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Research Article

Evaluation of Railway Transportation Performance Based on CRITIC-Relative Entropy Method in China

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Railway transportation affects the overall transportation process and integrated sustainable development. Evaluation of the railway transportation performance is of great significance for building an efficient and comprehensive railway transportation system. The research establishes a methodology to evaluate railway transportation performance in China. Firstly, the research determines the indexes for evaluation of railway transportation performance, including railway safety, infrastructure, equipment, operation efficiency, and green development. Second, the weight of each index is calculated by using criteria importance through the intercriteria correlation method (CRITIC). Third, the railway transportation performance is assessed based on multi-criteria decision-making (MCDM), by applying the CRITIC-relative entropy method. Finally, the empirical analysis shows that, in 2018, the railway transportation performance is underdeveloped in almost half of China's railway bureaus and that there are obvious differences between railway bureaus in the east and west. The evaluation of railway transportation performance could be used to improve the sustainable ability of railway transportation in China.

1. Introduction

Railway transportation is an ecological type of transportation system and has played a key role in social and economic development in many countries since the 19th century. China is a populous and large economic volume country with a vast territory, and railway transportation is an important part of the integrated transportation system. In recent years, with the development of urbanization, railway transportation has developed rapidly in China. By the end of 2021, the total operation mileage of China's railways has reached 150,000 kilometers, including 40,000 kilometers of high-speed railways. Evaluation of the railway transportation performance has a great significance for building an efficient and comprehensive railway transportation system in China. At present, some progress has been made in theoretical exploration and concrete practice to gain a better understanding of railway transportation performance, including technique for order of preference by similarity to ideal solution (TOPSIS) [1], generalized function [2], coupling mode [3, 4], sequential interactive modeling for urban systems [5], space syntax [6], catastrophe progression method [7]. These methods make a significant contribution to the evaluation of railway transportation performance in a complicated decision-making environment. However, most of these previous studies only consider railway infrastructural, equipment, and service criteria for the assessment of the performance of railway transportation. In general, there are many other factors that affect railway transportation performance, such as safety factors, and green development factors [8–10], and these factors have become more and more important in railway transportation performance evaluation. In fact, the nature of railway transportation performance evaluation actually belongs to the issues of MCDM [11]. In this case, the weights of different factors which are used to distinguish the impact of different factors and the evaluation method which is used to measure the railway transportation performance have a great influence on the assessment results. Therefore, how to determine the index weights [12] and evaluation method [13, 14] reasonably become the key problems of railway transportation performance assessment. In the process of solving the index weight problem of multicriteria decision-making, there are three kinds of reliable methods. The first type is the subjective weighting method, such as expert scoring [15], Delphi [16] and analytic hierarchy process (AHP) [17], interval analytic hierarchy [18]. The second type is the objective weighting method, such as the variation coefficient method [19], variance maximization [20], CRITIC [21], and entropy weight method [22]. The other type is the combination method of subjectivity and objectivity [23–25], such as elimination et choice translating reality [26], fuzzy comprehensive evaluation method [27, 28]. In the process of solving the evaluation method problem of MCDA, there are different ways of ranking and the method chosen depends on the decision maker and the problem. The first type of comprehensive evaluation method is that can directly determine the index weight, including AHP [29, 30], and entropy weight method [31, 32]. The second type of evaluation method that indirectly determines the index weight, includes the fuzzy comprehensive evaluation method [33], matter element analysis method [34], grey comprehensive evaluation method [35], cosine method [36], TOPSIS [37], catastrophe progression method [38], osculating value method [39], relative entropy evaluation method [40], and Bayesian network model [41]. The above studies have developed research methods and applications for railway transportation performance. However, due to the complexity of railway transportation performance evaluation and the limitations of railway transportation statistics, it is difficult to get accurate index weights and obtain an appropriate comprehensive evaluation method for the railway transportation performance evaluation.

Therefore, this paper utilizes the idea of MCDM to propose an objective evaluation method for the evaluation of railway transportation performance in China. It includes the selection of evaluation indexes based on analyzing the characteristics of China's railway transportation, determination of the evaluation index weights, and establishment of an evaluation method. It advances the existing literature on railway transportation performance in at least the following three aspects: (i) establishing the railway transportation performance index, including railway safety, railway infrastructure, railway equipment, operation efficiency, and green development; (ii) using the CRITIC method to identify the weight of different evaluation criteria; and (iii) proposing weighted relative entropy method to evaluate China's railway transportation performance.

