J Inf Process Syst, Vol.16, No.5, pp.1064~1073, October 2020
https://doi.org/10.3745/JIPS.04.0188
ISSN 1976-913X (Print)
ISSN 2092-805X (Electronic)

JOURNAL OF INFORMATION PROCESSING SYSTEMS JIPS

An Evaluative Study of the Operational Safety of High-Speed Railway Stations Based on IEM-Fuzzy Comprehensive Assessment Theory

Li Wang*, Chunling Jin**, and Chongqi Xu*

Abstract
The general situation of system composition and safety management of high-speed railway terminal is investigated and a comprehensive evaluation index system of operational security is established on the basis of railway laws and regulations and previous research results to evaluate the operational security management of the high-speed railway terminal objectively and scientifically. Index weight is determined by introducing interval eigenvalue method (IEM), which aims to reduce the dependence of judgment matrix on consistency test and improve judgment accuracy. Operational security status of a high-speed railway terminal in northwest China is analyzed using the traditional model of fuzzy comprehensive evaluation, and a general technique idea and references for the operational security evaluation of the high-speed railway terminal are provided. IEM is introduced to determine the weight of each index, overcomes shortcomings of traditional analytic hierarchy process (AHP) method, and improves the accuracy and scientificity of the comprehensive evaluation. Risk factors, such as terrorist attacks, bad weather, and building fires, are intentionally avoided in the selection of evaluation indicators due to the complexity of risk factors in the operation of high-speed railway passenger stations and limitation of the length of the paper. However, such risk factors should be considered in the follow-up studies.

Keywords
Comprehensive Evaluation, Fuzzy Mathematical Theory, High-Speed Railway Terminal, Interval Eigenvalue Method (IEM), Operational Security

1. Introduction

High-speed railway construction industry has developed rapidly worldwide in China in recent years. More than 35,000 km of high-speed railway operation has been completed by the end of 2019, thereby accounting for more than two-thirds of the world's high-speed rail mileage. China reached the maximum high-speed rail mileage, highest transport density, and the most complex network operation scenarios in the world. As an important part of the high-speed railway system, safety of high-speed railway passenger stations directly affects the operation safety of the high-speed railway system. The continuous improvement of China's high-speed railway network has led to the rapid increase in the number of high-speed railway passenger stations, thereby indicating that the pressure of operation safety management of

Manuscript received March 20, 2020; first revision June 11, 2020; accepted June 14, 2020.
Corresponding Author: Li Wang (41513044@qq.com)
* School of Traffic and Transportation, Lanzhou Jiaotong University, Lanzhou, China (41513044@qq.com, 1277213459@qq.com)
** School of Civil Engineering, Lanzhou Jiaotong University, Lanzhou, China (522719061@qq.com)

high-speed railway passenger stations also increased. Compared with existing railway passenger stations with single function and closed operation, the high-speed railway passenger station is characterized by diverse passenger flow organization mode, frequent passenger flow, and complex facility configuration that increase the pressure of operation safety management in the high-speed railway passenger station [1]. Hence, the operation process of high-speed railway passenger stations is complex and operation management involves many risk factors. Effectively identifying risk and adverse factors in the operation of passenger stations and understanding the safety management level of passenger stations objectively and thoroughly are necessary to evaluate the safety management status of passenger stations scientifically and reasonably.

Safety management evaluation in various industries and fields and safety evaluation of railway stations have been extensively investigated. For example, Elms [2] explored the importance of accident management in railway operation and management, stated that we should focus on factors affecting the railway safety system, and proposed principles of balance, relevance, and transparency of the railway safety system. Small [3] analyzed the railway safety using accident tree method, compared the difference between existing railways and high-speed railways on the basis of historical data analysis, and formulated corresponding management measures. Zhen [4] classified and summarized risk sources of passenger safety in a large-scale high-speed railway station according to human, equipment, environmental, and management factors; conducted internal analysis on the internal relationship between each risk source; and assessed the risk range of common accidental events in the station and their corresponding prevention and control schemes or measures in accordance with characteristics of passenger transport organization of high-speed railway station. Zhang [5] classified existing types of passenger safety accidents in railway passenger stations, analyzed influencing factors of passenger transport safety using the mechanism of accidents, and obtained characteristics of different kinds of passenger safety problems in time and space. A suitable and improved entropy weight analytic hierarchy process (AHP) was then used to evaluate system indexes to obtain the safety status of the passenger station.

