

Research on risk assessment of high-speed railway operation based on network ANP

High-speed
railway
operation

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Abstract

Purpose – The causes of high-speed railway failures are complex, and it is difficult to quantitatively and accurately describe safety evaluation. The purpose of this paper is to construct a model to ensure the safety of high-speed railway operations.

Design/methodology/approach – The authors construct a high-speed railway operation safety evaluation index system from four aspects: personnel, equipment, environment and management and analyze the inter-coupling relationship of various safety factors. Based on the evaluation index system, the use of network analytic hierarchy process (ANP) and fuzzy comprehensive evaluation will be used to establish a high-speed railway operation safety evaluation model.

Findings – Through the literature investigation and field investigation, combined with high-speed railway safety key points and system composition, 4 first-level indicators and 17 second-level indicators were selected to construct a high-speed railway operation safety evaluation index system. It can be seen from the results that the personnel management system and the signal and control system have the largest weight.

Originality/value – On the basis of establishing an evaluation index system, comprehensively considering the internal coupling relationship between evaluation indexes and the fuzziness of high-speed railway operation safety evaluation, high-speed railway uses ANP fuzzy network analysis method to construct high-speed railway operation, and the safety evaluation model has certain advantages and practicability in the case of the relative lack of high-speed railway operation data and fault data.

Keywords High-speed railway, Influencing factors, Fuzzy comprehensive evaluation, Network analytic hierarchy process, Safety evaluation

Paper type Research paper

1. Introduction

As of the end of 2018, the mileage of China's high-speed railways that have been built and put into operation reached more than 29,000 km, accounting for more than 66% of the world's high-speed railway operating mileage. Although China's high-speed railway construction has made world-renowned achievements, it still needs to be improved in terms

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of operation management and safety assurance. High-speed railway operation safety assessment and risk management have received more and more value and attention.

As an important part of system engineering, safety evaluation aims to make a quantitative estimate or qualitative description of the damage or potential risk sources that the system or engineering may suffer in operation. The high-speed railway system is complicated in composition, and the normal operation of its power supply system, signal and communication system, wheel–rail system and control system are all related to the safe operation of the train. In addition, high-speed railways are also vulnerable to weather conditions, human interference and other factors during operation. At present, many experts and scholars in the field of safety at home and abroad use different methods and models to study and analyze the safety of high-speed railway operations: [Guo *et al.* \(2016\)](#) studied the impact of the personality characteristics of high-speed rail train drivers on driving safety, using the NEO personality scale and 221 high-speed train drivers of the original Beijing Railway Bureau were surveyed by questionnaires in this way, and the results of the survey were analyzed by modeling. [Qian *et al.* \(2019\)](#) used FLAC3D modeling software to analyze the stratum settlement characteristics when the high-speed railway line and the subway tunnel intersect at different angles, to study the impact of stratum settlement on the safety of the high-speed railway during tunnel excavation; [Xu *et al.* \(2019\)](#) analyzed the impact of axle fatigue damage on high-speed railway operation safety. The impact of railway operation safety is evaluated by analyzing the depth of scratches on the axle surface to evaluate the impact of scratches on fatigue performance. [Shi and Jian \(2018\)](#) used the analytic network process (ANP) and evidence theory to evaluate the risk level of wireless block centers. The above research mainly focuses on the impact of personnel, external environment, key equipment and other single factors on the safety of high-speed railways, without systematically summarizing and analyzing the risk factors. [Lisha *et al.* \(2015\)](#) established a safety situation evaluation model based on the construction of an urban rail transit station safety situation evaluation index system, using analytic hierarchy process (AHP) and entropy method. However, the AHP method ignores the coupling relationship between the evaluation indicators and is not completely applicable to the complex high-speed railway system. As an improvement and upgrade method of the AHP method, the ANP takes the interaction and mutual influence between indicators into account and has a wider applicability. ANP method has been more maturely used in risk evaluation ([Wang and Jianbin, 2019](#)), project bidding ([Chen *et al.*, 2018](#)), capability evaluation ([Wu *et al.*, 2018](#); [Qin, 2018](#); [He *et al.*, 2018](#)) and other fields.