The organization of the rest of this research is as follows: Section 2 constructs a research methodology by describing the application steps; Section 3 presents computational procedures and an analysis of the results; and Section 4 concludes and discusses this study.

2. Materials and Methods

The objective of the research is to evaluate railway transportation performance in different railway transportation bureaus in China. The study hypothesis is that railway transportation performance has different levels of development, and could be ranked according to the complex impact of criteria. According to the requirements of this paper, a flow chart of the proposed method is shown in Figure 1.

First. Determination of the index. Based on the relevant research, a railway transportation performance evaluation index system has been proposed according to the principles of the combination of scientific, operability, integrity, dynamic, and stability.

Second. Calculation of the index weight. The index weights are calculated by CRITIC, which could make full use of the information contained in each evaluation index.

Third. Establishing the evaluation method. The railway transportation performance is assessed by applying the CRITIC-relative entropy method.

2.1. Step 1: Determining the Index to Evaluate the Railway Transportation Performance. In this research, based on the characteristics of the railway transportation industry, the railway transportation performance is assessed by safety in production, railway infrastructure, railway equipment, railway operation efficiency, and railway green development. And these indexes are proposed by the principles of the combination of scientific, operability, integrity, dynamic, and stability [39]. The safety in production criteria reflects the development level of operational safety and is of vital importance to the development of the national economy and society. The infrastructural criteria address the development level of the railway network and are important to ensure the capacity of the railway lines. The equipment criteria indicate the modernization level of railway transportation equipment and are the basis for completing the production of passenger transport and freight transport. The operation efficiency criteria measure the operation status level of railway transportation. The green development criteria show the level of sustainability. These indicators comprehensively reflect the characteristics of railway transportation performance from the aspects of quality, quantity, efficiency, safety, and sustainability. Table 1 presents the studied criteria.

The rate of the equivalent incident (C1) [12] and the rate of employee death (C2) present the level of railway safety in production. The length of railway lines (C3) presents the level of the railway infrastructure quantity. The proportion of continuous welded rail (C4), the proportion of double-tracking railways (C5), and the proportion of high-speed railway mileage (C6) present the level of railway infrastructure quality. The number of locomotives (C7), number of passenger cars (C8), and number of freight cars (C9) present the modernization level of railway equipment. Passenger transport intensity (C10) and freight transport intensity (C11) measure the productivity of railway transportation. The revenue rate of transporting passengers person-kilometer (C12) and revenue rate of transporting freight per ton-kilometer (C13) present the level of the economic performance of the railway

