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STUDY ON GREEN ECOLOGICAL ASSESSMENT OF HIGH-SPEED RAILWAY USING UNASCERTAINED MEASURE AND AHP

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Subject review
Aiming at exploring the ecological effect of high-speed railway construction and operation, this paper establishes a green ecological assessment index system based on the concept of sustainable development, and sets up a green ecological assessment model based on unascertained measure and AHP. During the assessment process, the author firstly constructs the unascertained judgment matrix by introducing the unascertained theory, secondly determines index classification weight by AHP, and thirdly identifies the green grade according to the confidence criterion. On this basis, the author defines the green assessment grades. Then, the author carries out green ecological assessment of Beijing-Shanghai HighSpeed Railway (Xuzhou-Shanghai Section). The ecological score is 7.0089 and the resulting color is turquoise, which is consistent with the concept of sustainable development. The result shows that it is feasible to combine the unascertained measure and AHP into an ecological assessment method for high-speed railway construction project.

Keywords: *AHP; green ecology; high-speed railway construction project; sustainable development; unascertained measure*

Analiza zelene ekološke procjene brzovozeće željeznice primjenom neutvrđene mjere i AHP

Pregledni članak
U svrhu istraživanja ekološkog učinka konstrukcije i funkcioniranja brzovozeće željeznice, u radu se postavlja sustav određivanja indeksa zelene ekološke procjene na temelju koncepta održivog razvoja te se postavlja model ekološke procjene na osnovu neutvrđene mjere i AHP. U tom postupku autor najprije konstruira matricu neutvrđene procjene uvodeći neutvrđenu teoriju, zatim određuje težinu indeksa klasifikacije primjenom AHP, a kao treće određuje ekološki stupanj u skladu s kriterijem povjerenja. Na toj osnovi autor definira stupnjeve ekološke procjene. Zatim autor daje zelenu ekološku procjenu za željeznicu Beijing-Shanghai (dio Xuzhou-Shanghai). Ekološki omjer je 7.0089 a rezultirajuća boja je tirkizna, što je u skladu s konceptom održivog razvoja. Rezultat pokazuje da je izvodivo kombinirati neutvrđenu mjeru i AHP u metodi ekološke procjene za projekt izgradnje brzovozeće željeznice.

Ključne riječi: *AHP; neutvrđena mjera; održivi razvoj; projekt izgradnje brzovozeće željeznice; zelena ekologija*

1 Introduction

As one of the most important breakthroughs in passenger transport technology made in the 20th century, high-speed has become a synonym for modern society [1-3]. Opened in 1964, the Tōkaidō Shinkansen marked the dawn of the era of high-speed, and kicked off half a century of high-speed construction and research [4]. At the sight of Japan's success, developed nations quickly followed suit. High-speed railway sprung up around the world, such as TGV in France (1981), Direttissima in Italy (1988), ICE in Germany (1991), AVE in Spain (1992), the Acela Express in the United States (2000), and the KTC in South Korea (2004). It can be said that almost every developed country has high-speed railway at present [5].

The construction of China's high-speed railway began in 1999. On October 12, 2003, the first high-speed passenger railway line: Qinhuangdao-Shenyang passenger railway was opened. Since then, China has entered the era of high-speed railway construction. In 2008, Beijing–Tianjin Intercity Railway was opened up. The line accommodates trains travelling at maximum speed above 300 km, faster than that of any other Chinese railway at that time. A boom of high-speed railway construction ensued. By the end of 2015, China has built the world's longest high-speed network, consisting of 71 high-speed lines (segments) and 40,000 km of route in service (See Fig. 1) [3]. By 2020, all major and medium-sized cities in China will be covered by high-speed railway.

While stimulating the rapid development of regional economy, the boom of high-speed raiway also brings about greater pressure on the ecological environment. Therefore, reducing environmental burden is a new task for development of high-speed railway. Sustainable development means that high-speed railway construction project should promote economic, environmental, social and technological development. The sustainable development model should be consistent with the operating framework in Fig. 2 [6, 7]. In recent years, the "Green Railway" has become a kind of new concept of sustainable development of transportation. It reduces the negative effects on the ecological environment through the railway's own comparative advantages, and realizes the green environmental protection of high-speed railway from design, construction, operation and management. In order to reduce or avoid the ecological impact caused by high-speed railway construction, it is necessary to carry out the green ecological assessment of high-speed railway construction project.

Before the 1970s, there had not been a complete and orderly system for railway environmental protection. After the 1980s, the environmental protection became an important part of the railway construction. Many countries have conducted extensive and in-depth research into the environmental protection of railway construction such as the United States, Japan and Canada, and made breakthroughs in environmental effect assessment, established reasonable systems. In the feasibility study stage, the environmental effect of railway construction projects should be effectively predicted and demonstrated. In the selection of plans, the environmental protection should cause more concern than the project cost, have effective solutions and practical experience in dealing with the environmental problems of railway projects, and have relatively mature technology in the design of environmental protection. High-speed railway construction project has a wide range of environmental effect assessment, different countries have own environmental quality standards, Japan, Germany and France focus on the use of high technology to solve the environmental effect of high-speed railway construction.

The noise and vibration are the main contents of environmental effect assessment in Japan's railway construction and large-scale railway reconstruction projects [8, 9]. Germany and the United Kingdom have proposed measures to reduce noise and vibration in the environmental effect assessment of high-speed railway. France has focused on the environmental effect of high-speed railway construction.