Combined with the research foundation of relevant safety evaluation methods, the ANP is used to first sort out the many safety factors that affect the safe operation of high-speed railways, summarize the safety factor index system and systematically analyze the coupling relationship between the safety factors, and then use the ANP to obtain the contribution degree of each safety factor to the operation safety of the high-speed railway, and finally uses the fuzzy comprehensive evaluation method to make a comprehensive evaluation of the operation safety level of the high-speed railway.

2. Analysis of safety index of high-speed railway

Through consulting related literature ([Sishuai, 2011](#); [Feng *et al.*, 2013](#)) and going to several railway bureau group companies for field investigations, the factors affecting the safety of high-speed railway operations are divided into four aspects: personnel, equipment, environment and management. The four factors are coupled and influence each other, and jointly affect the safety of high-speed railway operations.

2.1 Evaluation index analysis

The factors affecting the safety of high-speed railway operations are analyzed from the four aspects of personnel, equipment, environment and management.

Personnel factors not only refer to the staff of various functional departments such as train depot, locomotive depot, public works depot and electricity depot during the operation of high-speed railway, but also include management personnel and technical operators at all levels, as well as passengers of high-speed rail trains. The staff is the main body of various tasks. The staff's safety literacy, business ability, vocational skills, response capability and emergency response capability in response to emergencies all affect the safe driving of high-speed railways. Combining the work characteristics of each train station on the high-speed railway, the safety factors of staff are divided into safety literacy and business level. Passengers are the main body of high-speed rail transportation services. Passengers' improper behavior when taking the high-speed rail trains, such as smoking triggering a smoke alarm and causing the train to stop temporarily, will also affect the safe operation of high-speed rail trains.

There are many types of equipment involved in the operation of high-speed railways, with high complexity and coupling. At the same time, the working environment of high-speed railways is outdoor, and various equipment are easily affected by natural environmental factors. Therefore, ensuring the normal operation and good operation of the equipment is the key to ensuring driving safety. The fixed infrastructure and mobile equipment involved in the operation of high-speed railways include tracks, wheel-rail systems, traction power supply systems, signal systems and communication systems. The track is a fixed infrastructure for high-speed railway operation. The smoothness of the track and track surface conditions directly affect the stability of the train and the comfort of passengers. The traction power supply system transports electric energy for electrified railways, and the main equipment includes the catenary system, traction substation and data acquisition and monitoring and control system. Among them, the catenary system is laid in the open air along the railway and has a complex structure, so the failure rate is higher. The high-speed train signal and control system is an important guarantee for the safety and efficiency of trains. It mainly includes the train control system, the dispatching centralized system and the station interlocking. The railway communication system is a system that realizes special railway communication services. The current high-speed railway communication system uses the GSM-R digital mobile communication system that has stricter requirements in terms of wireless field strength coverage, network service quality and reliability.

Environmental factors can be divided into natural environment and social environment. The natural environment includes weather conditions (including strong winds, rainstorms, blizzards, etc.), geological disasters (including mudslides, landslides, earthquakes, etc.), special soil sections (collapsible loess, expansive soil, etc.), etc. The social environment refers to the political, legal, economic and public security environment in social operations.

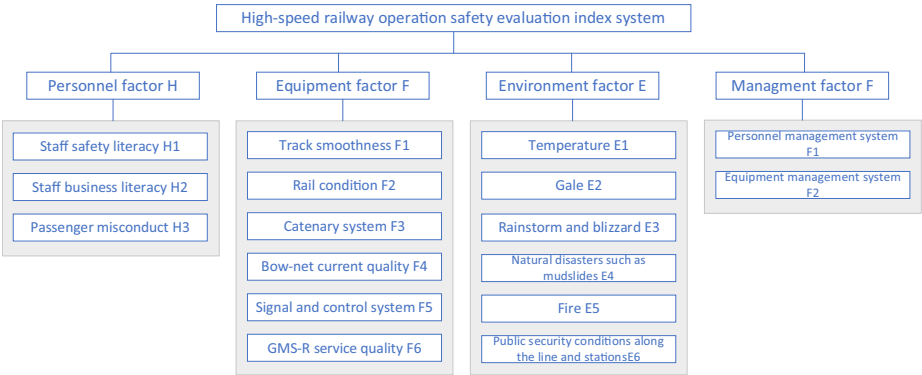
Management plays the role of planning, leading, organizing and coordinating in the operation of high-speed railways. A scientific and reasonable management system can make various tasks more efficient and orderly, thereby ensuring the safety of train operations. Combined with the characteristics of high-speed railway operations, the management system can be divided into personnel management system and equipment management system.