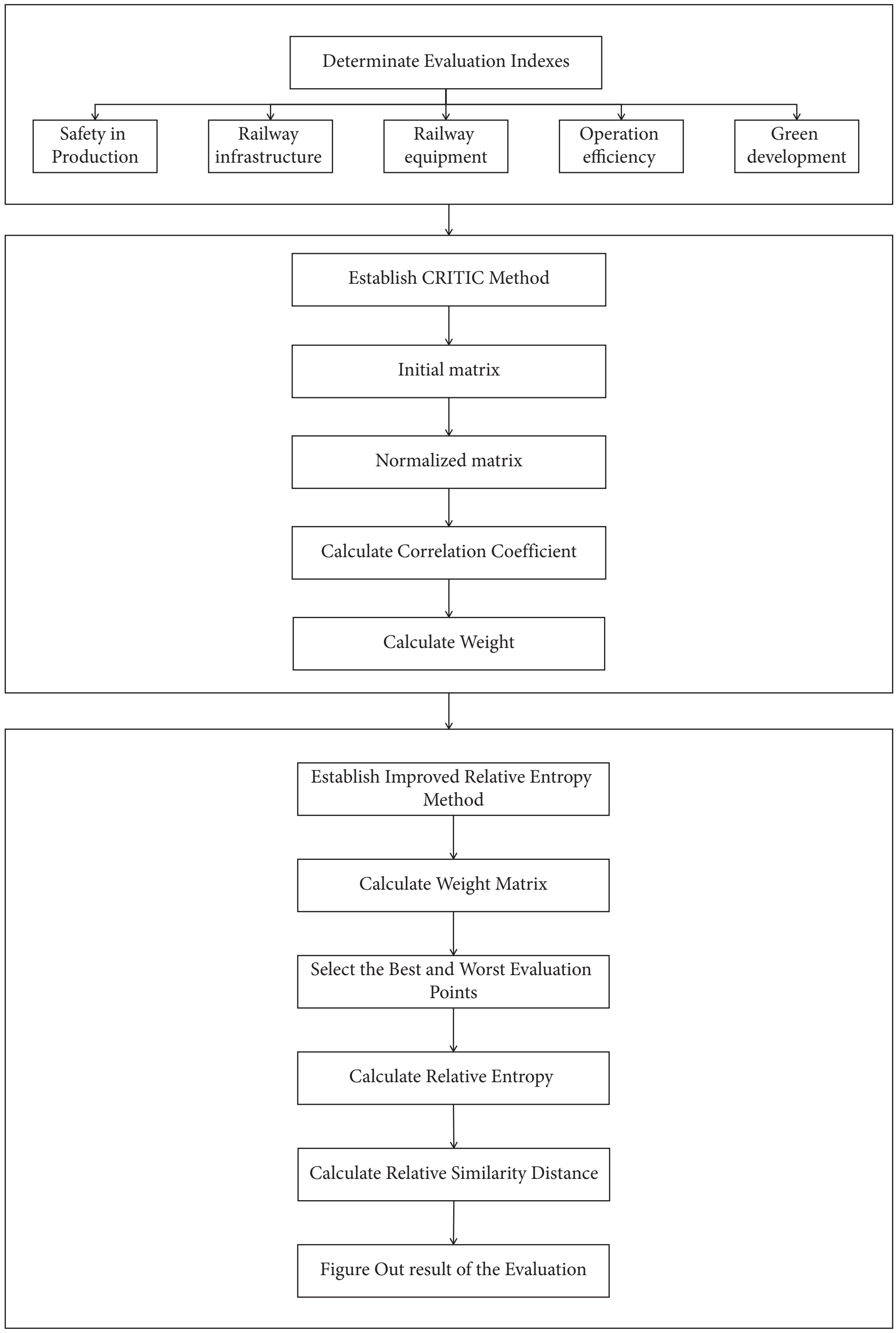

Figure 1: The steps of the railway transportation performance evaluation method.

transportation. The proportion of electrified railways (C14) and comprehensive energy consumption per unit transportation workload (C15) present the level of sustainability development.

2.2. Step 2: Calculation of the Index Weights Based on the CRITIC Method. In the process of railway transportation performance evaluation, it is easy to obtain the evaluation results based on the comprehensive evaluation value with the explicitly given weight vector. Therefore, it is necessary to reasonably determine the index weight to obtain accurate and scientific evaluation results. In this study, CRITIC is proposed to determine the weights of the objectives, and these weights are used to evaluate the relative importance of each objective in making the ranking of railway transportation performance in China. The CRITIC method is an

Table 1: Criteria for the railway transportation performance evaluation.

Criteria Type	Name	Index
Safety in production	C1	Rate of the equivalent incident, 1/million ton*kilometer
	C2	Rate of employees' death, 1/ten thousand employees
Railway infrastructure	C3	Length of railway lines (km)
	C4	Proportion of continuous welded rail (%)
	C5	Proportion of double-tracking railways (%)
	C6	Proportion of high-speed railway mileage (%)
Railway equipment	C7	Number of locomotives
	C8	Number of passenger cars
	C9	Number of freight cars
Operation efficiency	C10	Passenger transport intensity (ten thousand passengers/km)
	C11	Freight transport intensity (ten thousand freight/km)
	C12	Revenue rate of transporting passengers person-kilometer (yuan/one billion person-kilometer)
	C13	Revenue rate of transporting freight ton-kilometer (one billion ton-kilometer)
Green development	C14	Proportion of electrified railway (%)
	C15	Comprehensive energy consumption per unit transportation workload (kg/ten thousand kilometers)

objective weighting method [21], which can reflect the amount of information contained by each index through the relevance of indicators and the conflict between indicators [42]. Among them, the variability of the index is characterized by the standard deviation, which can reflect the size of the difference in the value of the evaluation object under the same indicator, and the conflict between indicators is characterized by the correlation coefficient. The CRITIC method is more objective and scientific [43]. The steps of the CRITIC method are as follows:

Step 1: Determining the decision matrix

For a finite set R of m alternatives and a given system of n indexes, MCDM in its general form can be defined as follows:

$$R = \left(r_{ij}\right)_{m\times n}(i = 1, 2, \cdots, m; j = 1, 2, \cdots, n). \tag{1}$$

Step 2: Calculating standardized matrix

Performing the forward or reverse processing of the decision matrix [44], we get

$$r_{ij}' = \begin{cases} \dfrac{r_{ij}}{\sqrt{\sum\left(r_{ij}^2\right)}}, \\ \\ \dfrac{1/r_{ij}}{\sqrt{\sum\left(1/r_{ij}^2\right)}}, \end{cases} \tag{2}$$

where r_{ij} is the positive index and r_{ij} is the negative index.

Step 3: Calculating the correlation coefficient of the index

The linear correlation coefficient r_{ij}' between index i and index j is defined as follows:

$$\rho_{ij} = \frac{\sum_1^m (r_i - \overline{r_i})\left(r_i - \overline{r_j}\right)}{\sqrt{\sum_1^m (r_i - \overline{r_i})^2 \sum_1^m \left(r_j - \overline{r_j}\right)^2}}, \tag{3}$$

where ρ_{ij} represents the correlation coefficient between the ith index and the jth index; $\overline{r_i}$ and $\overline{r_j}$ represent the mean value of the ith index and the jth index, respectively.

Step 4: Calculating the amount of information covered by each index

A measure of the conflict created by index j with respect to the decision situation defined by the rest of the index is described as follows:

$$c_j = \sigma_j \sum_{i=1}^{n}\left(1 - \rho_{ij}\right), \tag{4}$$

where σ_j represents the mean square deviation of the jth index; c_j represents conflict created by index j with respect to the decision.

Step 5: Calculating the weight of each index

The index weight value is defined as follows:

$$\omega_i = \frac{c_j}{\sum_1^n c_j}. \tag{5}$$

2.3. Step 3: Establishing the Evaluation Method Based on Relative Entropy Method. As mentioned above, the evaluation of railway transportation performance is actually the comparison of the evaluation results of multiple railway transportation bureaus, by applying the MCDM. Therefore, based on an explicitly given weight vector, it is easy to get accurate and scientific evaluation results by establishing an appropriate comprehensive evaluation method. In this study, the weighted relative entropy evaluation method is proposed to analyze railway transportation performance in China. Relative entropy is a basic concept in probability theory and information theory, which is proposed by Kullback and Leibler [45]. The relative entropy evaluation method combines relative entropy with the TOPSIS method [40]. The method uses relative entropy to measure the relative distance between the evaluated scheme and the ideal scheme [46], and the relative closeness degree is applied to identify order relations among all schemes [40, 47, 48]. The concrete steps of the weighted relative entropy evaluation method are as follows:

Step 1: Calculating weighted matrix

The weighted matrix R^* will be normalized by using equations (2)–(5), and the weighted matrix can be defined as follows:

$$R^* = \left(r_{ij}^*\right)_{m\times n}, r_{ij}^* = r_{ij} * \omega_i. \tag{6}$$

Step 2: Determining the positive and negative ideal solution

The positive and negative ideal solutions can be defined as follows:

$$\begin{cases} F_j^+ = \max r_{ij}^*, \\ F_j^- = \min r_{ij}^*, \end{cases} \tag{7}$$

where F_j^+ and F_j^- represents the positive ideal solution and negative ideal solution, respectively; $\max r_{ij}^*$ and $\min r_{ij}^*$ represents the maximum and minimum of the jth index.

