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Performance Evaluation of High-speed Railway Construction Projects Based on Combinatorial Weighting and Mutation Progression Method

*Yunyun Wang**
School of Management, Wuhan University of Technology
430070 Wuhan Hubei
P. R. China
qdwyy2008@163.com

ABSTRACT

To promote sustainable development of performance evaluation of high-speed railway construction projects, to summarize the gains and losses of construction projects in time, and to further improve project management, project quality and fund use efficiency, the performance evaluation index system is designed and developed. It's based on existing theoretical research results and domestic and foreign practical experience, according to the personalized characteristics of high-speed railway construction projects. Combined with entropy method, CRITIC (Criteria Importance Though Intercrieria Correlation) method and catastrophe theory, a performance evaluation model of high-speed railway construction project is constructed by combining weighted and catastrophe sequence. The main idea of this evaluation method is to get combined weights of each index by combining the entropy evaluation method with subjective and objective factors, and then it judges the performance level of high-speed railway construction projects by combining mutation sequence method. The example analysis shows that performance of high-speed railway construction projects is mainly reflected in three stages, namely design and construction, completion acceptance and operation and maintenance. It indicates that the evaluation index system is suitable for performance evaluation of projects under construction and completed projects, and has a positive promoting role in improving implementation effect and influence of railway construction projects, and has potential popularization and application value.

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1. Introduction

It is the practice of international financial organizations to evaluate the performance of high-speed rail construction projects, and an independent evaluation body has been set up to specifically handle this work. These organizations believe that project performance evaluation can work in three areas, namely accountability, learning, and resource allocation. At present, most developed countries have established a scientific and reasonable post-evaluation system, and the evaluation content runs through the whole process of project design, construction management and implementation effect (Tang et al., 2020). In China, performance *evaluation of domestic investment projects began in 2004, while performance evaluation of construction projects involving foreign loan investment began in 2008 and was improved in 2019, marked by the Ministry of Finance's release of the Performance Evaluation Management Measures for Loans and Grants Projects of International Financial Organizations and Foreign Governments on the basis of comprehensive relevant management measures. From the above international operating norms and management regulations issued by China, the promotion of project performance evaluation from the pilot to all construction investment projects in China, especially large-scale investment projects, has become an objective requirement. In accordance with this trend, it is very necessary and of great practical significance to strengthen the pilot work of performance evaluation of China's railway investment construction projects.*

In recent years, construction of high-speed railway in China has made rapid progress, and investment in fixed assets of high-speed railway has maintained a high level, reaching 823.9 billion RMB, with an average annual value of about 753.56 billion RMB. According to the 14th Five-Year Plan for the Development of Modern Comprehensive Transportation System, it is expected that by 2025, China's railway operating mileage will reach 165,000 kilometers, including 50,000 kilometers of high-speed railways. According to the Medium and Long Term Railway Network Plan, the railway network will reach 200,000 km by 2030, including 70,000 km of high-speed railways. Therefore, during this period, there will be a large number of new projects under construction in addition to the railway projects already under construction. In accordance with the relevant requirements of the Ministry of Finance, the competent department of railway construction projects has begun to conduct performance evaluation pilot including loans from the World Bank and the Asian Development Bank. It has initially formed a set of index system framework for performance evaluation of railway engineering projects, but is still in the stage of trying, exploring and gradually improving. It has not been formally implemented on the whole road. Therefore, it is very necessary to conduct theoretical research on performance evaluation and form a relatively perfect index evaluation system to promote the further development of performance evaluation in practice.

2. Literature Review

From the existing literature, foreign research on performance evaluation mainly focuses on three aspects. Firstly, it's performance evaluation index system. Diaz et al. proposed a theoretical framework for performance evaluation of construction projects based on six key performance indexes (KPIs), namely time, cost, quality, safety, on-site dispute minimization and environmental impact. Suprun & Stewart (2015) identified 36 sustainability indexes through literature analysis and expert opinions by adopting SF-entropy and fuzzy logic based methods. A sustainable development performance evaluation framework based on indexes was constructed to measure project performance. Ozorhon (2013) defined safety evaluation index of the railway transportation system of decision support system (DSS). Ozorhon et al. (2016) established a two-dimensional index based on scientific research input-output, built a theoretical framework for expert post-evaluation, used Delphi method to determine evaluation indexes at all levels, and entropy method to calculate the weights of indexes at all levels, and applied them to the evaluation system of research-based hospitals. The second is the research of performance evaluation method. Liu et al. (2018) established an enterprise performance evaluation system based on three dimensions of finance, society and ecology from a new perspective of environmental value chain, and evaluated the performance of three maritime enterprises by establishing overall, static, dynamic and comprehensive scoring models. Williams et al. (2013) used the multi-MCDM (mixed MCDM) method for comparative analysis and group decision-making to evaluate the logistics performance of 160 countries in the Organization for Economic Cooperation and Development. Dikmen et al. (2005) used a comprehensive indexing approach to assess e-service delivery performance. Thirdly, it's performance management research. Ghaben et al. (2017) analyzed the theoretical basis of port enterprise performance management under the condition of low-carbon economy. Zhou & Tang (2015) used data envelopment analysis (DEA) to establish an index system for engineering supervision, organization management and performance evaluation. Based on comprehensive analysis of the characteristics of engineering supervision organization and construction of DEA model index system, an evaluation method was proposed to analyze the main influencing factors of engineering supervision organization performance management.

