Research on Comprehensive Evaluation of Railway Technical Regulation System Based on FAHP

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Abstract: To improve the applicability, scientificity, and standardization of the railway technical regulation system, a comprehensive evaluation of the railway technical standard system is required to determine the next optimization direction. In light of the current state of the Chinese railway technical regulation system, this paper provides a comprehensive evaluation of the system using the fuzzy analytic hierarchy process (FAHP). It is suggested that in the future, we can improve the supervision level of the railway technical regulations by beginning with the establishment of deep integration management regulations for process flow and infrastructure.

Keywords: Railway Technical Regulations, Fuzzy Analytical Hierarchy Process (FAHP), Comprehensive Evaluation, Full Lifecycle Management.

1 INTRODUCTION

The railway is a strategic and critical national infrastructure that plays an important role in the national economy and people's livelihood. China's railways have advanced rapidly in recent years, particularly the high-speed lines that have been put into service in large numbers. The railway network's scale and structure are growing larger and more complex. China's railway operating mileage will have exceeded 150,000 km by the end of 2021, with high-speed railway mileage exceeding 40,000 km, ranking first in the world[1]. Simultaneously, numerous new technologies and equipment have been implemented in the railway, and the corresponding rules and regulations are constantly reforming and innovating.

The railway technical regulations define the procedures and methods of railway work, provide the necessary foundation for railway workers' work, and regulate their behavior, which is an important means of realizing safe railway transportation production management. To further improve the applicability, scientificity, and standardization of the railway technical regulations system, it is necessary to establish a sound railway technical regulations evaluation system, conduct a comprehensive evaluation from the standpoint of a clear hierarchy, reasonable structure, standard content, and scientific rigor, and promote the construction of railway technical standards[2].

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2 RESEARCH STATUS OF CHINA'S RAILWAY TECHNICAL REGULATIONS

2.1Railway Technical Regulation System

China's railway technical regulation system has formed a management system with *Railway Technical Management Regulation and Rules for High-speed Railway Operating Organization* as the core rules, and the specific rules of China Railway Group's professional rules, Railway Bureau group company and station section technical rules as the specific rules[3-4]. According to the professional management, according to the nature of the technical rules and regulations, it is divided into system technical rules and regulations, individual technical rules, and according to the professional category of technical rules and regulations, it is divided into train depot, civil engineering, signaling, maintenance, vehicle, communication, vehicles, power supply, freight, passenger transportation, information and other regulations[5]. Figure 1 shows the railway technical regulation system.

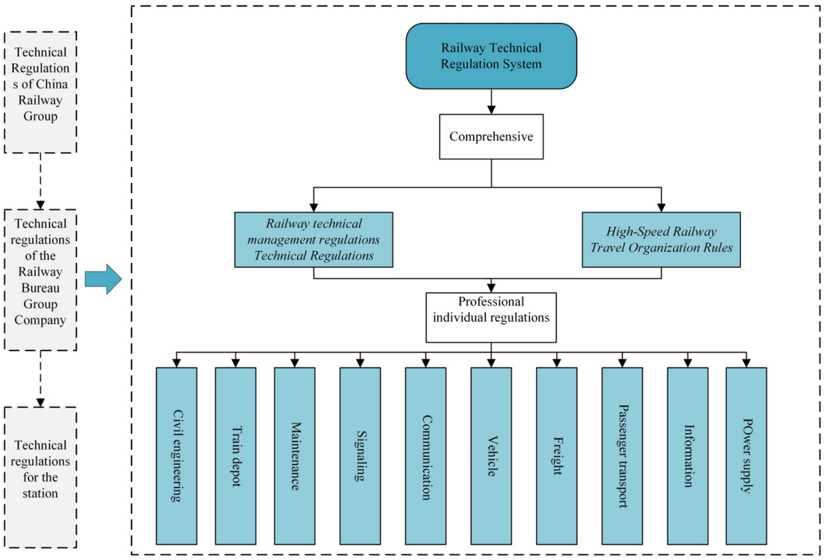

Figure 1. Railway Technical Regulation System.

