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Research on evaluation of basic railway safety management capability based on combination weighting – TOPSIS

Yankun Qi, Xiaoyu Li, Jinghui Liu, Hanqiu Li and Chen Yang
Railway Safety Research Center,
China Academy of Railway Sciences Corporation Limited, Beijing, China

Abstract

Purpose – To systematically characterize and objectively evaluate basic railway safety management capability, creating a closed-loop management approach which allows continuous improvement and optimization.

Design/methodology/approach – A basic railway safety management capability evaluation index system based on a comprehensive analysis of national safety management standards, railway safety rules and regulations and existing safety data from railway transport enterprises is presented. The system comprises a guideline layer including safety committee formation, work safety responsibility, safety management organization and safety rules and regulations as its components, along with an index layer consisting of 12 quantifiable indexes. Game theory combination weighting is utilized to integrate subjective and objective weight values derived using AHP and CRITIC methods and further combined using the TOPSIS method in order to construct a comprehensive basic railway safety management capability evaluation model.

Findings – The case study presented demonstrates that this evaluation index system and comprehensive evaluation model are capable of effectively characterizing and evaluating basic railway safety management capability and providing directional guidance for its sustained improvement.

Originality/value – Construction of an evaluation index system that is quantifiable, generalizable and accessible, accurately reflects the main aspects of railway transportation enterprises' basic safety management capability and provides interoperability across various railway transportation enterprises. The application of the game theoretic combination weighting method to derive composite weights which combine experts' subjective evaluations with the objectivity of data.

Keywords Railway transportation enterprises, Basic safety management capability, Evaluation index system, Combination weighting

Paper type Research paper

1. Introduction

Railway safety is a factor critical to national security and public safety, and foundational to the railway industry. The Party Group of China State Railway Group Co., Ltd. ("China Railway") has emphasized the need for research on safety evaluation indexes for modern railway safety assurance systems in order to facilitate the continuous improvement and enhancement of railway safety, with the goal of refining evaluation indexes such that they align with ensuring railways' high-quality development (Railway Party Office of China State Railway Group CO Ltd, 2023; Railway Party Office of China State Railway Group CO Ltd, 2024). Existing research has covered the evaluation of various aspects of railway operations. For instance, the evaluation of railway construction projects has been conducted using a comprehensive index

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system encompassing economic, social, and environmental benefits, whose results were calculated using a combination of fuzzy comprehensive evaluation and hierarchical analysis methods (Sun *et al.*, 2023). The design and construction, completion and acceptance, and operation and maintenance performance of railway construction projects has evaluated using improved hierarchical analysis and weighted average methods (Liu & Zhou, 2023). A safety system evaluation system for railway operation in plateau areas incorporating toughness theory has been developed in order to study its resilience. This addresses the challenges of combining the indexes' qualitative and quantitative aspects through assignment (Fan, Han, Jiang, & Lv, 2023). A comprehensive evaluation index system for the operational safety of urban rail transit lines has been systematically developed, based on detailed analysis including investigation of these indexes' definitions and calculation methods (Wang, Huang, & Li, 2013). A railway transportation network safety performance evaluation index system based on accident precursors has been developed (Valentino, Agostino, & Ilario, 2020). A comprehensive weighting determined via organically combining hierarchical analysis, MAWR, maximum entropy MEM, and other methods has been developed, and its validity verified through consideration of the interference of human factors with subjective weighting, and of potential data biases with objective weighting. A case study in railway signaling equipment risk assessment has been conducted (Liu, Yang, Cui, & Yang, 2020). A quantified evaluation system to assess high-speed railway dispatchers' emergency-handling capability has been established using a comprehensive evaluation model constructed based on the TOPSIS and CRITIC methods (Guo *et al.*, 2022). However, while the safety evaluation studies conducted in the aforementioned literature have covered various aspects of railway safety, including projects, passenger transportation, and employee safety (Zhou, Zuo, & Cheng, 2020; Zhang *et al.*, 2022), extant studies on railway safety management remain relatively limited, and this remains particularly true of evaluation of the basic safety management capability, which is still in an early stage of development.