Research on construction project performance evaluation involves many fields, and the literature with high relevance to this study mainly focuses on the following aspects. For example, Malekzadeh et al. (2021) analyzed the social impact assessment framework of World Bank loan projects and concluded that all the 10 criteria in the new framework integrated environmental and social factors. Dewi et al. (2019) put forward the evaluation index system of China's international aid projects, including objective evaluation index, process evaluation index, effect evaluation index and sustainable evaluation index. Then, it's research on performance evaluation standards of government-invested construction projects. Fartash et al. (2018) adopted percentage method and non-equidistant interval progressive average algorithm to develop corresponding standard scores and standard intervals respectively, and obtained standard coefficient of performance evaluation of government-invested capital construction projects. The third is research on the performance evaluation index of construction projects with great strategic significance. For example, Bahadori et al. (2021) built the evaluation index system of China's "Belt and Road" investment projects according to the principle of index system construction. The fourth is research on performance evaluation of transportation construction projects. He et al. (2018) studied performance evaluation index system of expressway construction projects, mainly analyzed and explained the meaning of indexes at each level, and obtained the index value. Besides research on performance evaluation indexes, there are also research on project management performance. Wang et al. (2020) systematically studied performance evaluation of construction project management and established a set of construction project management performance evaluation methods based on project management theory, performance evaluation theory, incentive theory, investigation, structural equation and statistical analysis. Specifically in the field of railway, there are relatively few studys on performance evaluation, mainly as follows. Tu et al. (2017) analyzed the problems and causes of performance evaluation of railway construction engineering projects, and put forward supporting measures and suggestions to speed up performance evaluation of railway construction engineering projects. Hoglmeier et al. (2013) evaluated and studied technical interface management maturity of railway bridge and tunnel engineering in difficult mountainous areas, and proposed an evaluation model based on variable weight and bullseye proximity. Bortoli et al. (2020) and Lin et al. (2019) statistically analyzed theoretical research results of relevant scholars, and designed performance evaluation index of railway material procurement based on the principles of "effectiveness, efficiency and economy".

The above correlation research provides a useful reference for constructing a scientific and reasonable project performance evaluation index system in railway industry. However, due to the different characteristics of the project, pertinence of these indexes is single and limited, and can only be used as a reference. Specific to the relevant research in the field of railway, although some literature has analyzed the main problems existing in the performance evaluation of construction projects, index system is not discussed too much. Some literature involves specific evaluation indexes of railway projects, but they only start from the aspect of procurement, without analyzing and refining construction projects, and lack pertinity. Therefore, on the whole, current research on performance evaluation index of railway construction projects can not meet the urgent needs of theoretical research and railway construction practice, and there is still a lot of room for improvement, which is the purpose of this study.

3. Methods

In this study, the entropy-CRITIC (Criteria Importance Though Intercrieria Correlation) combination weighting and mutation series method are used to evaluate the performance of high-speed railway construction projects. Before mutation progression evaluation method is used, the entropy-CRITIC combination weighting is used to calculate the weight of each index.