Step 3: Calculating the remoteness

The relative entropy of remoteness is determined as follows:

$$\begin{cases} g_j^+ = \sum_{i=1}^{m}\left(F_i^+ \lg\dfrac{F_i^+}{r_{ij}^*} + \left(1 - F_i^+\right)\lg\dfrac{1 - F_i^+}{1 - r_{ij}^*}\right), \\ \\ g_j^- = \sum_{i=1}^{m}\left(F_i^- \lg\dfrac{F_i^-}{r_{ij}^*} + \left(1 - F_i^-\right)\lg\dfrac{1 - F_i^-}{1 - r_{ij}^*}\right), \end{cases} \tag{8}$$

where g_j^+ represents the relative entropy between the jth scheme and positive ideal scheme; g_j^- represents the relative entropy between the jth scheme and negative ideal scheme; and r_{ij}^* represents the weighted decision index.

Step 4: Calculating relative closeness

Relative closeness is determined as follows:

$$S_j = \frac{g_j^-}{g_j^+ + g_j^-}, \quad (9)$$

where g_i^+ and g_j^- represents the relative entropy with the positive ideal scheme and negative ideal scheme, respectively.

Step 5: Figuring out the optimal evaluation unit

It is clearly shown that the smaller of the S_j means a low level of the railway transportation performance, and the bigger of the S_j means a high level of the railway transportation performance.

3. Results and Discussion

3.1. Data. In order to evaluate railway transportation performance in different railway transportation companies in China, the researchers investigate the statistical data of 18 railway bureaus in 2018 published by the China Railway Corporation [49], and some missing data come fromChina Statistical Yearbook 2019. Then, based on the statistical data of 18 railway transportation bureaus, the research normalizes the primitive matrix data and acquires the dimensionless normative matrix by using equation (1). The standardized matrix is shown in Table 2. According to the definition of the evaluation indexes, the 15 evaluation indexes are all fixed-value evaluation indicators. Among them, C1, C2, and C15 are cost evaluation indexes, and others are benefit evaluation indexes. In other words, if C1, C2, and C15 are close to 0, the better the performance of the railway bureau is; if the other evaluation index is close to 1, the higher performance of the railway transportation bureau is.

3.2. Calculation of the Value of the Railway Transportation Performance. According to the results of index dimensionless, the research calculates the weight of each index by using equations (2)–(5), and the results are shown in Table 3. From Table 3, we can see that the weight value of C1, C11, and C13 are larger, and these three indicators have a great influence on the evaluation results.

By using equations (6)–(9), the performance evaluation results of 18 railway transportation bureaus are shown in Table 4. From Table 4, we can find that the railway transportation performance of the 18 railway transportation bureaus is different and indices range from 0.02 to 0.53.

3.3. Discussion

3.3.1. Comparison Evaluation Results of Railway Transportation Performance. According to the evaluation results of railway transportation performance, the performance measurement rank of the 18 railway transportation bureaus is shown in Figure 2.

Judging from the results, it shows that Shanghai Railway Bureau, Zhengzhou Railway Bureau, Taiyuan Railway Bureau, Beijing Railway Bureau, and Guangzhou Railway Bureau round out the top five, which shows that the railway transportation performance of these railway bureaus is well-developed and could drive the development of other railway bureaus. Among them, the railway transportation performance value of Shanghai Railway Bureau has reached 0.53, which is far higher than that of other railway bureaus, and this shows that Shanghai Railway Bureau has achieved high-quality development. The reasons are as follows: Shanghai Railway Bureau which is located in the economically developed Yangtze River Delta region of China, mainly governs the lines in Shanghai, Jiangsu, Zhejiang, and Anhui provinces; the railway network of Shanghai Railway Bureau is the most intensive and perfect, and the undertaken passenger and freight transportation is the busiest in China. On the contrary, Qingzang Railway Bureau, Hohhot Railway Bureau, Urumqi Railway Bureau, Nanning Railway Bureau, and Wuhan Railway Bureau are the bottom five, which shows that the railway transportation performance of these railway bureaus is less developed. Among them, the railway transportation performance value of Qingzang Railway Bureau is the lowest. The reasons are as follows: Qingzang Railway Bureau locates on the Qinghai Tibet Plateau which is called the “global ridge,” and the railway scale, railway equipment quality, and railway operation efficiency are weak.

3.3.2. Spatial Pattern of Railway Transportation Performance. The railway transportation performance is divided into four levels, namely, 0–0.01, underdeveloped railway transportation performance; 0.01–0.20, less developed railway transportation performance; 0.20–0.30, relatively developed railway transportation performance; and >0.30, developed railway transportation performance. And the evaluation results are shown in Figure 3.