Based on the above analysis, the four main aspects of safety factors are further divided to construct a high-speed railway operation safety evaluation index system (Figure 1), including 4 first-level safety indicators and 17 second-level safety indicators, for the establishment of a safety evaluation model basis.

2.2 Analysis of coupling relationship of evaluation indexes

After the evaluation index system is established, the coupling relationship between the indexes should be analyzed and judged. The evaluation indicators are not independent of each other, but there are certain dependencies and feedback relationships. For example, the staff's low level of business may lead to improper

Figure 1.
High-speed railway
operation safety
evaluation indicators



operation of the equipment and cause vehicle failure; when the temperature changes, the tension and sag of the catenary will change with the thermal expansion and contraction, which will affect the quality of bow net of the flow; the public security disorder at the station may cause fire safety hazards; the control of the train system will take emergency measures such as automatic speed reduction and temporary parking to avoid safety accidents when encountering disasters such as heavy rain or snow or a collapse in front. By referring to relevant materials (Renchao and Dengbo, 2017) and consulting experts and scholars in related fields, the coupling relationship between the evaluation indicators is determined in Table 1.

3. Evaluation model construction

3.1 Network analytical process

The ANP is a comprehensive system evaluation method developed by T.L.Saaty on the basis of the AHP. The structure of ANP mainly consists of two parts, one is the control layer, which contains

Impact indicators		Affected indicators
Personnel factor H	H_1	H_2, E_5, E_6
	H_2	$H_1, F_1, F_2, F_3, F_4, F_5, F_6, E_5$
	H_3	F_2, F_5, E_5, E_6
Equipment factor F	F_1	F_1, F_2, F_4
	F_2	F_1, F_2, F_4
	F_3	F_4, F_6, E_5
	F_4	F_3, F_6
	F_5	$F_5, F_6, E_1, E_2, E_3, E_4, E_5, E_6$
	F_6	F_5
Environment factor E	E_1	F_1, F_3, E_2, E_5
	E_2	F_3, E_5
	E_3	F_2, F_3, F_6, E_4, E_5
	E_4	F_1, F_2, F_3, F_6
	E_5	F_2, F_3, F_4, E_6
	E_6	F_2, E_5, E_6
Management factor M	M_1	H_1, H_2, E_6
	M_2	$F_1, F_2, F_3, F_4, F_5, F_6$

Table 1.
Evaluation indicators
coupling relationship

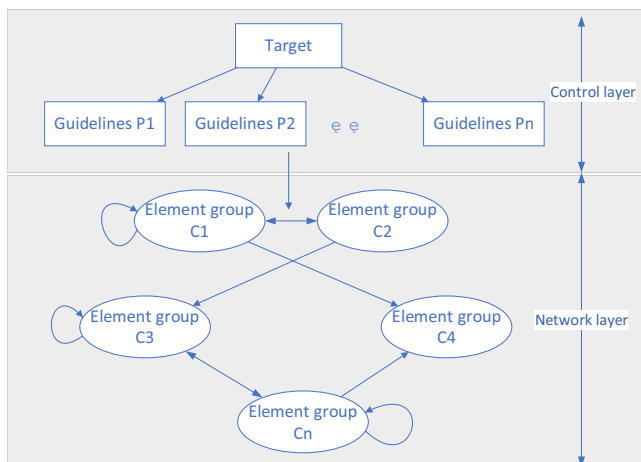


Figure 2.
ANP typical structure

goals and guidelines; the other is the network layer, the elements of the network layer are not independent, there is interaction and mutual influence (Figure 2). Compared with AHP, the hierarchical structure of ANP is more complex, not only a hierarchical structure, and at the same time, it also considers the loop and feedback between hierarchical structures, as well as the interdependence and dominance of internal elements at the same level. Therefore, for high-speed railway systems with complex obstacle causes and a coupling relationship between safety factors, ANP is used to determine the relative importance of each evaluation index, that is, the size of the weight, which is more suitable and advantageous than AHP.