General Secretary Xi Jinping emphasized the importance of "comprehensively strengthening basic safety capacity building", highlighting that institutional arrangements are essential to the promotion of reform and development in the work safety field. He urged the strengthening of basic work safety capacity building, and the timely improvement of work safety systems, standards, and regulations. These important remarks made by the General Secretary highlight the need to prioritize safety management's weakest links, such as systems, standards, and regulations, while the foundations of safety work are being addressed. This interpretation underscores the significance of basic safety management capability. While exploratory research on safety management evaluation during railway operation and construction based on the VIKOR and RM3 models has been conducted, limitations on the selection of qualitative evaluation indicators and methods render this evaluation process cumbersome, and its results subject to significant influence from experts' subjective opinions, and lacking in generality (Li, Zhang, Guo, & Song, 2019; Cui, Liu, Zhang, & Liang, 2024).

In summary, this paper presents an evaluation index system for basic railway safety management capability developed based upon existing national standards, China Railway safety management regulations, and other relevant institutional documents. Additionally, this research incorporates an analysis of existing safety data from railway transportation enterprises, proposing indexes' whose overall weights are determined using a game theoretic combination weighting method. Furthermore, the TOPSIS method is utilized to construct a comprehensive evaluation model for assessing basic railway safety management capability. Finally, to validate the feasibility of the evaluation index system and comprehensive evaluation model thus constructed, a railway transportation enterprise was selected for testing application of the model.

2. Index system for evaluating basic railway safety management capability

2.1 Framework of the evaluation index system

Basic safety management, the foundation of safety management, encompasses key elements including safety systems, standards, regulations, etc. Thus a high level of basic safety management ability is essential in ensuring railways' long-term safety. In 2021, China Railway's Party Group conducted a comprehensive review of the *Railway Law, Railway Safety Management Regulations*, and other relevant laws and regulations. Based on a meticulously study of provisions pertaining to railway safety, the group subsequently formulated its *Implementation Opinions of China Railway on Strengthening the Railway Safety Governance System* (Railway Safety Supervision of China State Railway Group CO Ltd, 2021). This initiative represented the establishment of a complete, systematic, comprehensive and effective railway safety governance system aligned with industry characteristics and adhering to principles of scientific rigor, standardization, and operational efficacy. In 2023, the China National Railway Group revised the *Safety Management Regulations of China Railway Corporation* (Railway Safety Supervision of China State Railway Group Co, Ltd, 2023; GB/T 43500-2023), to reflect the evolving needs of railway work safety in the new era. This revision established superior work safety regulations for State Railway enterprises, and a fundamental framework for enhancing the soundness of the system of safety management rules and regulations. In late 2023, the State Administration for Market Supervision and Regulation published *Safety Management Systems – Requirements* (GB/T 43500-2023GB/T 43500-2023). These requirements serve as guidance for organizations to enhance and optimize their safety management systems. The implementation of the aforementioned regulations and standards has successfully consolidated and reinforced existing basic safety management capability.

To systematically identify the primary factors influencing basic safety management capability, we have meticulously analyzed and synthesized the pertinent provisions outlined in the aforementioned regulations and standards. Furthermore, we have integrated these findings with safety management practices observed in application in railway transport enterprises. Based on this, we have devised an evaluation index system framework incorporating the formation of safety committees, work safety responsibilities, safety management organization, and safety rules and regulations, as presented in Table 1.

2.2 Principles for selecting evaluation indexes

Selection of indexes for evaluating basic railway safety management capability should emphasize the following four principles:

(1) The principle of typicality

The evaluation indexes should be typical and representative, and an excessive number of indexes should be avoided, while aiming to accurately reflect the main content of railway transportation enterprises' basic safety capability.

(2) The principle of generalizability

The evaluation indexes selected should be statistically available for different railway transportation enterprises and possess strong generality.

(3) The principle of quantifiability

In order to mitigate the impact of subjective factors on the evaluation results, index selection should adhere to the principle of quantifiability, implying that they should consist of actual quantifiable data obtained on site, ensuring that they are free from human interference, and maintaining the objectivity and fairness of the evaluation results.