Figure 1 China's high-speed railway construction plan till 2015 [3]

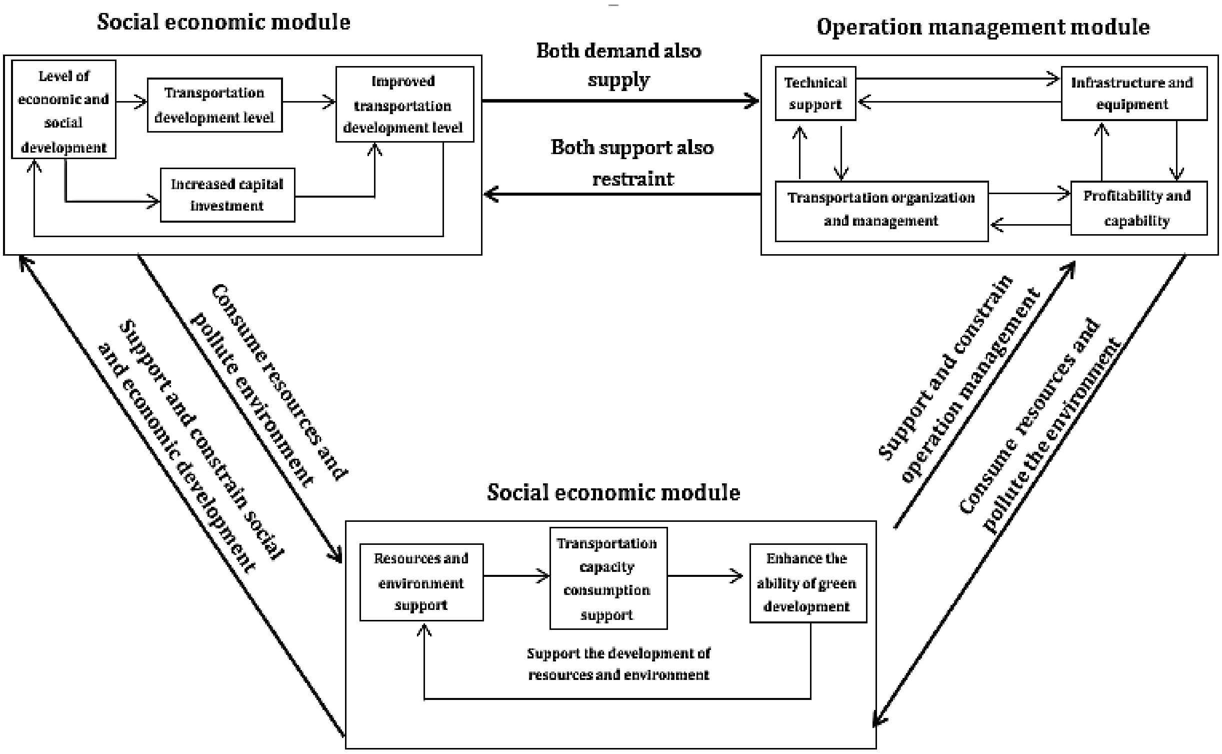

Figure 2 Mode framework for the sustainable development of high-speed railway [7]

In China, the research on railway ecological environment assessment starts early on. With the construction and development of high-speed railway, some scholars have done extensive exploration and research on ecological environmental protection of high-speed railway. Gao et al. [10] propose a semi-quantitative method for predicting the ecological environmental effect of railway construction project in northwestern China, identify the relative importance of acting factors and the levels of effect on ecological factors with the method, and explore the way to predict and evaluate the ecological environmental effect of railway construction project in northwestern China by the fuzzy comprehensive assessment. Jiao [11, 12] has been devoted to the model and method of noise assessment at home and abroad, and put forward to improve theory and method of noise assessment in our country. Chen [13] proposed a new method for environmental effect assessment of high-speed railway by combining LCA multi index assessment method, full scene analysis method, 3S technology and network method.

As for the acoustic environment effect assessment of high-speed railway, Su [14] makes suggestions on the determination of sound source location, and the prediction of noise and distance attenuation in bridge section of high-speed railway. Zhao et al. [15] apply mode prediction method to railway noise prediction, and make effective prediction and assessment of noise both qualitatively and quantitatively. The results show that the proposed method is a comprehensive and effective way to control railway noise pollution. Chen et al. [16] adopt the artificial neural network in the assessment of Qinghai-Tibet Railway and Qinghai-Tibet Highway, and carry out comprehensive quantitative assessment through the effective utilization of the MLP model. Based on the improved BP artificial neural network, Sun [17] establishes a three-layer feed-forward neural network model for the short and medium-term effects of high-speed railway construction, which improves the objectivity and accuracy of the eco-environment assessment. Zhang et al. [18] evaluate the cumulative effect of high-speed railway on eco-environment by scenario analysis, AHP, etc. and obtain qualitative and quantitative cumulative effect.