3 ESTABLISHMENT OF COMPREHENSIVE EVALUATION MODEL FOR RAILWAY TECHNICAL REGULATION SYSTEM

3.1Fuzzy Analytic Hierarchy Process

The fuzzy Analytic Hierarchy Process (FAHP) is an evaluation algorithm that is based on AHP and fuzzy theory. It is a mathematical evaluation method that takes into account both qualitative and quantitative factors. There are many relevant factors and uncertainties in the evaluation of railway technical regulations that are difficult to divide, making the evaluation process uncertain and subjective. As a result, the fuzzy analytic hierarchy process can more accurately and reasonably reflect the overall situation of the railway technical regulation system[6].

3.2Determination of Comprehensive Evaluation Model for Railway Technical Regulation System

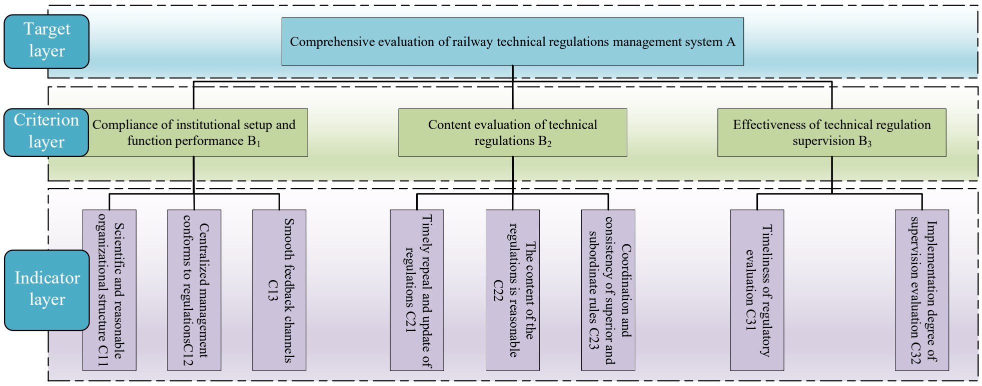

Figure 2. Evaluation model of railway technical regulation system.

In conjunction with railway operation characteristics and risk analysis, and drawing on the indicator setting method of current achievements, three criteria levels are divided: whether the institutional setting and function performance are standardized, the content evaluation of technical regulations, and the effectiveness of technical regulation supervision, and further divided into eight indicator levels. Figure 2 depicts the specific configuration of the evaluation indicator model[7].

4 COMPREHENSIVE EVALUATION METHOD OF RAILWAY TECHNICAL REGULATIONS BASED ON FUZZY COMPREHENSIVE EVALUATION METHOD

4.1Fuzzy Analytic Hierarchy Process

(1) Construct judgment matrix

First, in conjunction with expert opinions, the 1-9 scale method8] is used to determine the relative weight value of each factor at each level of the judgment matrix. The judgment matrix is then built, and the consistency test is run to ensure that the analytic hierarchy process (AHP) calculation results are rational. Then there's the n-order judgment matrix $\boldsymbol{A}$ constructed is defined as:

$$\boldsymbol{A}=\begin{bmatrix} 1 & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ 1/a_{1n} & \cdots & 1 \end{bmatrix} \tag{1}$$

(2) Judgment of consistency test

The judgment results are inconsistent because the judgment matrix was constructed subjectively. If the inconsistencies exceed a certain threshold, the judgment results become untrustworthy, so consistency must be checked. The consistency index *CI* is used to express the judgment matrix's consistency. The following is the formula:

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

To compare *CI* values, the "Random Consistency Indicator" *RI* is commonly used to measure *CI* indicators. Table 1 displays the general *RI* values.

Table 1. *RI* coefficient table.

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.94	1.12	1.24	1.32	1.41	1.45

The results of the comparison are expressed by the unfixed engagement ratio *CR*, as shown in Formula (3):

$$CR = \frac{CI}{RI} \tag{3}$$

The use of *CR* value to judge the accuracy of the degree of fit is referred to as consistency inspection. When $CR \leq 0.1$, the consistency of the judgment matrix is passed. Otherwise, the value of relative importance in the judgment matrix must be adjusted until the consistency inspection passes.