Table 1. Framework for basic railway safety management capability evaluation index system

Framework	Safety management systems – requirements	China railway safety management regulations	China Railway's implementation opinions on strengthening the railway safety governance system
Formation of safety committees	*5.1 Leadership* (Support establishment and operation of security management committees or working groups within organization.)	*Chapter III. Responsibility for safety in production* (Each unit should have a work safety committee)	*2.2 Organizational structure* (Establish Work Safety Committee) *2.3 Security decision-making* (Give full play to Work Safety Committee's role in order to provide effective support for safety decision-making.)
Responsibility for work safety	*5.3 Organizational structure, responsibilities and authorities* (It is essential to ensure the implementation of a comprehensive and robust safety accountability system throughout the organization.)	*Chapter III. Responsibility for safety in production* (A system of responsibility for work safety for all staff across all departments and levels shall established and continuously enhanced, with a strong emphasis on aligning it with the job responsibilities associated with each department and position.) *Chapter XII. Appraisals, rewards and punishments* (Clearly define assessment criteria for different types of disciplinary violations, and conduct assessments in strict adherence to these criteria. In addition, provide recognition and rewards to groups or individuals who demonstrate exceptional abilities in identifying safety hazards, preventing accidents, or contributing to work safety.)	*1.1 Full accountability for production safety* (Implement targeted revision and enhancement of the comprehensive work safety responsibility system across all levels and positions.) *1.2 Responsibility assessment* (Conducting evaluations and assessments of work safety duties performance.) *1.3 Accountability* (Ensure accountability for safety throughout the entire transportation production process.) *1.4 Positive incentives* (Encourage and guide workers to proactively identify and appropriately address significant safety hazards that could result in severe consequences.)
Safety management organization	*5.3 Organizational structure, responsibilities and authorities* (Each level of staff within the organization should take responsibility for managing the safety within its respective area.)		*2.2 Organizational structure* (Provide appropriate full-time or part-time production safety management personnel.)
Safety rules and regulations		*Chapter IV. Regulations* (Each unit must promptly amend, establish, supplement, or abolish rules and regulations to align with changes in the organization of production, equipment and facilities, and operating conditions.)	*2.4 Regulatory standards* (Promptly amend, establish, supplement, repeal, and interpret regulations, and publish a listing of effective regulations.)

Source(s): Authors' own work

(4) The principle of accessibility

While certain evaluation indexes could be chosen to better reflect levels of basic railway safety management capability, in consideration of the practical challenges associated with collecting statistics from railway transportation enterprises and acquiring evaluation data, some are not currently included in the index system.

2.3 Construction of the evaluation index system

The basic railway safety management capability evaluation index system has been developed based on the above framework, further elaborated based on research conducted on other relevant areas including railway transportation enterprises' station areas, safety supervision, statistics, etc., as shown in Table 2, below. The guideline layer consists of 4 first-level indexes, while the index layer comprises 12 second-level indexes. These indexes are quantified in units based on their respective meanings, with the sign of their values represented by "+" and "−".

3. Combination weighting to determine overall index weights

3.1 Subjective index weighting based on AHP

Due to the reliance of the majority of the basic railway safety management capability evaluations on management indexes, in this study, the AHP method is adopted to quantify the

Table 2. Evaluation of basic railway safety management capability index system

	Guideline layer (first-level indexes)	Index layer (second-level indexes)	Index quantification methodologies	Index sign
Basic railway safety management capability Evaluation index system	Formation of safety committee (A)	Number of deliberative decisions on major production safety matters (A1)	/Items	+
		Number of documents issued on behalf of safety Committee (A2)	/Items	+
		Number of full-time staff in safety office (A3)	/Persons	+
	Work safety responsibility (B)	Work safety accountability system coverage for all levels and positions (B1)	%	+
		Work safety responsibility publication issuance rate (B2)	%	+
		Work safety accountability system coverage for leading cadres (B3)	%	+
		Accountability system on-schedule completion rate (B4)	%	+
		Incentive value per 10,000 staff (B5)	Yuan/10,000 staff	+
		Number of awards (B6)	/Person-times	+
	Safety management organization (C)	Number of full/part-time) production safety managers per 100 staff (C1)	Persons/100 staff	+
	Safety rules and regulations (D)	Number of regulatory amendments (D1)	/Items	+
		Rate of publication of valid security documents (D2)	%	+

Note(s): The number of regulatory amendments (D1) does not follow the principle of "the higher, the better". Thus, if it exceeds a predetermined optimal value, the index is assigned a perfect score
Source(s): Authors' own work

various index weights. This involved consulting railway safety management experts possessing extensive on-site experience, including management in the safety supervision office, and relevant station section safety staff. Through this consultation, subjective weights for the indexes were obtained. Using AHP, these weights are calculated using the following specific steps:

Step 1. Create the index judgment matrix. Create the judgment matrix for each level of indexes using a scale of 1–9, as shown below:

$$G = \begin{pmatrix} u_{11} & u_{12} & u_{13} & \cdots & u_{1n} \\ u_{21} & u_{22} & u_{23} & \cdots & u_{2n} \\ u_{31} & u_{32} & u_{33} & \cdots & u_{3n} \\ \vdots & \vdots & \vdots & u_{b_1 b_2} & \vdots \\ u_{n1} & u_{n2} & u_{n3} & \cdots & u_{nn} \end{pmatrix} \tag{1}$$

where n is the number of indexes and $u_{b_1 b_2}$ is the weight of the b_1th index relative to the b_2th index.

Step 2. Determine the weight values. Calculate the eigenvector of the largest eigenroot $\lambda_{\max}$ of the judgment matrix G, which is ω after normalization; this contains the weight value foe each index.

Step 3. Ensure consistency. Conduct a consistency test on the judgment matrix G, calculating the consistency indexes CI and CR:

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1} \tag{2}$$

$$\mathrm{CR} = \mathrm{CI}/\mathrm{RI} \tag{3}$$

where RI represents a random consistency index determined by referral to a predefined table.

3.2 Objective index weighting based on CRITIC

In order to take account of the variability and correlation between the basic railway safety management capability evaluation indexes, we adopted the CRITIC assignment method, which introduces the concepts of comparative intensity and conflict. Comparative intensity is represented by the standard deviation; a larger standard deviation indicates a greater fluctuation and higher weight. Conflict, on the other hand, is represented by the correlation coefficient; a larger coefficient indicates less conflict and receives lower weight. The weight of indexes in CRITIC is calculated via the following specific steps:

Step 1. The data matrix for the indexes, denoted V, is constructed based on the number of evaluation objects (m) and the number of evaluation indexes (n), as follows:

$$V = \begin{pmatrix} v_{11} & v_{12} & v_{13} & \cdots & v_{1n} \\ v_{21} & v_{22} & v_{23} & \cdots & v_{2n} \\ v_{31} & v_{32} & v_{33} & \cdots & v_{3n} \\ \vdots & \vdots & \vdots & v_{ab} & \vdots \\ v_{m1} & v_{n2} & v_{n3} & \cdots & v_{mn} \end{pmatrix} \tag{4}$$

where v_{ab} is the bth evaluation index for the ath evaluation object, $a = 1, \cdots, m, b = 1, \cdots, n$.

Step 2. Correlation coefficients between the indexes are then calculated. Table 2 provided the various quantitative indexes incorporated into the evaluation index system. These included the work safety responsibility publication rate (B2), and the incentive amount per 10,000 population(B5), which could differ greatly in scale.

The correlation coefficient addresses such disparities in magnitude between the various indexes, while also providing insight into the degree and direction of correlation between them. It is calculated using the formula below:

$$r_{ab} = \frac{\sum_{l=1}^{m} (v_{la} - \overline{v}_a)(v_{lb} - \overline{v}_b)}{\sqrt{\sum_{l=1}^{m} (v_{la} - \overline{v}_a)^2} \sqrt{\sum_{l=1}^{m} (v_{lb} - \overline{v}_b)^2}} \tag{5}$$

where r_{ab} is the index correlation coefficient.

Step 3. Determine the informativeness of the indexes. Based on the correlation coefficient r_{ab}, information quantity of each index, G_b, can be calculated using the following formula:

$$G_b = \sigma_b \sum_{a=1}^{m} (1 - r_{ab}) \tag{6}$$

where σ_b is the mean squared error of the bth index:

$$\sigma_b = \sqrt{\frac{1}{m-1} \sum_{l=1}^{m} (v_{bl} - \overline{v}_b)^2}.$$

Step 4. Determine the weight values. Normalize the amount of information for each index G_b to derive the index weights ω_b:

$$\omega_b = \frac{G_b}{\sum_{l=1}^{n} G_l} \tag{7}$$

3.3 Overall weights based on game-theoretic portfolio assignment

Index weight values obtained via the AHP and CRITIC methods can be integrated while minimizing information loss due to the individual assignments via use of a game theoretic model for combined assignment (Feng, Xu, Yang, Zheng, & Zhang, 2024). The specific steps for calculating the overall weights via game-theoretic combinatorial assignment are as follows:

Step 1. Construct the weight vector set. The basic weight vector set for the evaluation indexes is:

$$\omega_k = \{\omega_{k1}, \omega_{k2}, \cdots, \omega_{kn}\} (k = 1, 2, \cdots, m) \tag{8}$$

ω, the weight vector set for the basic railway safety management capability evaluation indexes when k assignment methods are adopted, can constructed based on these sets:

$$\omega = \sum_{k=1}^{m} \lambda_k \omega_k^T \tag{9}$$

where λ_k contains linear composite weighting coefficients.

Step 2. Determine the linear composite weighting coefficients. According to game theory, balancing the weights under different assignment methods requires determination of the Nash equilibrium; this provides the composite weighting coefficients for the optimal weights. The objective is minimization of the deviation between the composite and basic weights (between ω and ω_k), which can be represented as follows:

$$\min \left\| \sum_{k=1}^{m} \lambda_k \omega_k^T - \omega_k \right\| \tag{10}$$

Based on the properties of matrix differential equations, the first-order derivative of the system of linear equations represented by Equation (10) is:

$$\begin{bmatrix} \omega_1\omega_1^T & \omega_1\omega_2^T & \cdots & \omega_1\omega_m^T \\ \omega_2\omega_1^T & \omega_2\omega_2^T & \cdots & \omega_2\omega_m^T \\ \vdots & \vdots & \vdots & \vdots \\ \omega_m\omega_1^T & \omega_m\omega_2^T & \cdots & \omega_m\omega_m^T \end{bmatrix} \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \vdots \\ \lambda_m \end{bmatrix} = \begin{bmatrix} \omega_1\omega_1^T \\ \omega_2\omega_2^T \\ \vdots \\ \omega_m\omega_m^T \end{bmatrix} \tag{11}$$

Step 3. Determine the composite weights. Using Equation (11), the linear composite weighting coefficients, $\lambda_{\text{op}} = [\lambda_1 \quad \lambda_2 \quad \cdots \quad \lambda_m]$, can be found and normalized thus:

$$\lambda_{\text{op}}^* = \frac{\lambda_k}{\sum_{k=1}^{m} \lambda_k} \tag{12}$$

Based on this, the overall weights can be derived:

$$\omega_{综} = \sum_{k=1}^{m} \lambda_{op}^* \omega_k^T \tag{13}$$

4. Calculation of basic railway safety management capability based on TOPSIS

TOPSIS comprehensive evaluation ranks evaluation objects based on their distance from the optimal solution (the optimal value of each index) and from the worst solution (the worst value of each index). The specific steps of this method are as follows:

Step 1. Normalization of the index data matrix based on the index attributes outlined in Table 2. During this process, all indexes undergo transformation into positive type indexes, yielding the positive index data matrix V'.

Step 2. Normalization of the positive data matrix. The index data matrix $V' = (v'_{ab})_{m\times n}$ is transformed into a normalized decision matrix $Z' = (z_{ab})_{m\times n}$ using Equation (14):

$$z_{ab} = \frac{v'_{ab}}{\sqrt{\sum_{a=1}^{m} {v'_{ab}}^2}} \tag{14}$$

Step 3. Calculation distances from most optimal and worst solutions for the objects of evaluation. First determine the optimal and worst solutions using Equations (15) and (16), respectively:

$$\begin{aligned} Z^+ &= \left(z_1^+, z_2^+, \cdots, z_n^+\right) \\ &= \left(\max\{z_{11}, z_{21}, \cdots, z_{m1}\}, \max\{z_{12}, z_{22}, \cdots, z_{m2}\}, \cdots, \max\{z_{1n}, z_{2n}, \cdots, z_{mn}\}\right) \end{aligned} \tag{15}$$

$$\begin{aligned} Z^- &= \left(z_1^-, z_2^-, \cdots, z_n^-\right) \\ &= \left(\min\{z_{11}, z_{21}, \cdots, z_{m1}\}, \min\{z_{12}, z_{22}, \cdots, z_{m2}\}, \cdots, \min\{z_{1n}, z_{2n}, \cdots, z_{mn}\}\right. \end{aligned} \tag{16}$$