3.1 Basic Model of Mutation Progression Evaluation Method

3.1.1. Mutation Model

In the mutation series evaluation model, it supposes that there is a potential function $f(x)$ *for a certain mutation type, and lets* $f^{'}(x)=0$ *be solved to get the equilibrium surface. Then, it lets* $f^{''}(x)=0$ *be solved to get the singularity set equation of the equilibrium surface. Finally, it* *solves $f^{'}(x)=0$ and $f^{'}(x)=0$ to get the branch break point set equation, which is the research focus and core of mutation theory. When control variable conforms to branch break point set equation, target system will mutate.*

1) Derivation process of bifurcation equation, taking cusp abrupt change model as an example: Firstly, potential function of the cusp mutation model is $f(x)=x^4+Bx^2+Cx$, where $f^{'}(x)=0$, $12x^2+2B=0$ is obtained. Secondly, it solves equation $f^{'}(x)=0$ and equation $f^{''}(x)=0$ to get the branch point set equation $B=-6x^2$, $C=8x^3$ in the decomposition form of cusp point mutation model. Finally, it combines the above two branch point set equations to get the bifurcation equation $8B^3+27C^2=0$.

Similarly, bifurcation point set equation of other mutation models can be obtained as follows:

2) Branch point set equations of dovetail mutation model $f(x)=x^5+Bx^3+Cx^2+Dx$ in decomposition form are $B=-6x^2$, $C=8x^3$, $D=-3x^4$.

3) Branch point set equations of butterfly mutation model $f(x)=x^6+Bx^5+Cx^3+Dx^2+Ex$ in decomposition form are $B=-10x^2, C=20x^3, D=-15x^4, E=4x^5$.

4) Branch point set equations of shack mutation model $f(x)=x^7+Bx^6+Cx^5+Dx^3+Ex^2+Fx$ in decomposition form are $B=-x^2, C=2x^3, D=-2x^4, E=4x^5, F=-5x^6$. Shed mutation model is not an elementary mutation model (state dimension 1, control dimension 5), but it is often used in mutation progression evaluation models.

3.1.2. Non-dimensional Processing of Evaluation Indexes

Evaluation index mainly includes qualitative index and quantitative index, in which quantitative index is treated without dimension by using range transformation method. Delphi method or questionnaire method is used to transform qualitative indexes into quantitative indexes. According to different evaluation indexes, quantitative indexes can be divided into positive indexes and negative indexes. Among them, the larger the positive index value, the better. The smaller the reverse index value, the better. Forward and reverse indicator conversion formula is shown in (1) and (2).

$$\delta_{ij}^{+}=\frac{x_{ij}-\min x_j}{\max x_j-\min x_j} \tag{1}$$

$$\delta_{ij}^{-}=\frac{\max x_j-x_{ij}}{\max x_j-\min x_j} \tag{2}$$

3.1.3. Normalization Formula of Mutation Model

Taking cusp mutation model as an example, solving $B=-6x^2$ and $C=8x^3$ yields $x_B=\sqrt{-\frac{B}{6}}$ and $x_C=\sqrt[3]{\frac{C}{8}}$, where x_B corresponds to the x value of B and x_C corresponds to the x value of C. In order to combine with fuzzy mathematical membership function, value range of control variable and state variable is the same. Their value is limited to [0,1]. It lets $B=6B^{'}$, and $C=8C^{'}$, to get $x_B=\sqrt{B^{'}}$, $x_C=\sqrt[3]{C^{'}}$. Thus, values of $B^{'}$, $C^{'}$ and x are restricted to [0,1], and combination of mutation model and fuzzy mathematics is realized. Normalization formula of cusp mutation model is obtained $x_B=\sqrt{B}$, and $x_C=\sqrt[3]{C}$. Similarly, normalization formula for solving other mutation models is shown as follows (Table 1).

Mutation type	Control dimension	Potential function	Normalization formula
Folding mutation	1	$f(x)=x^3+Bx$	$x_B=\sqrt{B}$
Cusp mutation	2	$f(x)=x^4+Bx^2+Cx$	$x_B=\sqrt{B},x_C=\sqrt[3]{C}$
Dovetail mutation	3	$f(x)=x^5+Bx^3+Cx^2+Dx$	$x_B=\sqrt{B},x_C=\sqrt[3]{C},x_D=\sqrt[4]{D}$
Butterfly mutation	4	$f(x)=x^6+Bx^5+Cx^3+Dx^2+Ex$	$x_B=\sqrt{B},x_C=\sqrt[3]{C},x_D=\sqrt[4]{D},x_E=\sqrt[5]{E}$
Shed mutation	5	$f(x)=x^7+Bx^6+Cx^5+Dx^3+Ex^2+Fx$	$x_B=\sqrt{B},x_C=\sqrt[3]{C},x_D=\sqrt[4]{D},x_E=\sqrt[5]{E},x_F=\sqrt[6]{F}$

Table 1. Normalization formulas of commonly used mutation models in mutation progression method

