# Evaluation of Emergency Management Capability for Railway Operation Emergencies Based on Variable Fuzzy Sets

**Bo Li, Yuan Liang, Delong Zou, Xiangyang Liu**

*Abstract*—**Considering the complexity and fuzziness of railway operation emergencies, this study proposes a variable fuzzy evaluation model to assess emergency management capability. Based on the four-stage emergency management framework—prevention, preparedness, response, and recovery—an index system consisting of 17 evaluation indicators for railway emergency management capability is established, with reference to the "dual prevention mechanism" for value assignment. To ensure scientific rigor and reliability, subjective weights obtained through Principal Component Analysis (PCA) are integrated with objective weights derived from the CRITIC method, thereby forming a combined subjective－objective weighting model. Using the "10・15" Beihe Railway passenger train derailment accident in Heilongjiang Province as a case study, four different parameter combinations of the variable fuzzy evaluation method are applied to calculate the grade characteristic values of emergency management capability. The results indicate that the evaluation level of emergency management capability for railway operation emergencies is Grade III (moderate), with potential for advancement to Grade II (stronger). Recommendations for enhancing the emergency management capability of railway operation emergencies are provided, thereby verifying the scientific validity and rationality of the proposed model.**

*Index Terms*—**railway operation emergencies; emergency management; combined weighting method; variable fuzzy evaluation.**

## I. INTRODUCTION[1]

In recent years, the scale of China’s railway network construction has been continuously expanding, accompanied by a growing demand for transportation. As a crucial component of the transportation system, the safe operation of railways is directly related to the safety of human lives, property, and social stability. However, various emergencies frequently occur during railway operations, such as natural disasters, equipment failures, and human-induced accidents. These incidents are often characterized by suddenness, uncertainty, and complexity, posing significant challenges to emergency management.

Extensive research has been conducted by scholars both in China and abroad on the evaluation of emergency management capability for railway emergencies. Balboa Adriana et al. [1] employed an intelligent emergency management system to receive information and detect different types of real-time railway emergencies, calculate evacuation processes, select and estimate routes, and facilitate communication with emergency service departments required for each incident, thereby supporting decision-making in railway emergencies. Luo Z. [2], focusing on the "7・23" Yong-Wen Line accident, analyzed the complete evolution process of railway emergencies based on complex network theory. Zhang Yue [3] applied the Functional Resonance Analysis Method (FRAM) to construct a system risk－accident evolution model for hazardous materials transportation accidents, analyzing the emergency response process driven by accident risk factors. Li Xiao [4] investigated the evolutionary patterns of railway emergencies using a Bayesian network approach. These studies provide valuable insights into the emergency management of railway operations, yet certain limitations remain.

Considering the complexity and fuzziness of influencing factors in railway emergency management, as well as the interrelationships among them, this study establishes a variable fuzzy evaluation model to assess emergency management capability in railway operations. Based on the four-stage model of railway emergency management, an index system of emergency management capability is developed. The "dual prevention mechanism" [5] is introduced as part of the value assignment criteria to quantify the evaluation indicators. To ensure the scientific rigor and reliability of the weighting process, subjective weights derived from Principal Component Analysis (PCA) are integrated with objective weights obtained through the CRITIC method, forming a combined subjective－objective weighting model that enhances comprehensiveness and accuracy. Finally, the proposed evaluation model is empirically validated through the analysis of the "10・15" Beihe Railway passenger train derailment accident in Heilongjiang Province, demonstrating its effectiveness.

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## II. CONSTRUCTION OF THE EMERGENCY MANAGEMENT CAPABILITY INDEX SYSTEM FOR RAILWAY OPERATION EMERGENCIES

Emergency management of railway incidents refers to the management process covering the entire life cycle of railway emergencies. At present, the emergency management cycle model is primarily based on crisis management research, with the widely recognized "four-stage" model comprising prevention, preparedness, response, and recovery [6]. Drawing on accident statistics of railway operation emergencies from recent years [7 – 10], and combined with relevant accident investigation reports, an index system for evaluating the emergency management capability of railway operation emergencies is established. This framework is developed with reference to the requirements of the Emergency Plan for Urban Rail Transit Operation Emergencies (JT/T1051-2016), particularly in aspects such as "organizational command system," "early warning and monitoring," "information reporting," and "emergency response," as well as the Regulations on Emergency Rescue, Investigation, and Handling of Railway Traffic Accidents [11]. The resulting evaluation system, as shown in Table 1, consists of 17 secondary indicators, each of which is defined independently.