The distances of the ath evaluation object from the optimal and worst solutions are then defined by Equations (17) and (18), respectively:

$$d_a^+ = \sqrt{\sum_{b=1}^{n} \left(z_b^+ - z_{ab}\right)^2 \omega_b} \tag{17}$$

$$d_a^- = \sqrt{\sum_{b=1}^{n} \left(z_b^- - z_{ab}\right)^2 \omega_b} \tag{18}$$

Step 4. The comprehensive evaluation index is calculated based on the distance between the evaluation object and both optimal and worst solutions using Equation (19):

$$s_a = \frac{d_a^-}{d_a^+ + d_a^-} \tag{19}$$

Finally, the comprehensive evaluation indexes obtained from Equation (19) are sorted from largest to smallest, giving the ranking by advantage/disadvantage for each evaluation object.

5. Example analysis

A railway transportation enterprise was selected to verify the feasibility of this evaluation index system methodology for assessing basic railway safety management capability. Values for the three latest years for indexes related to basic railway safety management capability were obtained via interviews with personnel in various sections of the enterprise.

5.1 Calculation of evaluation index weights

Step 1. Calculation of subjective weights for AHP indexes. Based on the basic railway safety management capability evaluation index system, railway safety management experts were invited to undertake pairwise comparisons of the importance of each layer's indexes, from which the corresponding judgment matrix for each layer could be constructed. Taking the first-level indexes of the guideline layer as an example, pairwise comparisons were made between the indexes pertaining to the formation of the safety committee, work safety responsibility, safety management organization, and safety rules and regulations, were conducted. Consequently, the judgment matrix for the guideline layer G_z was determined as follows:

$$G_z = \begin{bmatrix} 1 & 1/3 & 1/2 & 1/2 \\ 3 & 1 & 2 & 2 \\ 2 & 1/2 & 1 & 1 \\ 2 & 1/2 & 1 & 1 \end{bmatrix} \tag{20}$$

The calculated values of the weights were [0.12, 0.42, 0.23 and 0.23]. The guideline index layer weights were also similarly calculated, yielding a set of subjective AHP-based weights, as shown in Table 3.

Step 2. Calculation of objective weights for CRITIC indexes. Based on the index definitions, quantification methods, and statistical data, the optimal and worst values for the 12 indexes were determined, as presented in Table 4.

The objective weights for these evaluation indexes were calculated using Equations (4–7), based on the statistical index data for the past 3 years, along with their optimal and worst values.

Step 3. Calculation of overall weights. Based on subjective and objective weight values from Tables 3 and 5, game theoretic combined assignment was employed to determine the

Table 3. AHP index weight calculation

Evaluation indexes	Weighting factor	Evaluation indexes	Weighting factor
A1	0.0756	B4	0.0252
A2	0.0264	B5	0.0588
A3	0.018	B6	0.0588
B1	0.1512	C1	0.23
B2	0.0546	D1	0.0575
B3	0.0714	D2	0.1725

Source(s): Authors' own work

Table 4. Optimal and worst values of secondary indexes

Secondary indexes	Optimum value	Minimum value
Number of deliberative decisions on major production safety matters (A1)	20	0
Number of documents issued on behalf of safety Committee (A2)	15	0
Number of full-time staff in safety office (A3)	15	0
Coverage of work safety accountability system at all levels and positions (B1)	100%	0
Work safety responsibility publication issuance rate (B2)	100%	0
Work safety accountability system coverage for leading cadres (B3)	100%	0
Accountability system on-schedule completion rate (B4)	100%	0
Incentive value per 10,000 staff (B5)	87.7	0
Number of awards (B6)	4,000	0
Number of full/part-time production safety managers per 100 staff (C1)	25	0
Number of regulatory amendments (D1)	10	0
Publication rate of valid security documents (D2)	100%	0

Source(s): Authors' own work

Table 5. CRITIC index weight calculation

Evaluation indexes	Weighting factor	Evaluation indexes	Weighting factor
A1	0.2849	B4	0.0624
A2	0.0483	B5	0.0428
A3	0.0438	B6	0.1290
B1	0.0624	C1	0.0767
B2	0.0624	D1	0.0624
B3	0.0624	D2	0.0624

Source(s): Authors' own work

overall weights for the railway safety management basic capability evaluation indexes using the calculations given in Equations (8–13). The results, represented in vector form as [0.1816, 0.0375, 0.0311, 0.1062, 0.0586, 0.0668, 0.0440, 0.0507, 0.0944, 0.1523, 0.0600, 0.1167], and are illustrated in Figure 1.