According to Figure 3, the following are the main spatial pattern of the railway transportation performance in China: (1) 3 railway bureaus (16.67%) have developed railway transportation performance; 4 railway bureaus (22.22%) have relatively developed railway transportation performance; 8 railway bureaus (44.44%) have less developed railway transportation performance; 3 railway bureaus (16.67%) have underdeveloped railway transportation performance. (2) The railway transportation performance shows a pattern of decline from coastal bureaus toward the interior of the bureaus, with the highest railway transportation performance indices in coastal bureaus and the lowest indices in western bureaus and parts of central bureaus. (3) The railway transportation performance is significantly higher in central and eastern bureaus than in western bureaus, for example, Shanghai Railway Bureau, Zhengzhou Railway Bureau, Taiyuan Railway Bureau, Beijing Railway Bureau, and Guangzhou Railway Bureau have higher railway transportation performance than other areas of China, which is consistent with China’s economic development pattern.

Table 2: The results of index dimensionless.

	Ha'erbin	Shenyang	Beijing	Taiyuan	Hohhot	Zhengzhou	Wuhan	Xi'an	Jinan	Shanghai	Nanchang	Guangzhou	Nanning	Chengdu	Kunming	Lanzhou	Urumqi	Qingzang
C1	0.04	0.01	0.11	0.04	0.02	0.33	0.10	0.13	0.13	0.73	0.14	0.12	0.09	0.19	0.31	0.35	0.09	0.04
C2	0.34	0.43	0.35	0.22	0.12	0.21	0.20	0.18	0.18	0.36	0.18	0.25	0.14	0.25	0.08	0.17	0.12	0.05
C3	0.26	0.44	0.27	0.14	0.20	0.13	0.17	0.16	0.18	0.34	0.26	0.31	0.18	0.32	0.12	0.17	0.20	0.10
C4	0.20	0.24	0.24	0.23	0.24	0.24	0.25	0.25	0.25	0.24	0.22	0.24	0.24	0.25	0.23	0.25	0.19	0.25
C5	0.16	0.19	0.27	0.29	0.15	0.32	0.35	0.23	0.27	0.28	0.23	0.26	0.19	0.20	0.14	0.24	0.19	0.14
C6	0.12	0.19	0.22	0.11	0.05	0.26	0.23	0.15	0.28	0.36	0.36	0.39	0.29	0.25	0.24	0.18	0.12	0.06
C7	0.22	0.40	0.33	0.23	0.19	0.26	0.20	0.26	0.15	0.29	0.14	0.27	0.16	0.27	0.12	0.27	0.16	0.07
C8	0.27	0.33	0.14	0.10	0.12	0.11	0.13	0.11	0.17	0.48	0.26	0.47	0.14	0.32	0.12	0.11	0.16	0.05
C9	0.26	0.44	0.27	0.14	0.20	0.13	0.17	0.16	0.18	0.34	0.26	0.31	0.18	0.32	0.12	0.17	0.20	0.10
C10	0.11	0.14	0.31	0.14	0.05	0.29	0.29	0.18	0.21	0.53	0.24	0.40	0.16	0.24	0.12	0.09	0.05	0.04
C11	0.14	0.14	0.20	0.84	0.18	0.23	0.08	0.18	0.19	0.10	0.06	0.06	0.10	0.06	0.08	0.08	0.11	0.06
C12	0.26	0.18	0.29	0.26	0.16	0.17	0.21	0.22	0.19	0.30	0.20	0.29	0.20	0.30	0.36	0.14	0.16	0.20
C13	0.34	0.20	0.15	0.27	0.37	0.16	0.10	0.24	0.22	0.23	0.13	0.12	0.24	0.14	0.26	0.13	0.34	0.34
C14	0.10	0.17	0.24	0.29	0.11	0.27	0.30	0.27	0.30	0.24	0.25	0.24	0.20	0.28	0.23	0.30	0.15	0.12
C15	0.25	0.24	0.22	0.33	0.30	0.23	0.25	0.16	0.23	0.22	0.21	0.22	0.26	0.20	0.16	0.28	0.24	0.18

Table 3: Calculation results of the index weight.