3.1.4. Selection principle of mutation decision

According to different influence directions of control variables on state variables, system abrupt decision follows two principles, namely "complementary" and "non-complementary". Complementarity principle means that control variables in the system are complementary to state variables, and value of intermediate state variable x *is the average value of initial mutation sequence of the control variables, then* $x=(x_1+x_2+\cdots+x_n)/n, n\le 5$. *The principle of non-complementarity means that none of control variables in the system has any effect on state variable. In this case, value of intermediate state variable* x *is the minimum value of state variable, then* $x=min\{x_1, x_2, \cdots, x_n\}, n\le 5$. *is the state variable, and are mutation level values of the lower control variables respectively.*

3.2. Improvement of mutation progression evaluation method based on combination weighting

At present, most scholars use Delphi method or questionnaire survey to rank control variables, but the ranking results are often highly subjective and cannot be changed according to relative change degree of each control variable. It results in the lack of objectivity and rationality of evaluation results. This study uses combined weight method of entropy and CRITIC to sort importance of evaluation indexes, which ensures objectivity and rationality of performance evaluation index system of high-speed railway construction projects.

3.2.1 Entropy Method

Entropy method is an objective weighting method used to judge statistical dispersion of indexes. When the information is less, the greater the uncertainty, the greater the entropy. When there is more information, uncertainty decreases and entropy decreases. The weight of evaluation index is determined according to its entropy. The greater the relative change of the index, the greater its weight. General procedure of entropy method can be divided into the following steps.

1) It calculates specific gravity γ_{ij} *of* x_{ij}*, where:*

1) It calculates specific gravity γ_{ij} *of* x_{ij}*, where:*

$$\gamma_{ij}=\frac{x_{ij}}{\sum_{i=1}^{m}x_{ij}}, (i=1,2,3,\cdots,m, j=1,2,3,\cdots,n) \quad (3)$$

2) It calculates the entropy ρ_j *of item j, where:*

$$\rho_j = -k\sum_{i=1}^{m}\gamma_{ij}\ln\gamma_{ij}, (i=1,2,3,\cdots,m, j=1,2,3,\cdots,n),\ k=\frac{1}{\ln m}(m \text{ is sample size}) \quad (4)$$

3) It calculates the difference coefficient μ_j of item j, where:

$$\mu_j = 1-\rho_j \quad (5)$$

4) It calculates the weight w_j of item j, where:

$$w_j = \frac{\mu_j}{\sum_{j=1}^{n}\mu_j} \quad (6)$$

5) The outermost index weight $W=(w_1,w_2,\cdots,w_n)$ is determined according to the above steps, and weight values of the lower indexes are added to obtain weight values of the upper indexes. According to this method, all weight values of performance evaluation indexes of high-speed railway construction projects are decomposed into the bottom indexes.

6) According to the weight vector $W=(w_1,w_2,\cdots,w_n)$, it ranks the importance of performance evaluation indexes of high-speed railway construction projects, and obtain the overall ranking of indexes.

3.2.2. Objective Weight Calculation based on CRITIC Method

Indexes evaluating performance of high-speed railway construction projects often have a certain correlation. In this study, CRITIC method is used to calculate objective weight. Assuming that there are m *schemes and each scheme has* n *indexes, evaluation matrix* X *can be represented, and elements in the matrix evaluate values of the schemes under the corresponding indexes. The calculation formula is shown in equation (7).*

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix} \quad (7)$$

1) Index Homology Processing

When determining risk assessment indexes, there may be some negative indexes, such as the quality of prefabricated parts. The greater the value of the index, the lower the risk, while the greater the value of the positive index, the higher the risk. When these two indexes exist at the same time, it will increase the difficulty of calculation. Therefore, in order to facilitate calculation, it is necessary to carry out codirectization of indexes when necessary. The conversion formula is shown in equation (8).

$$x'_{ij} = \frac{1}{\lambda + \max|X_i| + x_{ij}} \quad (8)$$

In the formula, index value is represented by x_{ij}. Index values of homologization are expressed as x'_{ij}. The maximum value of the i*-th indicator is represented by $max|X_i|$. The compatibility coefficient is expressed as λ and is generally set to 0.1. After the above processing, evaluation matrix X' after the positive transformation can be obtained.*

2) Standardization of Indexes

Since the meaning and units of each index in evaluation matrix are different, the value of each index needs to be converted to the same standard, and processing method is shown in equation (9). is index value that has been standardized.

$$x''_{ij} = \frac{x'_{ij} - \min(x'_{ij})}{\max(x'_{ij}) - \min(x'_{ij})} \quad (9)$$

