approach comprehensively evaluates the risk of aviation emergency rescue and performs reverse-order analysis of the evaluation results to realize timely investigation of weak links at each layer, thereby standardizing the code of conduct and operating procedures for the implementation of aviation emergency rescue. According to the evaluation results of the criteria-level indexes listed in Table 15, the risks of factors such as professional equipment and infrastructure are relatively high. For example, in terms of infrastructures, general airports and civil airports cannot meet rescue needs. In terms of professional equipment, helicopters, UAV, and other equipment cannot meet rescue needs.

In order to reduce the risk of aviation emergency rescue to a reasonable acceptable range and thereby improve the ability of aviation emergency rescue, this article puts forward several safety suggestions.

(1) Establish airports, takeoff and landing points, and various ground service infrastructure with reasonable layout and sufficient quantity. Due to the lagging development of China's economic level, management concept, and personnel training, the foundation of aviation emergency rescue is not solid. We must strengthen the aviation emergency rescue infrastructure to meet the high-intensity and high-density rescue flight support work

(2) Establish an aviation emergency rescue equipment guarantee system adapted to China's national conditions. Rescue equipment is the material basis of aviation emergency rescue. Aviation design rescue equipment mainly includes helicopters, rotorcraft, and unmanned aerial vehicles. The state should increase investment in the preresearch of models and technologies of various aircraft, solve the problem of rescue aircraft power, independently support airborne equipment, and actively guide enterprises to enter the field of manufacturing special equipment for aviation emergency rescue. Advanced equipment can be quickly put into rescue and protect people from danger

(3) Establish professional training bases. At present, China lacks a specialized aviation emergency rescue team, so the rescue forces are assembled from various departments, and the level of specialization is low, when carrying out rescue tasks. Thus, it is necessary to establish a professional training base to implement planned and systematic professional training for aviation emergency rescue teams

(4) Strengthen safety training of aviation emergency rescue. Safety training of aviation emergency rescue should be conducted regularly, including training courses and emergency drills. The content of the training course should provide trainees with basic rescue knowledge and work skill. Emergency drills can ensure that rescue team members can effectively deal with emergencies. By formulating emergency plans for emergencies and carrying out emergency drills, the shortcomings of the emergency rescue plans were discovered in time

However, the method of this study has certain limitations, such as when the consensus-based IAHP method is applied to compute index weight, the influence of human factor cannot be completely eliminated. Future research can use artificial neural network, rough set theory, and decision tree to calculate risk factor weight in aviation emergency rescue, making the results of risk assessment more objective.

Data Availability

The data used in this paper will be available upon request, please contact the corresponding author.

Conflicts of Interest

The authors claim no conflicts of interest.

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