Assuming that there are N element groups in the network layer, first take e_{ik} ($i = 1 \dots N$; $k = 1 \dots n$) in the element group C_i as the sub-criteria to construct the element e_{jl} ($j = 1 \dots n$; $l = 1 \dots m$) to compare the relative importance of e_{ik} , that is, the judgment matrix, and the ranking vector $(w_{j1}^{(ik)}, w_{j2}^{(ik)}, \dots, w_{jl}^{(ik)}, \dots, w_{jm}^{(ik)})^T$ is obtained by the characteristic root method, and $\sum w_{ji}^{(ik)} = 1$. By analogy, the ranking vector of the elements in the element group C_j to all the elements in C_i can be obtained, so that we can obtain the ranking matrix W_{ij} . If the elements in the element group C_i are not affected by C_j , then $W_{ij} = 0$:

$$W_{ij} = \begin{bmatrix} w_{j1}^{(i1)} & w_{j1}^{(i2)} & \dots & w_{j1}^{(ik)} & \dots & w_{j1}^{(in)} \\ w_{j2}^{(i1)} & w_{j2}^{(i2)} & \dots & w_{j2}^{(ik)} & \dots & w_{j2}^{(in)} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ w_{jl}^{(i1)} & w_{jl}^{(i2)} & \dots & w_{jl}^{(ik)} & \dots & w_{jl}^{(in)} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ w_{jm}^{(i1)} & w_{jm}^{(i2)} & \dots & w_{jm}^{(ik)} & \dots & w_{jm}^{(in)} \end{bmatrix}$$

There are $N \times N$ such sorting matrices, and the super-matrix W is obtained by forming sub-blocks of the sorting matrix. The core work of ANP is to solve the super matrix:

$$W = \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1N} \\ W_{21} & W_{22} & \cdots & W_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ W_{N1} & W_{N2} & \cdots & W_{NN} \end{bmatrix}$$

It can be seen from the above definition that the column vector of the super matrix sub-block W_{ij} is normalized, but the column vector of the super matrix W is not normalized. Therefore, it is also necessary to perform weighting processing on the super matrix, that is, to compare the element groups in pairs to obtain the judgment matrix and pass the consistency test, and obtain the normalized eigenvector by the eigen-root method, thereby obtaining the weighting matrix A' :

$$A' = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1N} \\ a_{21} & a_{22} & \cdots & a_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ a_{N1} & a_{N2} & \cdots & a_{NN} \end{bmatrix}$$

From $-W = A \times W$, the weighted hypermatrix $-W$ is obtained. Finally, when $W^\infty = \lim_{t \rightarrow \infty} -W^t$ exists, the limit supermatrix W^∞ is obtained.

3.2 Fuzzy comprehensive evaluation

In the objective world, there are many phenomena with uncertain nature, and these undefined phenomena are called fuzzy phenomena. In engineering applications, there are also a large number of factors and indicators that are restricted by various factors and difficult to quantify. Fuzzy comprehensive evaluation is based on fuzzy mathematics, according to the theory of membership degree and the principle of fuzzy composite operation, quantitatively evaluate many indicators with unclear boundaries, and then make a systematic overall evaluation of fuzzy phenomena (Du *et al.*, 2015).

First of all, it is necessary to establish the factor set U and the comment set V of the evaluation object based on experience and relevant research data. $U = \{u_1, u_2, \dots, u_m\}$, m is the number of evaluation indicators; $V = \{v_1, v_2, \dots, v_n\}$, n is the number of evaluation levels.

According to the membership degrees of m evaluation factors to n evaluation levels, a fuzzy relationship matrix R is constructed:

$$R = ((r_{ij})_{m \times n}) = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}$$

In the formula, r_{ij} is the degree of membership of the evaluation factor u_i on the evaluation level v_j , that is, the frequency distribution, which is generally normalized so that $\sum r_{ij} = 1$.

After obtaining the fuzzy relationship matrix R , it is necessary to judge the relative importance of each evaluation factor, and obtain the evaluation factor weight distribution set A , $A = \{a_1, a_2, \dots, a_i, \dots, a_m\}$, where a_i represents the proportion of evaluation factor u_i in the factor set, and $\sum a_i = 1$.

Use the weight vector A to perform fuzzy synthesis operation on the fuzzy relationship matrix to obtain the fuzzy subset B of the membership degree of the evaluation target at each evaluation level, $B = A \times R = \{b_1, b_2, \dots, b_j, \dots, b_n\}$, where b_j represents the membership degree of the evaluation target on the evaluation level v_j . $\times$ is the symbol of composite operation. Generally, there are different fuzzy composite operation methods such as search operator and ordinary matrix multiplication.