3) Objective weight calculation of indexes

Standard deviation σ_i of each index and correlation coefficient ρ_{ij} can be obtained through standard matrix X''. The calculation formulas are shown in equation (10) and (11).

$$\sigma_i = \sqrt{\frac{1}{m}\sum_{j=1}^{m}(x_j^n - \bar{x}_i^n)^2}, i = 1, 2, \cdots, n \quad (10)$$

$$\rho_{ij} = \mathrm{cov}(X_i^n, X_j^n) / (\sigma_i \sigma_j), i = 1, 2, \cdots, n \quad (11)$$

Where, mean value of index i is represented by x_i''. The covariance between index i and index j is expressed by $\mathrm{cov}(X_i^n, X_j^n)$. The information G_i contained in each index is shown in equation (12).

$$G_i = \sigma_i \sum_{j=1}^{n}(1 - \rho_{ij}), \; i = 1, 2, \cdots, n \quad (12)$$

The larger the G_i, the higher the relative importance of the i index and the greater the amount of information contained. Then objective weight β_i of the indicator i is calculated according to this value, and calculation formula is shown in equation (13).

$$\beta_i = \frac{G_i}{\sum_{j=1}^{n} G_j} \quad (13)$$

4) Determination of comprehensive weight

Subjective weight vector α and objective weight vector β are obtained by entropy method and CRITIC method respectively. Comprehensive weight is composed of these two kinds of weights, and weight of each index in the evaluation process can be fully reflected through their complementarity. In order to make comprehensive weight ω_i as close as possible to α_i and β_i, principle of minimum differentiation information can be adopted to obtain comprehensive weight ω_i. The objective function is shown in equation (14).

$$\begin{cases} \min J(\omega) = \sum_{i=1}^{n}(\omega_i \ln \frac{\omega_i}{\alpha_i} + \omega_i \ln \frac{\omega_i}{\beta_i}) \\ s.t. \sum_{i=1}^{n} \omega_i = 1, \omega_i \geq 0 \quad i = 1, 2, \cdots, n \end{cases} \quad (14)$$

To solve this optimization model, comprehensive weight is obtained, as shown in equation (15).

$$\omega_i = \frac{\sqrt{\alpha_i \beta_i}}{\sum_{j=1}^{n} \sqrt{\alpha_i \beta_i}} \qquad (15)$$

Comprehensive weight vector is shown in equation (16).

$$\omega = [\omega_1, \omega_2, \cdots, \omega_n]^T \qquad (16)$$

3.4. Analysis of influencing factors of performance evaluation of high-speed railway construction projects

According to aforementioned combing of project performance evaluation indexes, combined with the needs of practical work and application, primary indexes of performance evaluation of high-speed railway construction projects should be based on the indexes determined by relevant documents promulgated by the Ministry of Finance. At the same time, secondary and tertiary indexes need to be specialized according to personality characteristics of high-speed railway construction projects.

3.4.1.Identification of evaluation indexes

According to content definition of the above indexes, they can be specifically divided into secondary indexes and tertiary indexes (Table 2). These indexes include evaluation of three important stages of high-speed railway construction project design, completion acceptance, and operation and maintenance. Because these three stages have some different characteristics, application of indexes will be different. For example, selection of evaluation indexes for projects under construction needs to highlight intermediate indexes such as project efficiency, project effectiveness and project sustainability, while completed projects need to highlight two-end indexes of project relevance and project influence.

Target layer	Secondary index	Symbol	Tertiary index	Symbol
Performance evaluation of high-speed railway construction projects	Project relevance	A1	Policy consistency at design time	A11
			Policy consistency during evaluation	A12
			Requirements fit at design time	A13
			Requirements fit during evaluation	A14
	Project efficiency	A2	Project implementation schedule	A21
			Project output progress	A22
			Project asset quality	A23
			Project management efficiency	A24
			Project risk control	A25
	Project effect	A3	Project outcome completion probability	A31
			Benefit distribution goodness	A32
			Cost effectiveness	A33
	Project sustainability	A4	Fund plan availability rate	A41
			Policy-institutional arrangements	A42
			Repayment ability	A43
			Asset economics	A44
			Project operating cost	A45
	Project influence	A5	Transportation network improvement	A51
			Economic driving role of the regions along the route	A52

Table 2. Performance evaluation index system of high-speed railway construction projects

4. Result Analysis and Discussion

Four projects (hereinafter referred to as SD project, AH project, JX project and GD project) belonging to JJ high-speed railway, the backbone line of China's high-speed railway. They are taken as research objects to evaluate the performance evaluation of high-speed railway construction projects. The study score each equipment under different evaluation indexes based on cascade combination scoring method. 1, 3, 5, 7, 9 are used to represent the performance level in each case, and the higher the score, the better the performance level.