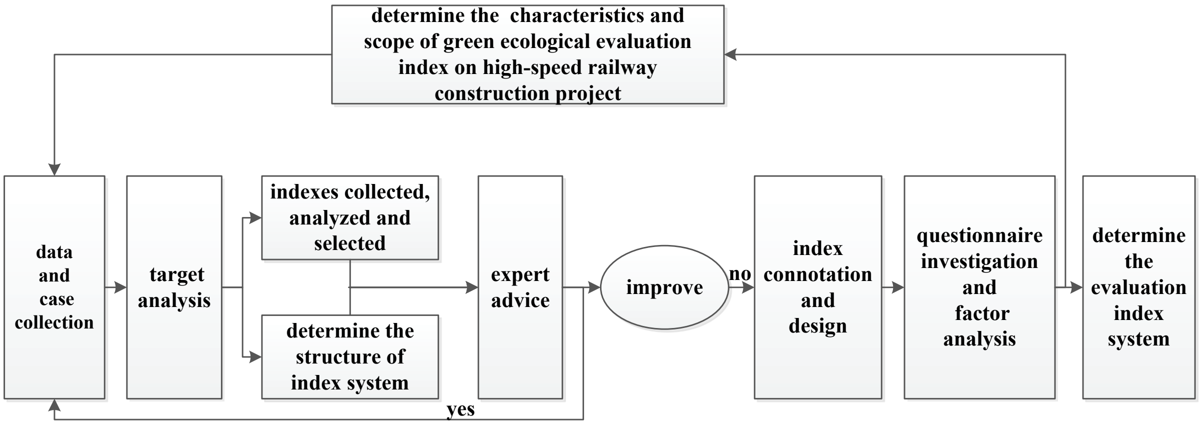

Figure 3 The establishing process of index system of green ecological assessment on high-speed railway construction

As above, most of researchers focus on effect of high-speed railway construction and operation on eco-environment. Only a few of them tackle high-speed railway ecological environmental effect assessment. What is worse, the limited research on ecological environmental effect only discusses qualitative assessment. As for the assessment itself, the index characteristics and assessment methods have great limitations. The assessment results cannot guide the planning, design, construction, operation and management of high-speed railway, and cannot serve as the basis for high-speed railway route selection and decision-making by relevant departments. In light of the research at home and abroad, high-speed railway green ecological assessment is still in the stage of research and development. In-depth research has to be done on this topic. The green ecology of high-speed railway construction is a decision-making process involving multiple uncertain indices. There is great uncertainty and concealment because the decision-maker not only has to consider a lot of quantitative indices but also a large number of qualitative indices. Unascertained theory can better integrate the uncertain information in social science and natural science, and make a comprehensive analysis, which provides a better way to solve such problems. However, there are some shortcomings in using the unascertained measure theory to determine the weights of complex index systems. In this case, the analytic hierarchy process (AHP) should be adopted to determine the weight. By judging the objective reality, the AHP quantifies the relative importance of each layer, and expresses the relative importance weights of all elements on every layer accurately by mathematical methods. As a result, the author combines the unascertained measure theory and AHP to construct a green ecological comprehensive assessment model for high-speed railway construction project. Based on the model, the author carries out a thorough research on the green ecological assessment of Beijing-Shanghai High-Speed Railway (Xuzhou-Shanghai Section), which lays a solid foundation for establishing and improving the green ecological assessment theory of high-speed railway construction project in China.

2 Construction of assessment index system

2.1 Selection principle of assessment index

Since 1992, when the United Nations Environment and Development Conference was held in Rio de Janeiro, the international community has continued to promote the implementation of various sustainable development plans and agendas. In 1994, China adopted *"The Administrative Center for China's Agenda: 21"* [19], which proposed to promote integrated economic, social, environmental and resource strategies for sustainable development objectives. Therefore, this paper is based on the idea of high-speed railway construction project situation and sustainable development with reference to relevant research results [20-22] combined with systematic interviews with experts working in government departments, construction enterprises, design units, railway transport departments, consulting units and research institutes, and prepares a questionnaire for green ecological assessment of high-speed railway construction project on the basis of interview findings. After a pretest among selected samples and reliability and validity tests, the questionnaire is optimized, improved and finalized. Next, the author extracts common factors with factor analysis method and field survey. Giving comprehensive consideration to the interrelation between the various factors, the author finally constructs a post assessment index system for high-speed railway construction projects. Four layers of indices are introduced, namely the target layer (main index), criteria layer (first indices), sub-criteria layer (secondary indices), and solution layer (third indices). See Fig. 3 for the construction process of the green ecological assessment index system for high-speed railway construction project, and see Tab. 1 for the green ecological assessment index system.

2.2 The principles of determining the classification criteria for green ecological assessment indices

See Tab. 1 for the classification criteria for green ecological assessment indices of high-speed railway construction project. The principles are as follows:

(1) Standardization of index data: Data standardization, namely the dimensionless and normalization of data, is the method to eliminate the influence of primitive variables through mathematical transformation. Different assessment indices have different units, even if they have different indices of the same unit, the magnitude of their numerical value varies greatly, which is the different dimension. If index values of different dimensions are used directly in comprehensive assessment, it is possible to exaggerate the role of the larger values.

(2) Quantification of indices: For most of the indices that constitute the assessment index system has been quantified, you can directly adopt a certain method for comprehensive assessment. The qualified indices imported to the comprehensive assessment index system should be quantified. The quantification method reveals the position of the evaluator, and affects the conclusion of the assessment. In this paper, there are several index quantification methods: AHP, expert scoring (Delphi) and scale scoring.

(3) Determination of index standard value: The index standard value is a very important quantity in the assessment process. It is the standard to measure the satisfaction degree of the target value of the evaluated object. Normally, the index standard value reflects people's requirements on the level of development of a certain aspect of the assessment object in a certain period. The requirements demonstrate the objective possibility for a certain aspect of a class of objects or a certain object to reach the level of development, and the subjective expectations of people on the objects. In the green ecological assessment index system of high-speed railway, the index standard value should reflect the general requirement of "greenness". The index standard value of railway green assessment must be determined in accordance with relevant national codes and plans and in view of the characteristics of the railway.