According to the principle of maximum degree of membership, the final evaluation result is obtained, and the largest in b_j is the evaluation level of the evaluation target.

4. High-speed railway operation risk assessment method based on analytic network process

The ANP considers the interaction and mutual influence between indicators and then determines the weight of each safety factor, taking into account the complexity of the evaluation object. According to the analysis of the coupling relationship between the evaluation factors, the ANP network layer structure is established (Figure 3).

4.1 Determination of the weights of first-level risk factors

According to the Saaty 1–9 scale (Table 2), and compare the relative importance of the first-level evaluation factors in pairs, the judgment matrix is constructed according to expert judgment (Table 3). Through the consistency test, the weight of each factor is obtained.

4.2 Determination of the weights of second-level risk factors

Using the Saaty1–9 scale table, the relative importance of each evaluation factor is compared in pairs by means of expert scoring, and a pairwise comparison matrix is obtained. Then use the decision-making software Super Decision to establish a judgment matrix and pass the consistency test. The ranking vector is obtained by the eigen-root

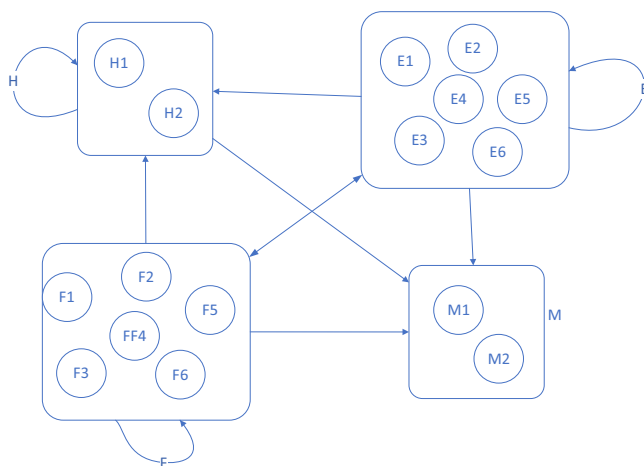


Figure 3.
ANP model network
layer structure

method, and then establish the ranking matrix, then the unweighted super matrix is calculated (Table 4).

The weighted super matrix is obtained by weighting the corresponding secondary evaluation factors (Table 5). Finally, perform the limit operation on the weighted super matrix to obtain the limit super matrix (Table 6). The weights of the primary evaluation factors and secondary evaluation factors are shown in Figures 4 and 5, respectively. After normalizing the weight of each evaluation factor, the weight vector *A* of the factor set is obtained:

$$A = (0.051, 0.108, 0.053, 0.011, 0.006, 0.044, 0.046, 0.180, 0.114, 0.013, 0.007, 0.046, 0.008, 0.021, 0.009, 0.235, 0.049)$$

It can be seen from Figure 4 that the first-level factor that has the greatest impact on the safety of high-speed railway operations is the equipment factor, followed by the management factor. The high-speed railway system has a complex structure and high degree of coupling and involves many types of equipment elements and a high degree of automation. Therefore, ensuring the normal operation of equipment is the key to ensuring the safety of high-speed railway operations; management elements are the dominant factors for overall coordination of personnel, equipment, environment and other factors, and management is the dominant factor in the overall planning of man-machine-environment. Therefore, a sound, scientific, reasonable and efficient management system can reduce the risk of the other three safety factors, thereby ensuring the safety of high-speed rail.

From Figure 5, we can see that the two secondary factors, the personnel management system and the signal and control system, have the greatest impact on the safety of high-speed railway operations. The personnel management system ensures that the staff of various departments and levels carry out various tasks in a safe, orderly and efficient

Table 2.
Saaty 1–9 scale table

Serial number	Importance level	Value
1	<i>i</i> and <i>j</i> are equally important	1
2	The <i>i</i> element is slightly more important than the <i>j</i> element	3
3	The <i>i</i> element is obviously more important than the <i>j</i> element	5
4	The <i>i</i> element is more important than the <i>j</i> element	7
5	The <i>i</i> element is extremely important than the <i>j</i> element	9
6	The <i>i</i> element is slightly less important than the <i>j</i> element	1/3
7	The <i>i</i> element is obviously less important than the <i>j</i> element	1/5
8	The <i>i</i> element is less important than the <i>j</i> element	1/7
9	The <i>i</i> element is extremely less important than the <i>j</i> element	1/9