4.1. Determine the weights of indexes at all levels

For high-speed railway construction projects, the above four aspects of project relevance, project efficiency, project effect, project sustainability and project influence should be comprehensively evaluated and comprehensive performance level of the project should be determined. According to evaluation model of combination weighted and sudden change sequence method established above, this study adopts entropy-critic group method to determine the weight of each index, and obtains weight value of each tertiary index through calculation (Table 3).

Target layer	Secondary index	Symbol	Tertiary index	Symbol	Entropy weight	CRITIC weight	Comprehensive weight	Ranking
Performance evaluation of high-speed railway construction projects	Project relevance	A1	Policy consistency at design time	A11	0.0785	0.0884	0.0842	4
			Policy consistency during evaluation	A12	0.0262	0.0253	0.0260	17
			Requirements fit at design time	A13	0.0398	0.0353	0.0379	14
			Requirements fit during evaluation	A14	0.0484	0.0722	0.0597	7
	Project efficiency	A2	Project implementation schedule	A21	0.0811	0.0906	0.0866	2
			Project output progress	A22	0.0905	0.0804	0.0862	3
			Project asset quality	A23	0.0686	0.0905	0.0796	5
			Project management efficiency	A24	0.0565	0.0624	0.0600	6
			Project risk control	A25	0.0446	0.0374	0.0413	12
	Project effect	A3	Project outcome completion probability	A31	0.0955	0.0781	0.0873	1
			Benefit distribution goodness	A32	0.0517	0.0351	0.0430	11
			Cost effectiveness	A33	0.0283	0.0341	0.0314	16
	Project sustainability	A4	Fund plan availability rate	A41	0.0569	0.0527	0.0553	8
			Policy-institutional arrangements	A42	0.0153	0.0424	0.0257	18
			Repayment ability	A43	0.0731	0.0408	0.0552	9
			Asset economics	A44	0.0358	0.0291	0.0326	15
			Project operating cost	A45	0.0201	0.0145	0.0172	19
	Project influence	A5	Transportation network improvement	A51	0.0385	0.0418	0.0405	13
			Economic driving role of the regions along the route	A52	0.0505	0.0489	0.0502	10

Table 3. Calculation result of entropy-CRITIC combination method

4.2. Determine the type of mutation system

According to the mutation progression method, mutation system types are classified, and those of each level index in evaluation index system are determined. The type of mutation system corresponding to performance evaluation index system of high-speed railway construction projects designed is shown as follows (Table 4).

Evaluation objective	Mutation type	Secondary index	Comprehensive weight	Mutation type	Tertiary index	Comprehensive weight
Performance evaluation of high-speed railway construction projects	Shed mutation	A1	0.2560	Butterfly mutation	Policy consistency at design time	0.0842
					Policy consistency during evaluation	0.0260
					Requirements fit at design time	0.0379
					Requirements fit during evaluation	0.0597
		A2	0.1096	Shed mutation	Project implementation schedule	0.0866
					Project output progress	0.0862
					Project asset quality	0.0796
					Project management efficiency	0.0600
					Project risk control	0.0413
		A3	0.2449	Butterfly mutation	Project outcome completion probability	0.0873
					Benefit distribution goodness	0.0430
					Cost effectiveness	0.0314
		A4	0.1440	Shed mutation	Fund plan availability rate	0.0553
					Policy-institutional arrangements	0.0257
					Repayment ability	0.0552
					Asset economics	0.0326
					Project operating cost	0.0172
		A5	0.2455	Cusp mutation	Transportation network improvement	0.0405
					Economic driving role of the regions along the route	0.0502

Table 4. Performance evaluation index weights and abrupt system types of high-speed railway construction projects

4.3. Using of mutation progression method for evaluation

(1) According to the requirements of evaluation objectives, this study selects 15 experts from universities and related fields of high-speed railway to score performance evaluation of high-speed railway construction projects according to evaluation standards. Evaluation standards and values of the indexes are shown as follows (Table 5). Among them, high performance of evaluation criteria is the optimal state, which meets the requirements of 90% of the evaluation criteria. Evaluation standard performance is high and 70% of evaluation standard is met. Evaluation criteria medium performance meets 50% of evaluation criteria. Performance of evaluation criteria is low, meeting 30% requirement of evaluation criteria. The worst state is very low performance of evaluation criteria, which does not meet predetermined requirements at all.