3 Unascertained measurement [23, 24]

The concept of "uncertainty" is first proposed by Mill in 1836 [25]. It exists extensively in subjective and objective worlds. The uncertain information carries two fundamental connotations: randomness and ambiguity. In 1933, the Soviet mathematician Kolmogorov proposed the stochastic problem for the first time, and established the probability theory and the axiomatic method [26]. In 1965, American scholar Zaden gave the concept of fuzzy information in 1965, and created the fuzzy set theory, which developed the research area of uncertainty [27]. Deng, a scholar in China, founded the grey system theory in 1982 [28]. Based on the research of grey system theory, Wang established a universal grey set in 1991, which contained all kinds of uncertain information [29]. In 1990, according to the needs of architectural engineering theory, Academician Wang, a famous scientist in China, proposed three kinds of information concepts, namely, unascertained information, which is distinguished from random information and fuzzy information [30]. At present, there is a unified understanding of fuzzy information, random information and gray information in uncertain information, but there is no uniform definition for unascertained information. However, theorists basically agree that unascertained information is a purely subjective uncertainty resulting from the decision maker's lack of information to determine the true state and quantity of the object. The subjective and cognitional uncertainty, arising from the decision maker's inability of determining the actual status and quantity of things under the lack of information and objective constraints, is fundamentally different from concepts like randomness, which only deals with things bound to happen in future, fuzziness, which reflects the nature of a certain feature of things that do not have any clear definition and assessment target, and grayness.

Thanks to the concerted efforts of scholars like Álvaro [31] and Wu [32], so far, a systematic theory and method have been developed for unascertained information, which is first proposed by Academician Wang.

Setting F as the property space of object space U, $\{F_1, F_2, \cdots, F_k\}$ are some of the divisions of F, and there are a lot of property factors x to affect object space U which are considered as indices or attributes. Supposing there are m attributes $\{I_1 \quad I_2 \quad \cdots \quad \cdots \quad I_m\}$ that influence factors x, then $I = \{I_1 \quad I_2 \quad \cdots \quad \cdots \quad I_m\}$ can be referred to attribute space in object space U. If x_i for any given $\in U$, set observed value I_j of influencing factors x about a sort of attribute j as x_{ij} that can be precisely measured. However, when information is unknown or incomplete, it is difficult or even impossible to show the properties F of factor x_i with observed value x_{ij}. In fact, the expression of varying degree in nature reflects the difference in quantization of some attributes, and then the degree of quantization can be present in the form of data that can be estimated or indirectly measured. However, the measurement standards and conditions, including normalization, additivity and non-negativity, must be met. Only in this way can we obtain a measurement to describe the degree of nature, which is referred to as an unascertained measure.

Table 1 The index system and classification standard of green ecological assessment of high-speed railway construction project.

Overall index	First index	Secondary index	Grading standards				
			Non green	Yellow green	Green	Turquoise	Dark green
Green ecological assessment of high-speed railway construction project G	Ecological protection G_1	Bypass and avoidance rate of ecological sensitive area G_{11}	1-3	3-5	5-7	7-9	9
		Farmland occupation ratio (%) G_{12}	>90	80-90	70-80	60-70	<60
		Influence degree of animal species G_{13}	1-3	3-5	5-7	7-9	9
		Influence degree of plant species G_{14}	1-3	3-5	5-7	7-9	9
		Utilization rate of excavation (%) G_{15}	<20	20-40	40-60	60-80	>80
		Ratio of the bridges and tunnels (%) G_{16}	<10	10-20	20-40	40-60	>60
		Landscape coordination degree G_{17}	1-3	3-5	5-7	7-9	9
	Soil and water conservation G_2	Governance rate of disturbed landform (%) G_{21}	>80	80-90	90-95	95-100	100
		Control rate of soil and water loss (%) G_{22}	<80	80-85	85-90	90-95	>95
		Control degree of soil and water loss (%) G_{23}	<75	75-85	85-90	90-95	>95
		Control ratio of soil loss G_{24}	>2.5	2.0-2.5	1.5-2	1.0-1.5	1.0
		Stopped slag rate (%) G_{25}	<80	80-90	90-95	95-100	100
		Vegetation restoration coefficient (%) G_{26}	<80	80-90	90-95	95-100	100
	Environmental effect G_3	Dust control rate G_{31}	1-3	3-5	5-7	7-9	9
		Standard discharge rate of construction waste water G_{32}	1-3	3-5	5-7	7-9	9
		Standard rate of construction noise G_{33}	1-3	3-5	5-7	7-9	9
		Variation of SO_2 and NO_2 G_{34}	1-3	3-5	5-7	7-9	9
	Social and economic benefits G_4	Demolition satisfaction G_{41}	1-3	3-5	5-7	7-9	9
		Ratio of environmental protection investment (%) G_{42}	0-1	1-2	2-3	3-5	5
		Degree of public participation G_{43}	<50	50-60	60-80	80-90	>90
		Environmental benefits yield (%) G_{44}	<2	2-4	4-6	6-7	>7

4 The establishment of the unascertained measure model [23, 24]

Set $x_1, x_2,..., x_n$ as assessment objects of study, set object space $U = \{x_1, x_2,..., x_n\}$. The assessment $x_i \in U$ $(i = 1, 2,..., n)$ has m first indices $I_1, I_2,..., I_m$, and $\overline{I} = \{I_1, I_2,..., I_m\}$. For $I_i \in \overline{I}$ has k secondary assessment indices $I_{i1}, I_{i2},..., I_{ik}$, and $\overline{I_i} = \{I_{i1}, I_{i2},..., I_{ik}\}$. Therefore, x_{ij} can be expressed as k dimensional vector $x_{ij} = \{x_{ij1}, x_{ij2},..., x_{ijk}\}$, x_{ijr} means the value of the secondary indices of I_j, which is x_i's first index. Each x_{ijr} has p assessment grades $c_1, c_2,..., c_p$, and the assessment space is $C = \{c_1, c_2,..., c_p\}$.