However, the literature on railway safety mainly focuses on the evaluation of passenger transport and train operation safety of existing railway stations, while research on the operation safety evaluation of high-speed railway passenger stations is limited and not systematized. The design of the evaluation index system is based on the human, machine, environment, and management components of the system theory, which can solve the problem of overlapping evaluation indexes. The weight of the evaluation index is mostly determined by building a traditional judgment matrix and using the AHP. However, experts have difficulty in using traditional pairwise judgment matrix and obtaining accurate assessments. The typically high matrix order in the case of many indexes makes it difficult to pass the consistency test of the matrix [6].

The evaluation of operation safety management of the high-speed railway passenger station is a comprehensive multifactor and multilevel evaluation problem, and some fuzziness and uncertainty exist in the evaluation process. Therefore, many scholars choose the AHP–fuzzy comprehensive evaluation instead of the linear evaluation model to improve the accuracy to a certain extent. However, the traditional AHP–fuzzy comprehensive evaluation fails to solve the problem of evaluation index empowerment, while the comprehensive evaluation is carried out based on the index weight. If the index weight is inaccurately determined, then large errors in the evaluation results will affect the overall evaluation effect.

Regulations and research reviews of railway departments in China as well as causes and mechanisms of safety accidents in high-speed railway passenger stations were analyzed according to relevant laws.

On the basis of the investigation of high-speed railway passenger stations and consultation of experts in the railway industry, this study comprehensively analyzes the relevance of the high-speed railway operation and passenger stations and constructs an evaluation system composed of 4 criteria and 18 specific indicators. An interval number judgment matrix is constructed to replace the traditional judgment matrix and solves the problem of ineffective assessment on the importance of factors by experts and improves the assessment accuracy. Interval eigenvalue method (IEM) is introduced to determine the index weight. The calculation process is simple and consistency dependence on the judgment matrix is small. An evaluation method of the safety operation of the high-speed railway passenger station based on the interval number fuzzy analysis that combines IEM with the fuzzy analysis method is proposed in this study. An interval number is used in the evaluation process to express evaluation indexes and subsequently reduces the uncertainty and fuzziness of evaluation factors, thereby enhancing the objectivity and credibility of the evaluation results and providing a new idea for the evaluation of the operation safety management of high-speed railway passenger stations.

2. Construction of the Evaluation Index System

An index system is crucial and the basis for evaluation. The operation safety management of the high-speed railway passenger station is a systematic process in which personnel, equipment, environment, and organization management are combined organically and controlled to achieve specific operation safety purposes. The evaluation index system should generally be scientific, systematic, and comprehensive. The operation safety management of the high-speed railway passenger station reflects the control power of the station on organization and safety management systems. The operation safety management of the high-speed railway passenger station in this study refers to the safety management process directly related to business operations of the high-speed railway station, while processes unrelated to the operation, such as building fires, terrorist attacks, and natural disasters, are excluded from the scope of this evaluation.

A comprehensive evaluation index system of the operation safety management of the high-speed railway passenger station consisting of 4 criteria levels and 18 specific indicators is constructed according to relevant requirements of regulations of the railway safety and technology management (high-speed railway part) using field investigation, results of previous studies, expert investigation, accident cause analysis, and other methods (Table 1).

3. Evaluation Model of the Operation Safety Management of the High-Speed Railway Passenger Station

3.1 Determination of Index Weights

Interval analytic hierarchy process (IAHP), a fusion of the traditional AHP method and interval mathematics, can effectively solve problems related to the importance of various factors that experts inaccurately evaluate. The IEM is a simple, effective, and practical approach with high accuracy that can efficiently use all the information of the judgment matrix. Moreover, the small consistency dependence of IEM on the judgment matrix allows it to be applied in the calculation of indicator weights. The interval

Table 1. Evaluation index system and index weight of the operation safety management of high-speed railway terminal