Table 3.
First-level risk factor
weight judgment
matrix

Risk factor	<i>H</i>	<i>F</i>	<i>E</i>	<i>M</i>
<i>H</i>	0.250	0.208	0.084	0
<i>F</i>	0	0.462	0.438	0
<i>E</i>	0	0.251	0.423	0
<i>M</i>	0.750	0.078	0.055	0

Risk factors	H			F						E			M					
	H ₁	H ₂	H ₃	F ₁	F ₂	F ₃	F ₄	F ₅	F ₆	E ₁	E ₂	E ₃	E ₄	E ₅	E ₆	M ₁	M ₂	
H	H ₁	0	1.000	0	0	0	0	0	0	0	0	0	0	0.750	0.167	0	0	
	H ₂	1.000	0	0	1.000	0.750	1.000	1.000	0.250	1.000	0	0	0	0	0	0	0	
	H ₃	0	0	0	0	0.250	0	0	0.750	0	0	0	0	0.250	0.833	0	0	
	F ₁	0	0	0	0.833	0.333	0	0.135	0	0	0	0	0	0	0	0	0	
	F ₂	0	0	0	0.167	0.667	0	0.081	0	0	0	0	0	0	0	0	0	
	F ₃	0	0	0	0	0	0	0.784	0	0.250	0	0	0	0	0.250	0	0	
F	F ₄	0	0	0	0	0	1.000	0	0	0.250	0	0	0	0	0	0	0	
	F ₅	0	0	0	0	0	0	0.250	0.500	1.000	1.000	1.000	1.000	0.750	1.000	0	0	
	F ₆	0	0	0	0	0	0	0.750	0	0	0	0	0	0	0	0	0	
	E ₁	0	0	0	0.750	0	0.188	0	0	0	1.000	0	0	0.149	0	0	0	
	E ₂	0	0	0	0	0	0.371	0	0	0	0	0	0	0.143	0	0	0	
	E ₃	0	0	0	0	0.632	0.345	0	0	0.833	0	0	0	1.000	0.078	0	0	
E	E ₄	0	0	0	0.250	0.214	0.041	0	0	0.167	0	0	0	0	0	0	0	
	E ₅	0	0	0	0	0.052	0.056	1.000	0	0	0	0	0	0	0	0	0	
	E ₆	0	0	0	0	0.102	0	0	0	0	0	0	0	0.629	0.833	0	0	
	M ₁	1.000	1.000	0	0	0	0	0	0	0	0	0	0	0	0.167	0	0	
	M	M ₁	1.000	1.000	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0
		M ₂	0	0	0	1.000	1.000	1.000	1.000	1.000	0	0	0	0	0	0	0	0

Table 4.
Unweighted overrun
super matrix of
secondary risk
factors relative to
primary risk factors

Table 5.
Weighted overrun
super matrix of
secondary risk
factors relative to
primary risk factors

Risk factors	H			F						E			M					
	H ₁	H ₂	H ₃	F ₁	F ₂	F ₃	F ₄	F ₅	F ₆	E ₁	E ₂	E ₃	E ₄	E ₅	E ₆	M ₁	M ₂	
H	H ₁	0	0.250	0	0	0	0	0	0	0	0	0	0	0.067	0.014	0	0	
	H ₂	0.250	0	0	0.209	0.156	0.209	0.209	0.070	0.209	0	0	0	0	0	0	0	
	H ₃	0	0	0	0	0.052	0	0	0.209	0	0	0	0	0.022	0.070	0	0	
	F ₁	0	0	0	0.385	0.154	0	0.062	0	0	0	0	0	0	0	0	0	
	F ₂	0	0	0	0.077	0.308	0	0.038	0	0	0	0	0	0	0	0	0	
	F ₃	0	0	0	0	0	0	0.362	0	0.116	0	0	0	0	0.116	0	0	
F	F ₄	0	0	0	0	0	0.462	0	0.116	0	0	0	0	0	0	0	0	
	F ₅	0	0	0	0	0	0	0.154	0.231	1.000	0.508	1.000	0.508	0.347	0.438	0	0	
	F ₆	0	0	0	0	0	0	0.463	0	0	0	0	0	0	0	0	0	
	E ₁	0	0	0	0.188	0	0.047	0	0	0	0.492	0	0	0.067	0	0	0	
	E ₂	0	0	0	0	0	0.093	0	0	0	0	0	0	0.064	0	0	0	
	E ₃	0	0	0	0	0.159	0.087	0	0	0.209	0	0	0	0.035	0	0	0	
E	E ₄	0	0	0	0.063	0.054	0.010	0	0.042	0	0	0	0.492	0.035	0	0	0	
	E ₅	0	0	0	0	0.013	0.014	0.251	0	0	0	0	0	0	0	0	0	
	E ₆	0	0	0	0	0.026	0	0	0	0	0	0	0	0	0.353	0	0	
	M ₁	0.750	0.750	0	0	0	0	0	0	0	0	0	0	0.282	0.071	0	0	
	M	M ₂	0	0	0	0.078	0.078	0.078	0.078	0.105	0.078	0	0	0	0	0.055	0	0
			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