4.1 The single-index measure
4.1.1 The single-index measure matrix

Set $\mu_{ijrq} = \mu(x_{ijr} \in c_q)$ to express the degree that x_{ijr} belongs to c_q, which is the q^{th} assessment class (rating). μ must meet the following conditions:

$$0 \le \mu(x_{ijrq} \in c_q) \le 1 \quad i = 1, 2,..., n \\ j = 1, 2,..., m;\ r = 1, 2,..., k;\ q = 1, 2,..., p \tag{1}$$

$$u(x_{ijr} \in C) = 1 \tag{2}$$

$$\mu\left(x_{ijr} \in \bigcup_{l=1}^{q} c_l \right) = \sum_{l=1}^{q} \mu(x_{ijr} \in c_l). \tag{3}$$

Define Eq. (2) as the normalization and Eq. (3) as the additivity. That which meets the three equations above is unascertained measurement. The matrix that follows is a single index measure matrix [33].

$$(\mu_{ijrq})_{k\times p} = \begin{bmatrix} \mu_{ij11} & \mu_{ij12} & \cdots & \mu_{ij1p} \\ \mu_{ij21} & \mu_{ij22} & \cdots & \mu_{ij2p} \\ \cdots & \cdots & \ddots & \cdots \\ \mu_{ijk1} & \mu_{ijk2} & \cdots & \mu_{ijkp} \end{bmatrix}. \tag{4}$$

4.1.2 The distinction weight of single-index

Using the concept of information entropy to define the peak of index I_{ijr}.

$$V_{ijr} = 1 + \frac{1}{\ln p} \sum_{q=1}^{p} \mu_{ijrq} \ln \mu_{ijrq}. \tag{5}$$

p in Eq. (4) represents the number of the evaluated ratings, μ_{ijrq} is the measure of a single index, and the value of V_{ijr} expresses the degree that I_{ijr} is different from each assessment class. The distinction weight is as follows:

$$\omega_{ijr} = \frac{V_{ijr}}{\sum_{r=1}^{k} V_{ijr}}. \tag{6}$$

$\sum_{r=1}^{k} \omega_{ijr} = 1$, $0 \le \omega_{ijr} \le 1$, ω_{ijr} is the classification weights of I_{jr}. $\omega_{ij} = (\omega_{ij1}, \omega_{ij2},..., \omega_{ijk})$ is the classification weight vector of secondary grade index [34].

4.2 The first grade index measure

Set $\mu_{iq} = \mu(x_i \in c_q)$ to express the degree that sample x_i belongs to c_r, which is the r^{th} assessment class (rating).

$$\mu_{iq} = \sum_{j=1}^{m} \omega_{ij} \mu_{ijq}. \tag{7}$$

Due to $0 \le \mu_{iq} \le 1$, and $\sum_{q=1}^{p} \mu_{iq} = \sum_{q=1}^{p}\sum_{j=1}^{m} \omega_{ij}\mu_{ijq} = = \sum_{j=1}^{m}\omega_{ij}\sum_{q=1}^{p}\mu_{ijq} = \sum_{j=1}^{m}\omega_{ij} = 1$, μ_{iq} is the unascertained measure. Define $(\mu_{i1}, \mu_{i2}, \cdots, \mu_{ip})$ as the measure assessment vector of x_i's composite index. The matrix $(\mu_{iq})_{n\times p} = \begin{bmatrix} \mu_{11} & \mu_{12} & \cdots & \mu_{1p} \\ \mu_{21} & \mu_{22} & \cdots & \mu_{2p} \\ \cdots & \cdots & \ddots & \cdots \\ \mu_{n1} & \mu_{n2} & \cdots & \mu_{np} \end{bmatrix}$ is the measure matrix of the comprehensive index [35].

4.3 The determination of first grade index weight by AHP

In 1970s, AHP was proposed by Saaty, an American expert on operations research. It uses a certain scale to objectively quantify the subjective judgments by human beings, and tries to minimize the drawbacks of subjective assumptions. The multi-criteria assessment method combines quantification and qualification. It is systematic, hierarchical, simple and practical. Thanks to its practicality and effectiveness in handling complex decision-making problems, the method quickly attracted academic interest across the world. Pairwise comparison reached adopting a matrix, consisted of Saaty's basic scale of 1–9. This scale is adopted in matrices to look for relative criteria's weights and to compare the alternatives linked to every criterion. Tab. 2 summarizes the basic ratio scale. All final weighted coefficients are shown in matrices. Alternatives and criteria can be ranked based on the overall aggregated weights in matrices. The alternative with the highest overall weight would be the most preferable [36].

Table 2 Saaty's scale for AHP pairwise comparisons

Weight	Description
1	Equal importance
3	Moderately more important
5	Strongly more important
7	Very strongly more important
9	Dominant importance
2, 4, 6, 8	Reciprocals

Based on this first index's judgment matrix, the weights of every first grade index can be calculated by the geometric calculation method of mean.

$$\overline{\omega_i} = \sqrt[n]{\prod_{j=1}^{n} a_{ij}} \quad (i = 1, 2, ..., n) \tag{8}$$

Then making the normalized processing, using the following equation:

$$\omega_i = \frac{\overline{\omega_i}}{\sum_{i=1}^{n}\overline{\omega_i}}. \tag{9}$$

The weight vector of first index is obtained: $\omega = (\omega_1, \omega_2, \cdots, \omega_n)^{\mathrm{T}}$.