4.2Determination of Subordination Degree and Evaluation Level

Following the determination of the indicators, experts will assign the corresponding evaluation grade to each factor in the evaluation model based on the actual situation. Following the scoring of all experts, the frequency of each project grade will be calculated, and the membership degree will be obtained following the normalized calculation, in order to establish a single factor evaluation matrix. G={G1,G2,G3,G4,G5}={I (very poor), II (poor), III (general), IV (good), V (very good)} are the five evaluation levels[9].

4.3Fuzzy Comprehensive Evaluation

(1) First level fuzzy comprehensive evaluation

Because the factors of the second layer constrain the factors of the first layer, the multifactor evaluation of the second layer will be influenced by the factors of the first layer. As a result,

$\boldsymbol{R}_{1i}$ is chosen as the second layer's independent factor judgment matrix, and $\boldsymbol{R}_{1i}$ is shown in equation (4).

$$\boldsymbol{R}_{1i} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1p} \\ r_{21} & r_{22} & \cdots & r_{2p} \\ \vdots & \vdots & \vdots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{np} \end{bmatrix} \tag{4}$$

The first level of fuzzy comprehensive evaluation is:

$$\begin{aligned} B_{1i} &= \mathrm{Z}_{1i} \bullet \boldsymbol{R}_{1i} \\ &= (z_{11}, z_{12}, \cdots, z_{1n}) \bullet \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1p} \\ r_{21} & r_{22} & \cdots & r_{2p} \\ \vdots & \vdots & \vdots & \vdots \\ r_{n1} & r_{n1} & \cdots & r_{np} \end{bmatrix} \\ &= (b_{11}, b_{12}, \cdots, b_{1p}) \end{aligned} \tag{5}$$

Where, $\overline{Z}_{ji} = \left[Z_1, Z_2, \cdots, Z_n\right]^{\mathrm{T}}$ can represent the weight vector of the *i*-th index in the *j*-th level fuzzy comprehensive evaluation process, and *i* is the *i*-th evaluation index.

5 MODEL APPLICATION AND EVALUATION RESULT ANALYSIS

This paper invited ten experts in relevant fields and technicians from the Chinese Academy of Railway Sciences to form an expert group to investigate the current state of the railway technical regulation system, grade and evaluate the questionnaire issued, and finally collect the questionnaire for summary, which is used to construct the independent factor judgment matrix of formula (4).

5.1Construct Judgment Matrix and Perform Consistency Check

The expert group is asked to compare the relative importance of each element in pairs by constructing the judgment matrix shown below using the 1-9 scale method. The weight of each element is then calculated by MATLAB using the above method, and the consistency is checked. Details can be found from Table 2 to Table 5.

Table 2. Consistency check table of judgment matrix of primary indicators.

	B_1	B_2	B_3	Z_i
B_1	1	1/2	3	0.320
B_2	2	1	4	0.558
B_3	1/3	1/4	1	0.136

The calculated value is 0.0158, less than 0.1, it passes the consistency test.

Table 3. Consistency inspection table of criteria layer(B_1).

	C_{11}	C_{12}	C_{13}	Z_i
C_{11}	1	2	4	0.558
C_{12}	1/2	1	3	0.320
C_{13}	1/4	1/3	1	0.136

The calculated value is 0.0158, less than 0.1, it passes the consistency test.

Table 4. Consistency inspection table of criteria layer(B_2).

	C_{21}	C_{22}	C_{23}	Z_i
C_{21}	1	1/3	2	0.239
C_{22}	3	1	4	0.625
C_{23}	1/2	1/4	1	0.136

The calculated value is 0.0157, less than 0.1, it passes the consistency test.

Table 5. Consistency inspection table of criteria layer(B_3).

	C_{31}	C_{32}	Z_i
C_{31}	1	1/3	0.25
C_{32}	3	1	0.75

Because Table 5 is a second-order matrix, the consistency test is not required, and all of the matrices listed above pass it.