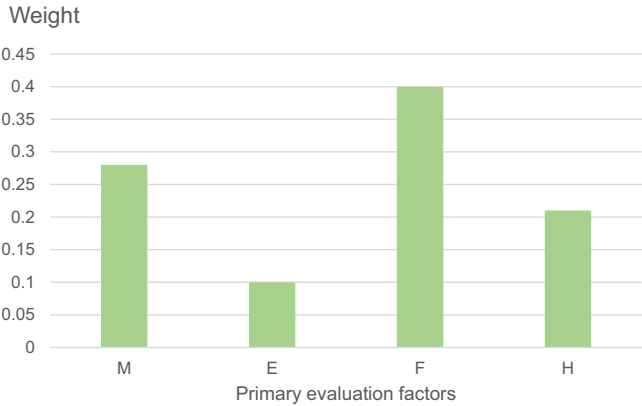
Risk factors	H			F						E			M				
	H ₁	H ₂	H ₃	F ₁	F ₂	F ₃	F ₄	F ₅	F ₆	E ₁	E ₂	E ₃	E ₄	E ₅	E ₆	M ₁	M ₂
H	H ₁	0.125	0	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0	0
	H ₂	0.125	0	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0	0
	H ₃	0	0	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0	0
F	F ₁	0	0	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0	0
	F ₂	0	0	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0	0
	F ₃	0	0	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0	0
E	F ₄	0	0	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0	0
	F ₅	0	0	0.210	0.210	0.210	0.210	0.210	0.210	0.210	0.210	0.210	0.210	0.210	0.210	0	0
	F ₆	0	0	0.133	0.133	0.133	0.133	0.133	0.133	0.133	0.133	0.133	0.133	0.133	0.133	0	0
E	E ₁	0	0	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0	0
	E ₂	0	0	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0	0
	E ₃	0	0	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0	0
M	E ₄	0	0	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0	0
	E ₅	0	0	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0	0
	E ₆	0	0	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0	0
M	M ₁	0.750	0.750	0	0.149	0.149	0.149	0.149	0.149	0.149	0.149	0.149	0.149	0.149	0.149	0	0
	M ₂	0	0	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0	0

Table 6.
Weighted over-limit
super matrix of the
secondary risk
factors relative to the
primary risk factors

Table 7.
Frequency
distribution of
survey results

Factor	Expert comment			
	V_1	V_2	V_3	V_4
H_1	6	4	4	1
H_2	2	9	3	1
H_3	6	8	1	0
F_1	3	8	4	0
F_2	6	5	1	3
F_3	5	3	5	2
F_4	5	4	6	0
F_5	6	4	3	2
F_6	3	5	7	0
E_1	9	5	1	0
E_2	4	8	3	0
E_3	4	4	6	1
E_4	11	4	0	0
E_5	8	5	2	0
E_6	10	5	0	0
M_1	3	5	5	2
M_2	5	3	5	2

Figure 4.
Weight distribution
of primary evaluation
factors



manner; the signal and control system of high-speed trains is mainly used for dispatching and commanding and automatic control of trains. At the same time, when the train encounters severe weather, sudden natural disasters or platform emergencies, the train control system can take corresponding measures to avoid accidents, so it is the core technical equipment to ensure safe driving and improve operational efficiency.