**Table 1** Evaluation Index System for Emergency Management Capability of Railway Operation Emergencies

| Target Layer | Primary Indicator ($y_i$) | Secondary Indicator ($y_{ij}$) | Connotation of Secondary Indicator |
|---|---|---|---|
| Emergency management capability of railway operation emergencies | Emergency prevention and early warning capability | Risk assessment level | Ability of the assessment system to predict and identify potential emergencies, including the accuracy and comprehensiveness of risk identification, risk assessment, and risk classification. |
| | | Facility safety | Safety of railway facilities in design, construction, and maintenance, including the quality and safety assurance of critical infrastructure such as bridges, tunnels, and tracks. |
| | | Integrity of technical facilities | Degree of completeness and reliability of technical equipment used in railway operations, such as monitoring systems, communication devices, and signaling systems. |
| | Emergency preparedness capability | Organizational management capacity | Structure, role division, and coordination capability of emergency management organizations, including leadership, decision-making, and execution capacity. |
| | | Applicability and completeness of emergency plans | Coverage, applicability, and operability of emergency plans, ensuring effective guidance for different types of emergencies. |
| | | Frequency of training and drills | Frequency of training and drills related to emergency plans, enhancing the practical competence and response speed of emergency personnel through regular training and simulations. |
| | | Material reserve capacity | Status of emergency material reserves, including the quantity and quality of medical supplies, rescue equipment, and logistical support materials, as well as efficiency in material management and allocation. |
| | | Level of coordination mechanisms | Degree of collaboration among different departments and institutions, including information sharing, resource integration, and joint action capability. |
| | Emergency response capability | On-site communication and command assurance | Stability and effectiveness of on-site communication and command systems during emergencies, ensuring efficient coordination and resource deployment. |
| | | Emergency handling capacity | Capability of emergency teams in response and handling, including rapid reaction, decisive decision-making, and effective action. |
| | | Initiation of emergency response | Speed and procedure of initiating emergency response after an incident, including declaration of emergency status and rapid assembly of response teams. |
| | | Passenger resettlement efficiency | Effectiveness of passenger evacuation, resettlement, and basic living support measures following an emergency. |
| | | Timeliness and accuracy of information updates | Speed of information updates and transmission during emergencies, as well as the accuracy and transparency of information. |
| | Emergency recovery capability | Post-disaster repair and recovery capacity | Ability of the railway system to repair and recover after an incident, including the speed of infrastructure repair and restoration of normal operations. |
| | | Operation recovery capacity | Speed and effectiveness of restoring normal operations after an incident, ensuring the railway system returns to stable operation as quickly as possible. |
| | | Accident review and summarization capacity | Ability to summarize and reflect on the emergency response process, extracting lessons learned to provide reference for future emergency management. |
| | | Implementation of corrective measures through | Degree of implementation of corrective measures for problems identified during emergency response, including improvement of |

| Target Layer | Primary Indicator ($y_i$) | Secondary Indicator ($y_{ij}$) | Connotation of Secondary Indicator |
|---|---|---|---|
| | | feedback mechanism | feedback mechanisms and effectiveness of corrective actions. |

## III. Variable Fuzzy Evaluation Model for Emergency Management Capability of Railway Operation Emergencies

### A. PCA–CRITIC Combined Weighting Method

The PCA–CRITIC combined weighting method is a multi-criteria comprehensive evaluation approach that integrates Principal Component Analysis (PCA) with the CRITIC method, while employing the Lagrange multiplier method to optimize weight assignment and obtain comprehensive indicator weights. The purpose of this method is to optimize the combination of subjective and objective weights, thereby ensuring a more rational and scientifically sound distribution of indicator weights.

The Principal Component Analysis (PCA) is a multivariate statistical technique that determines the weights of principal components based on their contribution rates and uses factor loadings to establish the weights of evaluation indicators [12]. Given the sample set of railway operation emergency management capacity $\{y_j\}(j=1,2,\ldots,m)$ and the set of evaluation indicators $\{x_i\}(i=1,2,\ldots,n)$, the PCA method can be applied using Excel software to calculate subjective weights of evaluation indicators through the following steps:

① Data standardization: To avoid interference from expert scoring on indicator weights, actual sample data of evaluation indicators are selected for weight calculation. The sample data are standardized to obtain the score matrix Z

② Principal component analysis: First standardize the data; then perform PCA to obtain the component matrix $F=(f_{ij})$; select the principal components with cumulative variance $s_i$ exceeding 85% for calculation.