Evaluation level	Optimal	Good	Medium	Normal	Poor
Evaluation criteria	High standard	Good standard	Medium level	Low level	Very low level
Corresponding evaluation value	9	7	5	3	1
Corresponding rating level	[9, 10)	[7, 9)	[5, 7)	[3, 5)	[1, 3)

Table 5. Evaluation standards and values of indexes

(2) No dimensional evaluation index. It takes average of the expert score data of each index. The dimensionless treatment of positive index adopts formula (1), and dimensionless treatment of negative index adopts formula (2). Calculation results are shown as follows (Table 6). (+) indicates that indexes at the next level follow the "complementary" principle, and (-) indicates that indexes at the lower level follow the "non-complementary" principle.

Evaluation objective	Secondary index	Tertiary index	Expert rating mean				No dimensional value			
			SD project	AH project	JX project	GD project	SD project	AH project	JX project	GD project
Performance evaluation of high-speed railway construction projects	A1+	A11	8.33	7.13	3.93	3.60	0.667	0.067	0.467	0.300
		A12	4.20	7.00	9.27	9.20	0.600	0.000	0.133	0.100
		A13	7.60	7.93	7.67	7.27	0.300	0.467	0.333	0.133
		A14	5.00	6.87	4.80	6.40	0.000	0.933	0.900	0.700
	A2-	A21	4.27	7.20	5.80	5.13	0.633	0.100	0.400	0.067
		A22	3.93	7.20	3.47	6.80	0.467	0.100	0.233	0.900
		A23	8.47	6.80	3.60	7.47	0.733	0.900	0.300	0.233
		A24	3.47	8.87	7.60	3.67	0.233	0.933	0.300	0.333
		A25	8.53	6.67	4.13	7.00	0.767	0.833	0.567	0.000
	A3-	A31	9.47	6.60	8.20	3.60	0.233	0.800	0.600	0.300
		A32	7.80	9.47	4.20	5.93	0.400	0.233	0.600	0.467
		A33	6.67	8.67	7.47	9.13	0.833	0.833	0.233	0.067
	A4+	A41	5.20	4.00	7.60	5.33	0.100	0.500	0.300	0.167
		A42	6.40	3.93	9.33	5.73	0.700	0.467	0.167	0.367
		A43	4.67	7.07	9.40	9.13	0.833	0.033	0.200	0.067
		A44	5.67	9.20	9.00	3.93	0.333	0.100	0.000	0.467
		A45	7.00	8.47	8.67	9.33	0.000	0.733	0.833	0.167
	A5+	A51	6.33	8.07	7.27	6.07	0.667	0.533	0.133	0.533
		A52	5.33	9.53	4.40	8.67	0.167	0.267	0.700	0.833

Table 6. Index evaluation scores and dimensionless values

(3) Calculating membership function value of mutation series

Firstly, project correlation in the second-level index system of performance evaluation of high-speed railway construction projects includes four tertiary indexes, which belong to butterfly mutation, and ranking of index importance is A11>A14>A13>A12, and belongs to the complementary mutation system, then: $x_{A1}^{1}=\frac{1}{4}(\sqrt{A11}+\sqrt[3]{A14}+\sqrt[4]{A13}+\sqrt[5]{A12})=\frac{1}{4}(\sqrt{0.667}+\sqrt[3]{0}+\sqrt[4]{0.300}+\sqrt[5]{0.600})=0.615$.

The secondary index of performance evaluation of high-speed railway construction projects, project efficiency, includes five tertiary indexes, which belong to hut mutation, ranking of index importance is $A21>A22>A23>A24>A25$*, and belongs to complementary mutation system, then:* $x_{A2}^{1}=\min(\sqrt{A21},\sqrt[3]{A22},\sqrt[4]{A23},\sqrt[5]{A24},\sqrt[6]{A25})=0.747$.

The secondary index of performance evaluation of high-speed railway construction projects, project effect, includes three tertiar indexes , which belong to dovetail mutation, ranking of index importance is A31>A32>A33, and belong to complementary mutation system, then: $x_{A3}^{1}=\min(\sqrt{A32},\sqrt[3]{A31},\sqrt[4]{A34})=0.483$.

The secondary indexes of performance evaluation of high-speed railway construction projects, project sustainability, include five tertiar indexes, which belong to hut mutation, and the ranking of index importance is A41>A43>A44>A42>A45, and belong to complementary mutation system, then: $x_{A4}^{1}=\frac{1}{5}(\sqrt{A41}+\sqrt[3]{A43},\sqrt[4]{A44}+\sqrt[5]{A42}+\sqrt[6]{A45})=0.590$.