4.3 Determine the evaluation matrix

To illustrate the practical application of the fuzzy network analysis method, a calculation example is provided for reference. For the high-speed railway line S, a total of 15 experts were invited to determine the degree of S subordination to the comment set V based on 17 secondary evaluation factors. A total of 15 questionnaires were issued, 15 questionnaires were returned, and 15 valid questionnaires were received. The recovery rate and effective rate were both 100%. The reliability test coefficient of the questionnaire results Cronbach's

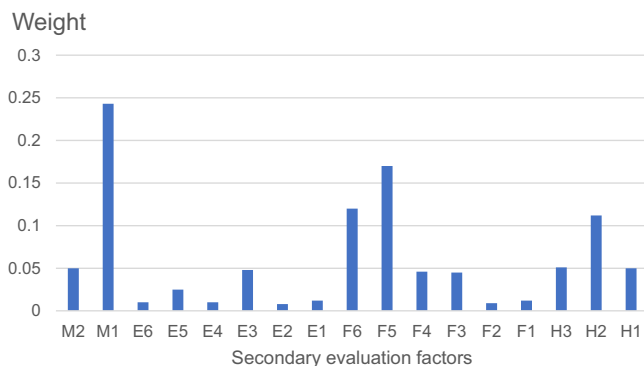


Figure 5.
Weight distribution
of secondary
evaluation factors

$\alpha = 0.809 > 0.800$, indicating that the questionnaire is internally consistent. The frequency distribution of expert questionnaire survey results is shown in [Table 6](#).

According to the frequency distribution table of the statistical survey results, the evaluation matrix R is obtained:

$$R = \begin{matrix} & \begin{matrix} V_1 & V_2 & V_3 & V_4 \end{matrix} \\ \begin{matrix} H_1 \\ H_2 \\ H_3 \\ F_1 \\ F_2 \\ F_3 \\ F_4 \\ F_5 \\ F_6 \\ E_1 \\ E_2 \\ E_3 \\ E_4 \\ E_5 \\ E_6 \\ M_1 \\ M_2 \end{matrix} & \left[\begin{array}{cccc} 0.400 & 0.267 & 0.267 & 0.067 \\ 0.133 & 0.600 & 0.200 & 0.067 \\ 0.400 & 0.533 & 0.067 & 0 \\ 0.200 & 0.533 & 0.267 & 0 \\ 0.400 & 0.333 & 0.067 & 0.200 \\ 0.333 & 0.200 & 0.333 & 0.133 \\ 0.333 & 0.267 & 0.400 & 0 \\ 0.400 & 0.267 & 0.200 & 0.133 \\ 0.200 & 0.333 & 0.467 & 0 \\ 0.600 & 0.333 & 0.067 & 0 \\ 0.267 & 0.533 & 0.200 & 0 \\ 0.267 & 0.267 & 0.400 & 0.067 \\ 0.733 & 0.267 & 0 & 0 \\ 0.533 & 0.333 & 0.133 & 0 \\ 0.667 & 0.333 & 0 & 0 \\ 0.200 & 0.333 & 0.333 & 0.133 \\ 0.333 & 0.200 & 0.333 & 0.133 \end{array} \right] \end{matrix}$$

4.4 Fuzzy comprehensive evaluation

Fuzzy transform the evaluation matrix R and the weight vector A : $B = A \times R$, where the fuzzy operator $\times$ adopts the $M(+, \bullet)$ operator (Lijuan and Qiao, 2012), that is, the weighted average method, and the operation rule of this operator is $b_j = \sum a_i \bullet r_{ij}$. Finally, the evaluation result $B = (0.294, 0.342, 0.282, 0.082)$ is obtained. According to the principle of maximum membership degree, it can be known that the comprehensive safety evaluation result of high-speed railway line S is “safer”.

5. Conclusion

Through literature investigation and field investigation, combined with high-speed railway safety key points and system composition, 4 first-level indicators and 17 second-level indicators were selected to construct a high-speed railway operation safety evaluation index system.

In view of the complex structure of the high-speed railway system and the high degree of coupling of fault factors, 17 secondary safety factors are analyzed through the ANP, and the relative importance of each evaluation factor to the operational safety of high-speed railways is obtained. It can be seen from the results that the personnel management system and the signal and control system have the largest weight.

On the basis of establishing an evaluation index system, comprehensively considering the internal coupling relationship between evaluation indexes and the fuzziness of high-speed railway operation safety evaluation, high-speed railway uses ANP fuzzy network analysis method to construct high-speed railway operation, and the safety evaluation model has certain advantages and practicability in the case of the relative lack of high-speed railway operation data and fault data.

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