③ Calculate the comprehensive score for each indicator $D_i$, as shown in formula (1).

$$D_i=\frac{\sum_{i=1}^{t}\left(\frac{f_{ij}}{\sqrt{\lambda_j}}\right)s_i}{\sum_{i=1}^{t}s_i},(i=1,2,\cdots,n;j=1,2,\cdots,m) \quad (1)$$

Where: $t$ is the number of principal components obtained from PCA.

④ Calculate the subjective weights of indicators using the comprehensive score $D_i$ and the percentage method $\omega_{1i}$ .

⑤ Consult expert opinions to judge whether the indicator weight distribution is reasonable; if not, re-determine the scoring matrix and return to step ① until the weights are deemed reasonable.

The CRITIC weighting method is an objective approach for determining weights in multi-criteria evaluation problems. Its core idea is to reflect the intrinsic relationships among indicators through their variability and conflict[12]. Using the CRITIC method to determine the objective weights of evaluation indicators involves the following calculation steps:

① Calculate the information quantity of each evaluation indicator C , as shown in formula (2).

$$C_i=\upsilon_i\sum_{i=1}^{n}(1-|r_{ij}|),(i=1,2,\cdots,n) \quad (2)$$

Where: $v_i$ is the standard deviation coefficient used to reflect the variability of the indicator; $r_{ij}$ is the correlation coefficient among indicators used to reflect their conflict.

② Calculate the objective weights of indicators using the information quantity $C_i$ and the percentage method $\omega_{2i}$.

By using the Lagrangian multiplier method to optimize the combination weighting, it can effectively reduce the loss of effective information and make the weight distribution more aligned with actual conditions. The specific calculation is as follows:

① Determine the comprehensive weight of the combination weighting using the percentage method based on the product of subjective and objective weights $\omega_i'$ 。

② Combine the minimum information entropy principle to establish the constraint conditions for the comprehensive weight calculation, see formula (3).

$$\min E=\sum_{i=1}^{n}\omega_{1i}\left(\ln\frac{\omega_{1i}}{\omega_{2i}}\right)+\sum_{i=1}^{n}\omega_{2i}\left(\ln\frac{\omega_{2i}}{\omega_{1i}}\right) \quad (3)$$

③ Calculate the optimized comprehensive weight $\omega_i$ , see formula (4).

$$\omega_i=\frac{(\omega_{1i}\omega_{2i})^{1/2}}{\sum_{i=1}^{n}(\omega_{1i}\omega_{2i})^{1/2}} \quad (4)$$

### B. Variable Fuzzy Evaluation Method

The theory of variable fuzzy sets is built on the foundation of classical fuzzy set theory and is a quantitative analysis method for multi-indicator, multi-level evaluation problems. Let the evaluation sample of railway emergency management capability for sudden accidents be X , $x_{ij}$ representing the i -th primary indicator and the j -th evaluation index's characteristic value. According to the evaluation purpose, the domain V of each factor can be divided into k emergency management capability levels, and the standard value interval of the h-th emergency management capability factor is set as $[a_{ijh},b_{ijh}]$ , with the upper and lower bounds of this interval being $[c_{ijh},d_{ijh}]$. M Usually refers to the point value matrix with a relative membership degree of 1($\mu_A(x_{ijh})=1$) within the standard interval $[a_{ijh},b_{ijh}]$ . The attraction domain $I_{ab}$, the range domain $I_{cd}$, and the fully belonging point value matrix M of the variable fuzzy set for railway emergency management capability are respectively shown in formulas (5) ~ to (7).

$$I_{ab}=([a_{ijh},b_{ijh}]) \quad (5)$$

$$I_{cd}=([c_{ijh},d_{ijh}]) \quad (6)$$

$$M = \left(m_{ijh}\right) \tag{7}$$

In the formula, the element in the i -th row and h -th column of M is $m_{ijh}$. Based on $h$ , determine $m_{ijh}$ : when $h=1$ , $m_{i1}=a_{i1}$ ; when $h=k$ , $m_{ik}=b_{ik}$ ; when $1<h<k$ , $m_{ih}\in(a_{ih}, b_{ih})$ . α