The largest characteristic roots $\lambda_{\max}$ can be calculated by the following equation:

$$\lambda_{\max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(AW)_i}{W_i}. \tag{10}$$

However, due to the extreme complexity of objective things, the influencing factors of subjective understanding occasionally cannot entirely meet the requirement of consistency. Thus, checking the matrix for consistency is necessary, and the process is as follows.

The consistency ratio requirements: $CR = \frac{CI}{RI} < 0.1$. $CI = \frac{\lambda_{\max} - n}{n-1}$, $\lambda_{\max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(AW)_i}{W_i}$. The mean random consistency index RI is shown in Tab. 3.

Table 3 The mean random consistency index

Order	2	3	4	5	6	7	8	9	10	11	12	13	14
RI	0	0.52	0.86	1.10	1.26	1.34	1.40	1.43	1.49	1.51	1.54	1.56	1.58

4.4 Identification

Because the assessment space C is an ordered partition class, the recognition criterion of maximum membership degree is inapplicable. Therefore, credible degree criterion is introduced. Set:

$$k_0 = \min_k \left\{ k : \sum_{l=1}^{k} \mu_{il} \ge \lambda, k = 1, 2, ..., p \right\} \tag{11}$$

Usually, λ = 0.6 or 0.7, so the assessment objects can be classified into c_{k0}.

5 Case study

The Beijing-Shanghai High Speed Railway is an important "one line" connecting Beijing and Shanghai's two major regional centers.The line has been suspended from Beijing South Railway Station to Shanghai Hongqiao Railway Station. Largely parallel to the existing Beijing-Shanghai Railway, the main line is 1,318.488 km long and has double tracks. The design speed is 380 km/h, and the initial operating speed is 310 km/h. Beijing-Shanghai High Speed Railway is equipped with 24 passenger stations, connecting three major economic regions: Beijing-Tianjin-Hebei, Shandong Peninsula, and Yangtze River Delta Economic Zone (See Fig. 4). On June 30, 2011, the world-renowned Beijing-Shanghai High Speed Railway is was officially opened. The Xuzhou-Shanghai Section of Beijing-Shanghai High Speed Railway starts from Xuzhou, Jiangshu Province, crosses over the Yangtze River at Dashengguan in Nanjing, Jiangsu Province, and ends at Shanghai. The main line of the section is 646.507 km in length. The railway passes through Suzhou, Bengbu and Tuzhou in Anhui Province and Nanjing, Zhenjiang, Changzhou, Wuxi and Suzhou in Jiangsu Province.

The Xuzhou-Shanghai Section of Beijing-Shanghai High Speed Railway passes through the main geological regions including Huanghuai alluvial plain, the Yangtze River terrace, the Yangtze River Delta plain, and some hilly areas. The plain and terrace fields are wide, the irrigation system is perfect, the surface of the land has crop vegetation all the year round, and there is basically no wasteland. The surface water is abundant along the routes, and the hydrologic characteristics are controlled by climate conditions. Due to the huge population and limited land resources, the land utilization rate exceeds 85%. Along the two sides of the region are mostly farmland, forest land, lakes and ponds, river networks, and urban construction land, yielding plenty of mineral and tourism resources. As the busiest regions in China, the regions along the section face severe shortage of transport capacity despite the well-developed transportation facilities.

Figure 4 Three surveyed places along Beijing-Shanghai high-speed railway in China [3]

Table 4 Measurement vectors and weights in the assessment index system

Overall Index	First Index	Secondary Index	Data	Measurement vector of secondary index
G	G_1(0.3158)	G_{11}(0.2278)		(0, 0.1, 0.4, 0.5, 0)
		G_{12}(0.1862)	73.52%	(0, 0, 0, 1, 0)
		G_{13}(0.1173)		(0, 0.4, 0.3, 0.3, 0)
		G_{14}(0.1076)		(0, 0.3, 0.3, 0.4, 0)
		G_{15}(0.1068)	76.2%	(0, 0, 0, 1, 0)
		G_{16}(0.1336)	89.6%	(0, 0, 0, 0, 1)
		G_{17}(0.1207)		(0, 0, 0.4, 0.4, 0.2)
	G_2(0.2613)	G_{21}(0.2307)	97.5%	(0, 0, 0, 1, 0)
		G_{22}(0.1692)	92.8%	(0, 0, 0, 1, 0)
		G_{23}(0.1614)	96.3%	(0, 0, 0, 0, 1)
		G_{24}(0.1376)	0.9%	(0, 0, 0, 0, 1)
		G_{25}(0.1227)	96.4%	(0, 0, 0, 1, 0)
		G_{26}(0.1784)	97.2%	(0, 0, 0, 1, 0)
	G_3(0.2182)	G_{31}(0.2614)		(0, 0.3, 0.4, 0.3, 0)
		G_{32}(0.2158)		(0, 0, 0.3, 0.6, 0.1)
		G_{33}(0.3675)		(0, 0.2, 0.4, 0.3, 0.1)
		G_{34}(0.1526)		(0, 0.2, 0.3, 0.4, 0.1)
	G_4(0.2047)	G_{41}(0.1823)		(0, 0.2, 0.3, 0.4, 0.1)
		G_{42}(0.3413)	4.3%	(0, 0, 0, 1, 0)
		G_{43}(0.2269)	96.5%	(0, 0, 0, 0, 1)
		G_{44}(0.2495)	RMB 87131.2 ten thousand /year	(0, 0, 0, 0, 1)

According to the grading of the green ecological assessment of the high-speed railway construction project in Literature [20], the green ecological assessment is divided into five grades according to the cascade theory: $C=\{c_1, c_2, c_3, c_4, c_5\}$, which correspond to the colors of non-green, yellowish green, turquoise, and dark green. In light of Saaty's 1-9 ratio scale estimation, $C=\{1, 3, 5, 7, 9\}$.