Index	Weight value
C1	0.12
C2	0.06
C3	0.05
C4	0.01
C5	0.04
C6	0.07
C7	0.05
C8	0.08
C9	0.06
C10	0.07
C11	0.15
C12	0.05
C13	0.10
C14	0.05
C15	0.04

Table 4: Evaluation results of railway transportation performance.

Railway transportation bureau	Evaluation value
Ha'erbin	0.13
Shenyang	0.15
Beijing	0.25
Taiyuan	0.34
Hohhot	0.06
Zhengzhou	0.34
Wuhan	0.12
Xi'an	0.16
Jinan	0.20
Shanghai	0.53
Nanchang	0.15
Guangzhou	0.22
Nanning	0.11
Chengdu	0.21
Kunming	0.15
Lanzhou	0.16
Urumqi	0.08
Qingzang	0.02

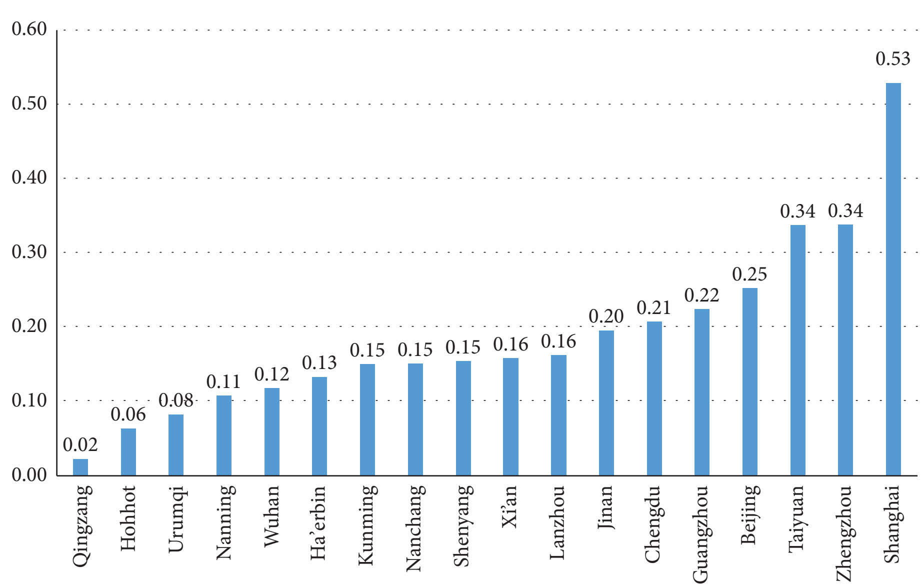

Figure 2: Comparison of performance evaluation results of 18 railway bureaus.

Figure 3: The assessment results of 18 railway bureaus.

4. Conclusions

Railways have unarguably many advantages, such as higher safety, less energy consumption, less pollution, and less traffic congestion, compared to other means of transport. Evaluation of the railway transportation performance has a great significance for building an efficient and comprehensive railway transportation system. Therefore, based on indicators of railway safety, railway infrastructure, railway equipment, operation efficiency, and green development, this research evaluates the railway transportation performance in China in 2018, by applying the CRITIC-relative entropy evaluation method. The findings are as follows: (1) In 2018, the railway transportation performance of the 18 railway transportation bureaus is different, among which Shanghai Railway Bureau is the most developed and Qingzang Railway Bureau is underdeveloped. (2) In 2018, the railway transportation performance in nearly 40% of the bureaus of China is ideal. (3) In 2018, the railway transportation performance is significantly higher in central and eastern bureaus than in western bureaus, which is consistent with China's economic development pattern. The results of this research could be used to improve the sustainability of the railway transportation bureau in China.

Data Availability

(1) The statistical data of 18 railway transportation bureaus in 2018 published by the China Railway Corporation; (2) company portals of the railway transportation bureaus; (3) China Statistical Yearbook 2019.

Conflicts of Interest

The authors declare no conflict of interest.

Authors' Contributions

L.Z. and S.Q. performed conceptualization; S.Q. curated the data; L.Z. and Q.C. performed the formal analysis; L.Z. acquired funding; L.Z.developed methodology; L.Z. wrote the original draft; L.Z. and C. Q. reviewed and edited the manuscript.

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