If $x_{ij}$ falls to the left of $m_{ijh}$ value, the membership function of $x_{ij}$ relative to emergency management capability h is:

$$\mu_{Ah}(x_{ij}) = \begin{cases} 0.5\left(1+\dfrac{x_{ij}-a_{ijh}}{m_{ijh}-a_{ijh}}\right), x_{ij}\in[a_{ijh}, m_{ih}] \\ 0.5\left(1-\dfrac{x_{ij}-a_{ijh}}{c_{ijh}-a_{ijh}}\right), x_{ij}\in[c_{ijh}, a_{ijh}] \end{cases} \tag{8}$$

If $x_{ij}$ falls to the right of $m_{ijh}$ value, the membership function of $x_{ij}$ relative to emergency management capability h is:

$$\mu_{Ah}(x_{ij}) = \begin{cases} 0.5\left(1+\dfrac{x_{ij}-b_{ijh}}{m_{ijh}-b_{ijh}}\right), x_{ij}\in[m_{ijh}, b_{ih}] \\ 0.5\left(1-\dfrac{x_{ij}-b_{ijh}}{d_{ijh}-b_{ijh}}\right), x_{ij}\in[b_{ijh}, d_{ijh}] \end{cases} \tag{9}$$

According to formula (8)~(9) it can be determined that $x_{ij}$ the relative membership degree matrix for each level ${}_iU=\mu_{Ah}(x_{ij})$ , using the variable fuzzy evaluation method, formula (10), to calculate the comprehensive relative membership degree of level h .

$${}_i\mu_h = \left\{1+\left(\frac{\sum_{j=1}^{m}\left[\omega_{ij}\left(1-\mu_{Ah}(x_{ij})\right)\right]^P}{\sum_{j=1}^{m}\left[\omega_{ij}\mu_{Ah}(x_{ij})\right]^P}\right)^{-1}\right\} \tag{10}$$

Where: ${}_i\mu_h'$ the non-normalized relative membership degree of the i first-level indicator in the emergency management capability evaluation system for railway operation emergency incidents; $\omega_{ij}$ the weight of the j second-level indicator under the i first-level indicator; $\alpha$ -the model optimization criterion parameter; $P$ - the distance parameter (when $P$=1 : formula (10) is Hamming distance; when $P$=2 : formula (10) is Euclidean distance). After normalization, the final matrix of relative membership degrees ${}_iU_h=({}_i\mu_h)$ is obtained.

Applying the level characteristic value formula, the level characteristic value of the first-level indicator i is hi . Let $H=(h_1, h_2, \ldots, h_n)$ , then the calculation formula for the level characteristic matrix of emergency management capability H is shown in formula (11).

### C. Variable Fuzzy Evaluation Model

To effectively assess the level of emergency management capability for railway operation emergency incidents, a variable fuzzy evaluation model for emergency management capability is constructed. First, considering four aspects: emergency prevention and early warning capability, emergency preparedness capability, emergency response capability, and emergency recovery capability, an evaluation index system for railway operation emergency management capability is established; secondly, the PCA-CRITIC combined weighting method is used to obtain the comprehensive weights of each evaluation index, and the variable fuzzy evaluation method is employed to obtain the feature value vectors of each sample; finally, the level of railway operation emergency management capability is determined through the feature value vectors. The specific process is shown in Figure 1.