The data used in this paper are taken from the *EIA Report on the Newly BuiltBeijing-Shanghai High Speed Railway (Xuzhou-Shanghai Section)* and the *Soil Conservation Plan of the Newly BuiltBeijing-Shanghai High Speed Railway (Xuzhou-Shanghai Section)*. The secondary indices are quantified based on the basic data and expert scoring (by an expert panel consisting of 10 experts in the industry). The single measure vectors of the secondary indices (See Tab. 4) are obtained in light of the scores and the membership degree equation.

Thus, according to the vector measures, the measurement matrix of the secondary index is established as follows:

$$I_1:\bar{\mu}_1=\begin{bmatrix}0&0.1&0.4&0.5&0\\0&0&0&1&0\\0&0.4&0.3&0.3&0\\0&0.3&0.3&0.4&0\\0&0&0&1&0\\0&0&0&0&1\\0&0&0.4&0.4&0.2\end{bmatrix}$$

$$I_2:\bar{\mu}_2=\begin{bmatrix}0&0&0&1&0\\0&0&0&1&0\\0&0&0&0&1\\0&0&0&0&1\\0&0&0&1&0\\0&0&0&1&0\end{bmatrix}$$

$$I_3:\bar{\mu}_3=\begin{bmatrix}0&0.3&0.4&0.3&0\\0&0&0.3&0.6&0.1\\0&0.2&0.4&0.3&0.1\\0&0.2&0.3&0.4&0.1\end{bmatrix}$$

$$I_4:\bar{\mu}_4=\begin{bmatrix}0&0.2&0.3&0.4&0.1\\0&0&0&1&0\\0&0&0&0&1\\0&0&0&0&1\end{bmatrix}$$

5.1 The weight calculation of second grade index

The weights of the secondary indices are calculated using information entropy. Below is the calculation of weight of ecological protection (G_1).

$$I_1:\bar{\mu}_1=\begin{bmatrix}0&0.1&0.4&0.5&0\\0&0&0&1&0\\0&0.4&0.3&0.3&0\\0&0.3&0.3&0.4&0\\0&0&0&1&0\\0&0&0&0&1\\0&0&0.4&0.4&0.2\end{bmatrix}$$

Using the Eq. (5): $v_{11}=0.5152$, $v_{12}=1$, $v_{13}=0.4404$, $v_{14}=0.4404$, $v_{15}=1$, $v_{16}=1$ and $v_{17}=0.4579$

Using the Eq. (6): $\omega_{11}=0.1061$, $\omega_{12}=0.2060$, $\omega_{13}=0.0907$, $\omega_{14}=0.0907$, $\omega_{15}=0.2060$, $\omega_{16}=0.2060$ and $\omega_{17}=0.0943$.

Thus, level indices can be obtained under the G_1 category weights:

$$\bar{\omega}_1=(0.1061\ \ 0.2060\ \ 0.0907\ \ 0.0907\ 0.2060\ \ 0.2050\ \ 0.0943)$$

In the same way, it can be concluded as follows:

$\bar{\omega}_2=(0.1667\ \ 0.1667\ \ 0.1667\ 0.1667\ \ 0.1667\ \ 0.1667)$,

$\bar{\omega}_3=(0.2978\ \ 0.4890\ \ 0.1066\ \ 0.1066)$,

$\bar{\omega}_4=(0.0768\ \ 0.3250\ \ 0.3250\ \ 0.3250)$.

5.2 The measure calculation of first grade index

Using the Eq. (7), the measurement vector of the first index under ecological protection (G_1) is:

$$\mu_1=\bar{\mu}_1\times\bar{\omega}_1=\begin{bmatrix}0.1061\\0.2060\\0.0907\\0.0907\\0.2060\\0.2050\\0.0943\end{bmatrix}^{\mathrm{T}}\times\begin{bmatrix}0&0.1&0.4&0.5&0\\0&0&0&1&0\\0&0.4&0.3&0.3&0\\0&0.3&0.3&0.4&0\\0&0&0&1&0\\0&0&0&0&1\\0&0&0.4&0.4&0.2\end{bmatrix}=$$
$$=(0\ 0.1696\ 0.1346\ 0.5662\ 0.2239)$$

The measurement vector of the first index under soil and water conservation (G_2) is:

$$\mu_2=\bar{\mu}_2\times\bar{\omega}_2=\begin{bmatrix}0.1667\\0.1667\\0.1667\\0.1667\\0.1667\\0.1667\end{bmatrix}^{\mathrm{T}}\times\begin{bmatrix}0&0&0&1&0\\0&0&0&1&0\\0&0&0&0&1\\0&0&0&0&1\\0&0&0&1&0\\0&0&0&1&0\end{bmatrix}=$$
$$=(0\ 0\ 0\ 0.5001\ 0.3334)$$

The measurement vector of the first index under environmental effect (G_3) is:

$$\mu_3=\bar{\omega}_3\times\bar{\mu}_3=\begin{bmatrix}0.2978\\0.4890\\0.1066\\0.1066\end{bmatrix}^{\mathrm{T}}\times\begin{bmatrix}0&0.3&0.4&0.3&0\\0&0&0.3&0.6&0.1\\0&0.2&0.4&0.3&0.1\\0&0.2&0.3&0.4&0.1\end{bmatrix}=$$
$$=(0\ \ 0.1320\ \ 0.3404\ \ 0.4574\ \ 0.0702)$$