The secondary index of performance evaluation of high-speed railway construction projects, project influence, includes two third-level indexes, which belong to cusp mutation, the ranking of index importance is A52>A51, and belong to complementary mutation system, then: $x_{A5}^{1}=\frac{1}{2}(\sqrt{A51}+\sqrt[3]{A54})=0.641$.

Secondly, it is target system. The overall objectives of performance evaluation of high-speed railway construction projects include five secondary indexes, which belong to hut mutation system, and ranking of index importance is A1>A5>A3>A4>A2. It is a complementary mutation system, then performance evaluation results of JJ high-speed railway SD construction project are as follows.

The four sections of JJ high-speed Rail (hereinafter referred to as SD section, AH section, JX section and GD section) belong to $x_{A}^{1}=\frac{1}{5}(\sqrt{A1}+\sqrt[3]{A5}+\sqrt[4]{A3}+\sqrt[5]{A4}+\sqrt[6]{A2})=0.877$.

According to the above calculation methods and steps, performance evaluation results of JJ high-speed railway AH construction project are as follows: $x_{A}^{2}=\frac{1}{5}(\sqrt{A1}+\sqrt[3]{A5}+\sqrt[4]{A3}+\sqrt[5]{A4}+\sqrt[6]{A2})=0.855$.

Performance evaluation results of JX construction project of JJ high-speed Railway are as follows: $x_{A}^{3}=\frac{1}{5}(\sqrt{A1}+\sqrt[3]{A5}+\sqrt[4]{A3}+\sqrt[5]{A4}+\sqrt[6]{A2})=0.909$.

Performance evaluation results of GD construction project of JJ high-speed Railway are as follows: $x_{A}^{4}=\frac{1}{5}(\sqrt{A1}+\sqrt[3]{A5}+\sqrt[4]{A3}+\sqrt[5]{A4}+\sqrt[6]{A2})=0.705$.

4.4. Result Analysis

Through combination weighting method, ranking of the main factors with the highest perfor-

mance level of high-speed railway construction projects is obtained. Completion probability of project results (0.0873)> project implementation progress (0.0866)> project output progress (0.0862)> policy consistency at design time (0.0842). It indicates that special attention should be paid to completion probability of project results in performance process of high-speed railway construction projects to prevent sudden changes. Implementation progress of high-speed railway construction projects has a great impact on the performance of high-speed railway construction projects. Factors such as cost effectiveness (0.0314), policy consistency (0.0260), policy-institutional arrangement (0.0257), and project operating cost (0.0172) have little influence on performance of high-speed railway construction projects.

According to calculation results, performance evaluation results of four high-speed railway construction projects of JJ high-speed rail, including SD project, AH project, JX project and GD project, are sorte. The performance levels are as follows from high to low: JX project >SD Project >AH project >GD project. GD project has the lowest performance level, and the control should be strengthened in terms of completion probability of project results, project implementation schedule, project output progress and consistency of design policies.

5. Conclusions

Firstly, development and design of high-speed railway performance evaluation indexes should not only be universal, but also reflect personalized characteristics of the railway industry. Universality needs to reflect index requirements at the national level, inheriting macro vision and overall requirements in the top-level design, while personalized characteristics should highlight essential characteristics of high-speed railway construction projects that are different from other construction projects. According to this requirement, performance evaluation index system of railway construction project is constructed, which includes 5 secondary indexes and 19 tertiary indexes.

Secondly, entropy-CRITIC combined weights-mutation sequence evaluation method is applied to evaluate performance evaluation of four JJ high-speed railway construction projects, and results show that performance level of JX project is the highest and that of GD project is the lowest. Based on the above analysis, it is found that AHP-CRITIC combination weighting and mutation sequence evaluation methods can reflect fuzziness of the performance evaluation of the evaluated high-speed railway construction project, effectively reduce information loss, and make evaluation results more accurate.

Thirdly, the timing of performance evaluation of high-speed railway projects should be selected according to the characteristics of the projects. Generally speaking, it is more appropriate to conduct performance evaluation in the middle period for projects under construction. For completed projects, there is a certain difference in time. For projects based on economic benefits, it should be carried out 3-5 years after the opening of the project. For projects based on social benefits, performance evaluation should be carried out 8-10 years after the opening of the project.

Declarations of interest

None

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None

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