5.2First Level Fuzzy Comprehensive Evaluation

The basic data scored by experts and the application of Equation 4 and Equation 5 are used for the first level fuzzy comprehensive evaluation.

(1) Whether the institutional setup and function performance are standardized

$$Z_{11} = (0.558\ \ 0.320\ \ 0.122)$$

$$\boldsymbol{R}_{11} = \begin{bmatrix} 0 & 0.2 & 0.5 & 0.3 & 0 \\ 0 & 0.3 & 0.2 & 0.4 & 0.1 \\ 0 & 0.1 & 0.1 & 0.5 & 0.3 \end{bmatrix}$$

$$B_{11} = Z_{11} \bullet \boldsymbol{R}_{11} = (0\ \ 0.2198\ \ 0.3552\ \ 0.3564\ \ 0.0686)$$

(2) Content evaluation of technical regulations

$$Z_{12} = (0.239\ \ 0.625\ \ 0.136)$$

$$\boldsymbol{R}_{12} = \begin{bmatrix} 0 & 0 & 0.3 & 0.5 & 0.2 \\ 0 & 0.1 & 0.4 & 0.4 & 0.1 \\ 0 & 0.1 & 0.3 & 0.4 & 0.2 \end{bmatrix}$$

$$B_{12} = Z_{12} \bullet \boldsymbol{R}_{12} = (0\ \ 0.0761\ \ 0.3625\ \ 0.4239\ \ 0.1375)$$

(3) Effectiveness of technical regulation supervision

$$Z_{13} = (0.25\ \ 0.75)$$

$$\boldsymbol{R}_{13} = \begin{bmatrix} 0 & 0.3 & 0.4 & 0.3 & 0 \\ 0 & 0.3 & 0.4 & 0.2 & 0.1 \end{bmatrix}$$

$$B_{13} = Z_{12} \bullet \boldsymbol{R}_{13} = (0\ \ 0.3000\ \ 0.4000\ \ 0.2250\ \ 0.0750)$$

5.3Fuzzy Comprehensive Evaluation of Target Level

The fuzzy evaluation matrix of the target level is:

$$\boldsymbol{R}_2 = \begin{bmatrix} B_{11} \\ B_{12} \\ B_{13} \end{bmatrix} = \begin{bmatrix} 0 & 0.2198 & 0.3552 & 0.3564 & 0.0686 \\ 0 & 0.0761 & 0.3625 & 0.4239 & 0.1375 \\ 0 & 0.3000 & 0.4000 & 0.2250 & 0.0750 \end{bmatrix}$$

As shown in Table 2, the weight vector of the target layer is:

$$Z_2 = (0.320\ \ 0.558\ \ 0.122)$$

$$B_2 = Z_2 \bullet \boldsymbol{R}_2 = (0\ \ 0.1494\ \ 0.3647\ \ 0.3780\ \ 0.1078)$$

To sum up, the results of the fuzzy comprehensive evaluation of the railway technical regulation system are as follows:

$$G = \begin{bmatrix} \text{I} & \text{II} & \text{III} & \text{IV} & \text{V} \\ 0 & 0.1494 & 0.3647 & 0.3780 & 0.1078 \end{bmatrix}$$

According to the principle of maximum subordination degree[10], the railway technical rules and regulations system's fuzzy comprehensive evaluation level is good, the evaluation system has individual loopholes, and the risk level is low.

6 CONCLUSIONS

This paper conducts a comprehensive evaluation of the railway technical regulation system from the perspective of the railway technical regulation system's construction, as well as the current research situation of the railway technical regulations. The evaluation results show that the railway technical regulation system has a good fuzzy comprehensive evaluation grade, but the effectiveness of technical regulation supervision is relatively weak, and appropriate protective measures are needed to reduce the overall risk level. In the future, we can begin by establishing deep integration management rules of process flow and information flow, and comprehensively strengthen the lossless forward transmission and feedback optimization mechanism of information flow, so that we can realize standardized management of information flow throughout the life cycle based on process flow management, and effectively improve the supervision level of railway technical regulations.

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