The measurement vector of the first index under social and economic benefits (G_4) is:

$$\mu_4=\bar{\omega}_4\times\bar{\mu}_4=\begin{bmatrix}0.0768\\0.3250\\0.3250\\0.3250\end{bmatrix}^{\mathrm{T}}\times\begin{bmatrix}0&0.2&0.3&0.4&0.1\\0&0&0&1&0\\0&0&0&0&1\\0&0&0&0&1\end{bmatrix}=$$
$$=(0\ \ 0.0154\ \ 0.0230\ \ 0.3557\ \ 0.6577)$$

Thus the measurement matrix of the first index is:

$$\bar{\mu}=\begin{bmatrix}\mu_1\\\mu_2\\\mu_3\\\mu_4\end{bmatrix}=\begin{bmatrix}0&0.1696&0.1346&0.5662&0.2239\\0&0&0&0.5001&0.3334\\0&0.1320&0.3404&0.4574&0.0702\\0&0.0154&0.0230&0.3557&0.6577\end{bmatrix}$$

5.3 Determining the classification weight of first grade index

The first index judgment matrix is established using Saaty's 1–9 scale, and AHP is applied to calculate the weights as the final results (Tab. 4).

5.4 The calculation of comprehensive measure vector

Point multiplication of the first index weight and the first measurement matrix results in judgment matrix are as follows:

$$B = \omega_i^0 \times \overline{\mu} = \begin{bmatrix} 0.3158 \\ 0.2613 \\ 0.2182 \\ 0.2047 \end{bmatrix}^{\mathrm{T}} \times$$
$$\times \begin{bmatrix} 0 & 0.1696 & 0.1346 & 0.5662 & 0.2239 \\ 0 & 0 & 0 & 0.5001 & 0.3334 \\ 0 & 0.1320 & 0.3404 & 0.4574 & 0.0702 \\ 0 & 0.0154 & 0.0230 & 0.3557 & 0.6577 \end{bmatrix} =$$
$$= (0\ 0.0855\ 0.1215\ 0.4821\ 0.3078)$$

Giving comprehensive consideration to the assessment results, the author lists the overall green situation of Beijing-Shanghai High Speed Railway (Xuzhou-Shanghai Section) in Tab. 5.

Thus the score is calculated as:

$$S = B \times A = (0\ 0.0855\ 0.1215\ 0.4821\ 0.3078) \times (1\ 3\ 5\ 7\ 9) =$$
$$= 7.0089$$

The calculation results show that the overall score of Beijing-Shanghai High-Speed Railway (Xuzhou-Shanghai Section) is 7.0089, and the ecological assessment result is turquoise.

Table 5 Green ecological situation of the Beijing-Shanghai High-Speed Railway (Xuzhou-Shanghai Section).

Assessment result	Non green	Yellow green	Green	Turquoise	Dark green
Value	0	0.0855	0.1215	0.4821	0.3078
Rate	0	8.55%	12.15%	48.21%	30.78%

5.5 Confidence level recognition

Confidence level recognition is performed using the Eq. (11) and the calculated comprehensive measurement vector. Here, λ is set as 0.7:

when $\lambda = 0.7$, $k_0 = \min \sum_{l=1}^{k} \mu_{il} \geq 0.7$, $k = 5$.

According to the comprehensive assessment results of Beijing-Shanghai HighSpeed Railway (Xuzhou-Shanghai Section), the section falls to the turquoise grade in terms of ecological greenness. The result demonstrates small land occupation, low energy consumption, large transportation capacity, low pollution and strong adaptability. With these comparative advantages, Beijing-Shanghai HighSpeed Railway conforms to the national policies on energy utilization and environmental protection and the urban development planning of the cities along the route. Despite various degrees of effect on regional ecology, sound, vibration, water, electromagnetic field, etc., positive and effective prevention measures are taken in light of the local conditions during the design and construction, and environmental monitoring and management are enhanced during the construction and operation. With significant environmental, social and economic benefits, the railway is environmentally feasible as it obeys the principle of coordination between social, economic and environmental benefits, and embodies the philosophy of sustainable development.

6 Conclusions

(1) This study comprehensively considers the many factors affecting the ecological environment of high-speed railway construction project. The assessment index system of green ecology is established from 4 aspects: ecological protection, soil and water conservation, environmental effect and social and economic benefits. The safety comprehensive assessment is carried out using the unascertained measure model and AHP. It provides reliable basis for developing rapid and accurate ecological environment control measures and management solutions of high-speed railway construction project.

(2) The importance of the various assessment factors is not the same in the green ecological environment system of mining resources, so it is necessary to determine the weight of each factor. The modified AHP that achieves qualitative and quantitative assessment simultaneously is used. The weights are assigned more scientific, reasonable and satisfy the requirement of consistency thus fully reflecting the significance level of each assessment index.

(3) The judgment matrices are built based on the unascertained measure model which fully represents the uncertainty in the assessment. The level decision problem of the ecological environment in the high-speed construction area is solved using the confidence recognition criteria.

(4) According to the assessment of Beijing-Shanghai High Speed Railway (Xuzhou-Shanghai Section), the section is turquoise in terms of ecological greenness. The result indicates enhanced environmental monitoring and management in high-speed design, construction and operation, and proves the environmental feasibility and sustainability of the section. Besides, it also demonstrates that the proposed model is effective and can be used for the green ecological assessment of other high-speed construction projects.

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