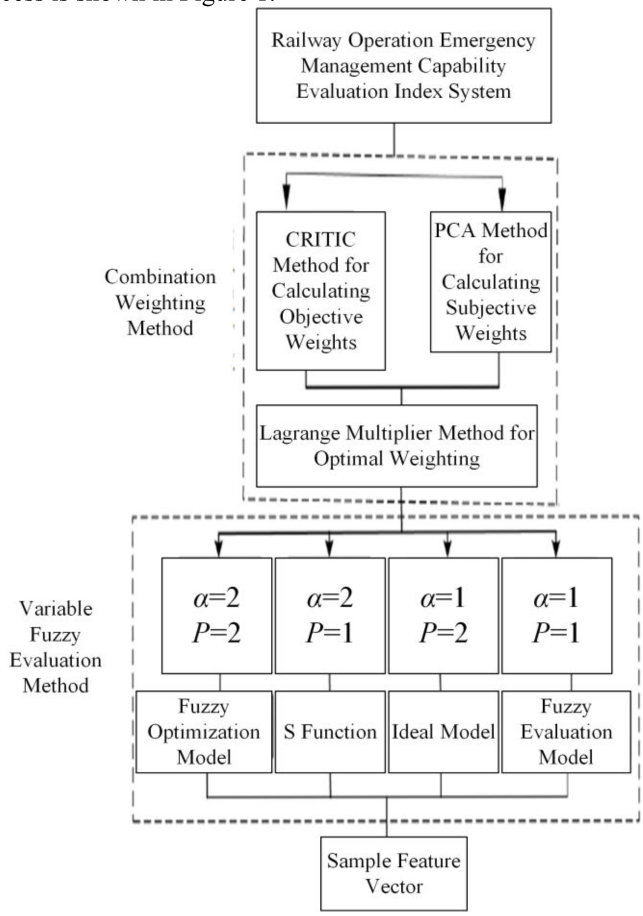


**Fig.1** Evaluation process of emergency management capability based on the variable fuzzy evaluation model

## IV. CASE ANALYSIS

### *A. Overview of the "10.15" Beibei Railway Passenger Train Derailment Accident*

On October 15, 2023, at 3:44 AM, train K5133 traveling from Harbin East to Heihe at a speed of 71 km/h collided with engineering vehicles that had derailed and encroached from the construction line between Sunwu North and Chaoshui stations on the Beibei line at kilometer 211.569. The collision caused the locomotive and cars 1 to 4 behind it to derail, resulting in a 10-hour and 1-minute interruption of railway operations on the Beibei line, constituting a major railway traffic accident.

After the accident occurred, the National Railway Administration and the Shenyang Railway Supervision and Administration Bureau immediately activated a Level 3 emergency response, dispatched personnel to the scene to coordinate and guide emergency rescue efforts, and organized investigations and handling of the accident. The Heihe City People ’ s Government promptly organized rescue operations, transferring and evacuating passengers and ensuring proper arrangements. Based on the actual situation of the accident and the accident report, three experts used the scoring criteria based on the "Dual Prevention Mechanism" to assign scores and obtain the evaluation indicator values, as shown in Table 2."

**Table 2** Sample indicator data for emergency management capability evaluation of railway emergency incidents

| Indicators | Expert 1 | Expert 2 | Expert 3 |
|---|---|---|---|
| $y_{11}$ | 57.5 | 55 | 60 |
| $y_{12}$ | 63 | 68.5 | 63.5 |
| $y_{13}$ | 61.5 | 69 | 72.5 |
| $y_{14}$ | 72 | 71 | 75.5 |
| $y_{21}$ | 81.5 | 88 | 83 |
| $y_{22}$ | 66 | 63.5 | 72 |
| $y_{23}$ | 75 | 71 | 73.5 |
| $y_{24}$ | 77 | 73.5 | 79 |
| $y_{31}$ | 81.5 | 85 | 75.5 |
| $y_{32}$ | 78 | 81.5 | 77.5 |
| $y_{33}$ | 80 | 77.5 | 74 |
| $y_{34}$ | 81 | 85.5 | 82 |
| $y_{35}$ | 79.5 | 78.5 | 72 |
| $y_{41}$ | 84 | 83.5 | 79 |
| $y_{42}$ | 77 | 80 | 80.5 |
| $y_{43}$ | 75 | 71 | 72.5 |
| $y_{44}$ | 60 | 63 | 67 |

The scoring criteria for the above indicators are based on relevant laws and regulations, such as the "Emergency Response Plan for Urban Rail Transit Operations Incidents" (JT/T1051-2016) and literature [13-15] , which assign values to on-site communication command support capabilities. The completeness of communication equipment is awarded 8 points; the reliability of communication system operation is awarded 7 points; emergency communication plans and drills are awarded 8 points; and the coordination of the command system is awarded 6 points. The total score is 29 points, which corresponds to 72.5 points on a percentage scale.

According to the "Railway Safety Risk Grading Control and Hidden Danger Investigation and Management Measures" and referencing the "Risk Grading Control" method within the "Dual Prevention Mechanism," the risk assessment ability of level 2 indicators is scored. The analysis is conducted using the collaborative risk four-color card (as shown in Table 3), where risk point identification in high-risk areas along the railway line scores 6 points (detailed scoring rules are in Table 4); the frequency and depth of railway section surveys score 7 points; the degree of system improvement for potential risks scores 8 points; and risk monitoring and updating scores 2 points. The total score is 23 points, which corresponds to 57.5 points on a percentage scale.