5.2 Calculation of comprehensive evaluation results

Comprehensive basic safety management capability evaluation scores for the railway transportation enterprise for the past three years were calculated using the TOPSIS evaluation method described in Section 3, as documented in Equations (14–19). To further verify the reliability of the method proposed in this paper, the results derived by TOPSIS evaluation were compared with the results obtained using weighted averaging. Figure 2 shows that the evaluation results derived via the proposed method align closely with the results of a weighted average calculation.

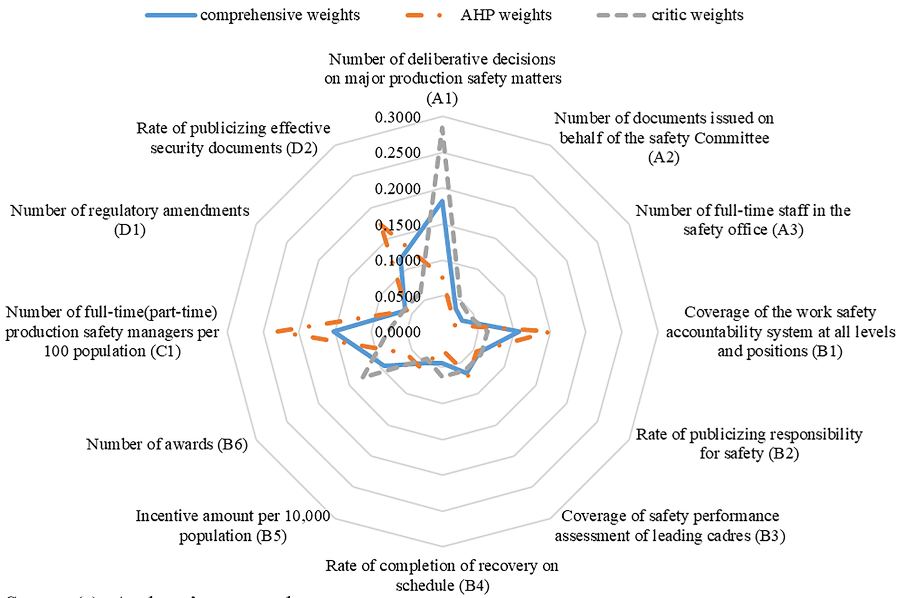

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Figure 1. Overall basic railway safety management capability evaluation index weights

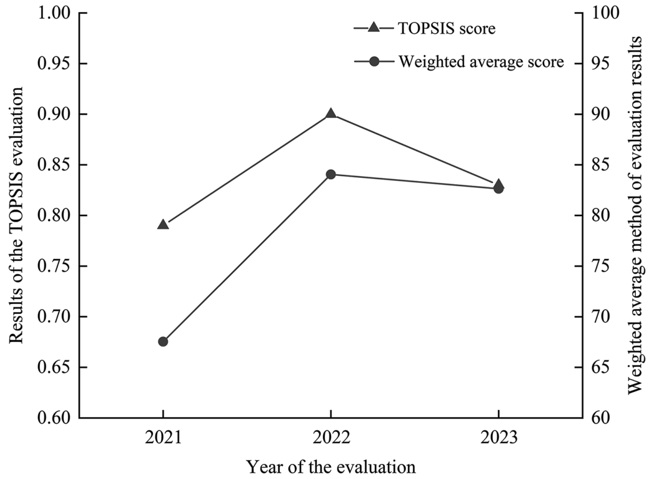

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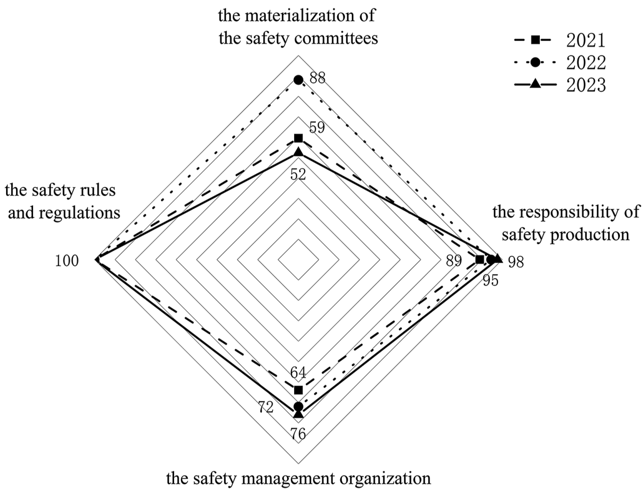
Figure 2. Overall basic railway safety management capability evaluation index weights