**Table 3** Risk Four-Color Card

| Risk Color Codes | Content |
|---|---|
| Red (High Risk) | Indicates immediate action is required; the risk significantly impacts safety, operations, environment, and other aspects. |
| Orange (Moderately High Risk) | Requires close attention and prompt handling; the risk poses a significant threat to railway operations or safety. |
| Yellow (Medium Risk) | Requires monitoring and standard controls; the risk has a certain impact on operations or safety. |
| Green (Low Risk) | The risk level is low; no special control measures are needed, but regular inspections are required. |

**Table 4** Risk Identification Scoring Rules

| Level | Content |
|---|---|
| Comprehensive (Full score 10 points) | All red, orange, yellow, and green risks have been identified. |
| Fairly comprehensive (8 points) | Most red, orange, and yellow risks have been identified, with a few green risks overlooked. |
| Moderate (6 points) | Main red and orange risks have been identified, but some yellow and green risks are missing. |
| Less (4 points) | Some red and orange risks are inadequately identified; yellow and green risks are not fully recognized. |
| Very few (2 points) | Very few red risks identified; many orange, yellow, and green risks are missed. |
| Not identified (0 points) | Risk identification is essentially not performed. |

### B. *Variable Fuzzy Evaluation Model Calculation*

Combining the above calculation steps, firstly subjective weighting is performed. Experts, based on their professional knowledge and experience, subjectively assign initial weights to different evaluation indicators through hazard source identification, and further adjust the weights in conjunction with the quantitative results of risk assessment. The standardized data of emergency management capability assessment for railway operation sudden events are subjected to principal component analysis in Excel software, resulting in the component matrix and variance explanation table. Using formula (1), the linear combination coefficient matrix of indicators and the comprehensive score of emergency management capability are calculated. The weights of each evaluation indicator are obtained via percentage method, and the reasonableness of the weight distribution is judged in conjunction with expert opinions. After expert verification, the subjective weight distribution is deemed reasonable, and no further adjustment is necessary. Next, the indicator data are combined with formula (2) to calculate the information content of each evaluation indicator, and the objective weights are obtained through the percentage method. Finally, using formula (3), the comprehensive weights are calculated with the Lagrangian multiplier method. Table 5 shows the results of the weight calculation for the second-level indicators.

**Table 5** Results of Weight Calculation for Emergency Management Capability of Railway Operation Sudden Events

| Method Indicators | PCA Method | CRITIC Method | Composite Weighting Method |
|---|---|---|---|
| $y_{11}$ | 0.198 | 0.188 | 0.204 |
| $y_{12}$ | 0.217 | 0.370 | 0.368 |
| $y_{13}$ | 0.212 | 0.299 | 0.311 |

| | | | |
|---|---|---|---|
| $y_{14}$ | 0.273 | 0.143 | 0.117 |
| $y_{21}$ | 0.263 | 0.461 | 0.205 |
| $y_{22}$ | 0.222 | 0.243 | 0.530 |
| $y_{23}$ | 0.245 | 0.144 | 0.097 |
| $y_{24}$ | 0.270 | 0.152 | 0.168 |
| $y_{31}$ | 0.242 | 0.173 | 0.375 |
| $y_{32}$ | 0.296 | 0.125 | 0.080 |
| $y_{33}$ | 0.045 | 0.260 | 0.161 |
| $y_{34}$ | 0.286 | 0.212 | 0.085 |
| $y_{35}$ | 0.131 | 0.231 | 0.299 |
| $y_{41}$ | 0.235 | 0.301 | 0.204 |
| $y_{42}$ | 0.278 | 0.173 | 0.104 |
| $y_{43}$ | 0.212 | 0.211 | 0.139 |
| $y_{44}$ | 0.275 | 0.315 | 0.553 |

The variable fuzzy evaluation method is used to determine the emergency management capability level of the "October 15" Beibei Railway passenger train derailment accident. Based on the accident report, combined with the "Urban Rail Transit Emergency Response Plan" (JT/T1051-2016) and literature [12-14], the domain of the emergency management capability level for this evaluation object is V = { Strong, Fairly strong, Average, Weak, Poor},The five levels of emergency management capability are denoted as I, II, III, IV, and V. Taking the evaluation sample from Expert 1 as an example, the variable fuzzy evaluation method is applied to calculate the emergency management capability level for this incident. Referring to Table 2, the feature value vector for the target evaluation indicators is as follows:

$$X_1=(x_{11},x_{12},x_{13},x_{14},x_{21},x_{22},x_{23},x_{24},x_{31},x_{32},x_{33},x_{34},x_{35},x_{41},x_{42},x_{43},x_{44})$$
$$=(57.5,63,61.5,72,81.5,66,75,77,81.5,78,80,81,79.5,84,77,75,60)$$

In this system, if the risk score intervals of all indicators are consistent, then the attraction domain of the risk evaluation's variable fuzzy set is $I_{ab}$=([0，60)[60，70)[70，85)[85，90)[90，100]), and the range domain is $I_{cd}$=([0，70)[0，85)[60，90)[70，100)[85，100]). Based on the indicator attraction domain intervals and the requirements of the relative membership function for the point value matrix, the point value matrices for the four levels of each indicator are determined as (mi1，mi2，mi3，mi4)=(0，65，77.5，87.5，100).

By calculating the point value matrix with a membership degree of 1, and then combining with the corresponding formula to compute the relative membership degree of each indicator to the stability level, the normalized membership degree matrix is obtained:

$$
{}_iu_h=\begin{bmatrix}
0 & 0 & 0 & 0.479 & 0.521\\
0 & 0 & 0.115 & 0.615 & 0.269\\
0 & 0 & 0.065 & 0.565 & 0.370\\
0 & 0.059 & 0.559 & 0.382 & 0\\
0 & 0.311 & 0.595 & 0.095 & 0\\
0 & 0 & 0.214 & 0.643 & 0.143\\
0 & 0.125 & 0.625 & 0.250 & 0\\
0 & 0.159 & 0.659 & 0.182 & 0\\
0 & 0.311 & 0.595 & 0.095 & 0\\
0 & 0.182 & 0.659 & 0.159 & 0\\
0 & 0.250 & 0.625 & 0.125 & 0\\
0 & 0.289 & 0.605 & 0.125 & 0\\
0 & 0.232 & 0.643 & 0.134 & 0\\
0 & 0.438 & 0.531 & 0.031 & 0\\
0 & 0.159 & 0.659 & 0.182 & 0\\
0 & 0.125 & 0.625 & 0.250 & 0\\
0 & 0 & 0 & 0.5 & 0.5
\end{bmatrix}
$$

Using the comprehensive weight values obtained from the above calculations, the overall relative membership degree of each indicator to the stability level under different parameter combinations is calculated using formula (5). The calculation results are shown in Table 6.

**Table 6** Comprehensive membership degrees of four evaluation models for level 1 indicators

| Level 1 indicators | $\omega_i$ | $\alpha$=1，$p$=1 | $\alpha$=1，$p$=2 | $\alpha$=2，$p$=1 | $\alpha$=2，$p$=2 |
|---|---|---|---|---|---|
| Emergency prevention and warning capability | 0.463 | 4.1697 | 4.1544 | 4.2097 | 4.2184 |
| Emergency preparedness capability | 0.240 | 3.4787 | 3.6236 | 3.5077 | 3.6999 |
| Emergency response capability | 0.203 | 2.8557 | 2.8418 | 2.8465 | 2.8316 |
| Emergency recovery capability | 0.094 | 3.6926 | 3.8942 | 3.7886 | 4.2067 |

Calculate the level feature value of each evaluation sample according to formula (6) H , and under different values of α and p , the H values of the target layer are 3.692、3.736、3.725、3.811 , with a deviation of only 0.119. The results are relatively stable, indicating that this model is stable and reliable. According to the evaluation $h+0.5\le H\le h+1$, $Tilted\ toward\ h-level$ , biased towards *h* level, it can be concluded that the four models' assessment results for the "10·15" Heilongjiang North Black Railway passenger train derailment railway traffic major accident emergency management capability level are all Level III (ordinary), and there is a trend towards Level II (moderate).

Based on expert scoring results of the emergency management capability for the "10·15" Heilongjiang North Black Railway passenger train derailment accident, and the emergency management capability level obtained through the variable fuzzy model, corresponding suggestions are proposed: establish and improve the passenger train risk assessment system; utilize big data and artificial intelligence technologies to enhance accident prediction and prevention capabilities; focus on summarizing experiences and implementing rectifications after accidents; continuously improve the emergency management mechanism to ensure rapid response and effective handling during emergencies, minimize accident losses and impacts, and ensure passenger safety.