5.3 Analysis of evaluation results

Data for second-level indexes collected on site were combined with the integrated weight values to create a standardized numerical radar map of the first-level indexes, shown in Figure 3.

Analysis of Figure 3 over the past three years reveals significant fluctuations in the evaluation scores related to safety committee formation, indicative of an ongoing need to enhance the operational effectiveness of the railway transport enterprise's safety committee. Active exploration of the safety committee's operational methods and strategies, and improvements in its operational system and mechanisms, are recommended. Ensuring the



Source(s): Authors' own work

Figure 3. First-level basic railway safety management capability index scores

effective implementation of significant work safety decisions and deployments, harnessing work safety's coordinating and integrating functionality, organizing special work safety activities, and bolstering the committee's authority, could also represent crucial steps towards guaranteeing the work safety committee's smooth and efficient functioning.

The work safety responsibility evaluation scores exhibited a significant upward trend over the three years. This can be attributed to the railway transport enterprise's establishment of a robust safety management information system. Using digitalized, intensive, and process-oriented methods, the system coordinates work safety responsibility announcements, ensures that cadres fulfill their duties, and incorporates modules for assessing accountability. These measures have enhanced the transparency of safety information, improving the efficiency of responsibility allocation. In order to fulfill the emerging demands of enhanced safety measures, further enhancement of the production safety responsibility system with clear responsibilities and a comprehensive mechanism is recommended. This entails strengthening management processes for duty fulfillment, ensuring the traceability of safety responsibilities throughout the entire production and operation process, conducting thorough investigations into accident responsibilities, improving the structure of safety assessment indexes, and allocating greater weight to safety assessment. These measures would effectively underscore the incentivizing role of safety assessment.

The safety management organization evaluation scores displayed a consistent increase over the three years. This can be attributed to the heightening importance attributed to railway safety by the management of the railway transportation enterprise. By increasing the number of full or part-time production safety management personnel, the capacity to control risks related to key position holders, equipment, facilities, and workplaces has been enhanced. It is recommended that safety management personnel assigned to new positions prioritize timely training in order to enhance their mastery and application of management theory knowledge. They should also skillfully employ safety theory to analyze problems and provide guidance during their practical work.

The evaluation scores for safety rules and regulations have consistently remained high. This can be attributed to the railway transportation enterprise's independent development of a system for the dissemination of safety documents, ensuring their timely adoption for use and widespread availability. Additionally, the leading teams of the enterprise actively tracked changes in higher-level rules and regulations, and ensured the synchronized updating and revision of their own rules and regulations. The integration of this system into the safety management information system as a module is recommended, in order to facilitate its effective promotion.

6. Conclusion

(1) This paper presents the construction of a quantifiable, universal, and accessible evaluation index system created via the systematic examination and analysis of national standards, rules and regulations, field data, and other relevant information. This system accurately reflects the main aspects of railway transportation enterprises' basic safety management capability, circumventing the limitations imposed by cumbersome traditional safety management evaluation processes and minimizing subjective interference. Furthermore, it also possesses the advantage of interoperability with various railway transportation enterprises.

(2) This paper introduces game theoretic combination weighting for the alignment of subjective and objective index weights calculated by AHP and CRITIC. By combining experts' subjective evaluations with the objectivity of data, this method guarantees a rational and scientific formulation of basic railway safety management capability index weightings.

(3) Analysis of the comprehensive evaluation results presented in this paper suggests that railway transport enterprises' level of production safety responsibility, safety regulations and systems can be effectively enhanced with the help of information technology. The next step could be deeper integration of information technology into work safety scenarios, continuing the development of basic railway safety management capability.

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Corresponding author
Xiaoyu Li can be contacted at: lixiaoyu_83@163.com