## V. Conclusion

1) This paper constructs an evaluation index system containing 17 second-level indicators of emergency management capabilities for railway operation emergencies, considering the complexity and fuzziness of each capability as well as the interrelationships among influencing factors. The system evaluates emergency prevention and early warning ability, emergency preparedness, emergency response, and emergency recovery capabilities.
2) By introducing the "dual prevention mechanism" to assign values to the index system, and using a combined subjective and objective weighting model based on PCA and CRITIC methods integrated with the Lagrangian multiplier method, the process of combining and assigning weights to indicators is optimized, effectively reducing information loss and ensuring the scientificity and reliability of the evaluation results.
3) The empirical analysis of the evaluation index system for emergency management capabilities of railway emergency incidents based on the variable fuzzy evaluation model for the "10·15" Heilongjiang North Black Railway passenger train derailment shows that the emergency management capability level of this railway emergency incident is Level III (ordinary), with potential to develop towards Level II (moderate). This demonstrates the effectiveness of the model and provides scientific guidance for emergency management of railway emergencies.

## References


[1] Balboa Adriana, Abreu Orlando, González-Villa Javier, Alvear Daniel. Intelligent emergency management syste for railway transport[J]. Transportation Research Procedia, 2021, 58: 193-200.

[2] Luo Z., Li K., Xin M., et al. A New Accident Analysis Method Based on Complex Network and Cascading Failure [J]. Discrete Dynamics in Nature and Society, 2013, 2013(2): 1-9.

[3] Zhang Yue, Shuai Bin, Huang Wencheng, Zhang Rui, Lei Yu, Xu Minhao. Study on the Evolution Mechanism of Railway Dangerous Goods Transportation Accidents Based on FRAM[J]. Chinese Journal of Safety Science, 2020, 30(02): 171-176.

[4] Li Xiao. Emergency Decision-Making for Railway Sudden Incidents Based on Bayesian Networks and Case Reasoning[D]. Xi'an: Chang'an University, 2021.

[5] Editorial Board of China Democracy and Legal System Publishing House. The Latest Revised Version of the Production Safety Law of the People's Republic of China - Bulletin of the Standing Committee of the National People's Congress[M]. Beijing: China Democracy and Legal System Publishing House, 2021.06.

[6] Zhou Xianhu. Research on Emergency Decision-Making for Railway Sudden Incidents Based on CBR[D]. Chengdu: Southwest Jiaotong University, 2018.

[7] Li Shengnan, Yan Haifeng, Wu Pengfei, Liu Siqi, Wang Xiantian, Wang Di. Coupling Risk Analysis of Railway Operation Accidents Based on N-K Model[J]. Modern Urban Rail Transit, 2023, (11): 103-109.

[8] Wei Qingchao, Chu Zhijie, Pan Zihua. Emergency Rescue Analysis of Operational Risks and Accidents in Low- and Medium-Speed Maglev Railways[J]. Urban Rail Transit Research, 2021, 24(05): 15-20.

[9] Gao Ningbo, Hu Qizhou, Zhang Bing, Zheng Liyuan. Data Classification-Based Prediction Method for High-Speed Railway Operational Accidents[J]. Transportation Information and Safety, 2015, 33(01): 71-78.

[10] Li Jingjing. Quantitative Study on Emergency Response Evaluation for High-Speed Railway Passenger Transport[D]. Beijing: China Academy of Railway Sciences, 2022.

[11] Legal Office of the State Council. Regulations on Emergency Rescue and Investigation of Railway Traffic Accidents[M]. Beijing: China Railway Publishing House, 2012.03.

[12] Li Jiahao, Xie Wanli, Yan Ming, Liu Qiqi, He Gaorui. Risk Assessment of Geological Disasters Based on PCA and Improved AHP-CRITIC Method: A Case Study of Shenmu City[J]. Journal of Earth Environment, 2023, 14(04): 472-487.

[13] Song Guoce, Wang Gaolei, Lu Dawei, Zhou Wenming. Risk Assessment Model and Application of External Environmental Safety Hazards in Railways Based on ISM-ANP[J]. Railway Transportation and Economy, 1-8.

[14] Yang Yixuan. Causal Analysis of Railway Traffic Accidents Based on HFACS and Apriori Algorithm[D]. Beijing: Beijing Jiaotong University, 2022.

[15] Nan Dongwei. Research on High-Speed Railway Operational Safety Based on Multi-Risk Coupling[D]. Lanzhou: Lanzhou Jiaotong University, 2020.


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