Target layer	Criterion layer	Weight	Index layer	Weight
Operation safety management of the high-speed railway passenger station (U)	Personnel capability level (U_1)	0.2519	Physical and mental condition of staff (U_{11})	0.1691
			Staff security concept and sense of responsibility (U_{12})	0.2291
			Level of professional knowledge and skills of staff (U_{13})	0.2676
			Level of staff emergency response capacity (U_{14})	0.2015
			Level of staff engagement (U_{15})	0.1327
	Equipment operation level (U_2)	0.1820	Completeness of equipment (U_{21})	0.3345
			Advanced level of equipment (U_{22})	0.3702
			Daily maintenance and maintenance of equipment (U_{23})	0.1412
			Equipment management level (U_{24})	0.1541
	Environmental security level (U_3)	0.1496	On-site production and operation environment (U_{31})	0.3614
			Level of security inspection in and out of the station (U_{32})	0.3461
			Security environment inside and outside the station (U_{33})	0.2042
			Workers' daily living environment (U_{34})	0.0883
	Organizational management level (U_4)	0.4163	Construction of safety production system and management system (U_{41})	0.3875
			Safety management agency effectiveness (U_{42})	0.1682
			Investment degree of special funds for safety production (U_{43})	0.1927
			Education and training of production safety and management personnel (U_{44})	0.2318
			Construction level of station emergency management mechanism (U_{45})	0.1198

number can be calculated as follows:

$$\mathrm{d} = [d^-, d^+] = \{x(C_{\mathrm{ij}}) \mid 0 < d^- < x(C_{\mathrm{ij}}) < d^+\},\ \mathrm{i} = 1,2,\cdots,m; j = 1,2,\cdots,n,$$

where d is the interval number. A vector (or matrix) consisting of interval numbers is an interval vector (or matrix) whose operation rules are the same as the rules of mathematical vectors (or matrices). The assumed interval number judgment matrix is expressed as follows:

$$D_{\mathrm{i}} = (d_{ij})_{n\times n} = [D^-, D^+],\ \text{and then}\ D^- = (\mathrm{d}_{\mathrm{ij}})^-_{n\times n},\ D^+ = (\mathrm{d}_{ij})^+_{n\times n}.$$

1) The normalized eigenvector x_i^- and x_i^+ corresponding to the maximum eigenvalue of D^- and D^+ can be expressed as follows:

$$\mathrm{x}_i^- = \frac{1}{\sum_{j=1}^{n} d_{ij}^-} d_{ij}^-, \qquad \mathrm{x}_i^+ = \frac{1}{\sum_{j=1}^{n} d_{ij}^+} d_{ij}^+. \tag{1}$$

2) Coefficients are calculated using $D^- = (d_{ij})^-_{n\times n}$ and $D^+ = (d_{ij})^+_{n\times n}$,

where

$$\alpha = \sqrt{\sum_{j=1}^{n} \frac{1}{\sum_{i=1}^{n} d_{ij}^{+}}}, \qquad \beta = \sqrt{\sum_{j=1}^{n} \frac{1}{\sum_{i=1}^{n} d_{ij}^{-}}}. \tag{2}$$

3) According to Formulas (1) and (2), the weight interval of each evaluation index can be obtained as follows:

$$\omega_i = [\omega_i^-, \omega_i^+] = [\alpha x_i^-, \alpha x_i^+]. \tag{3}$$

4) Based on ω_i obtained using Formula (3), the average of weights at both ends of the interval is taken as the weight of each index, which can be calculated as follows:

$$W_i = [\omega_i^-, \omega_i^+] / 2 . \tag{4}$$

Hence, the weight vector of each evaluation index is $W_i = [W_1, W_2, \cdots, W_{in}]^T$.

The interval number judgment matrix of the criterion layer in this index system is expressed as follows:

$$A = \begin{bmatrix} (1,1) & (2,3) & (2,4) & (1/4,1/2) \\ (1/3,1/2) & (1,1) & (2,3) & (1/4,1/3) \\ (1/4,1/2) & (1/3,1/2) & (1,1) & (1/5,1/4) \\ (2,4) & (3,4) & (4,5) & (1,1) \end{bmatrix}$$

Thus,

$$A^- = \begin{bmatrix} 1 & 2 & 2 & 1/4 \\ 1/3 & 1 & 2 & 1/4 \\ 1/4 & 1/3 & 1 & 1/5 \\ 2 & 3 & 4 & 1 \end{bmatrix}, \quad A^+ = \begin{bmatrix} 1 & 3 & 4 & 1/2 \\ 1/2 & 1 & 3 & 1/3 \\ 1/2 & 1/2 & 1 & 1/4 \\ 4 & 4 & 5 & 1 \end{bmatrix}.$$

The normalized eigenvector of the positive component corresponding to its maximum eigenvalue is obtained using Formula (1). Hence,

$$x^- = (0.2434, 0.1832, 0.1562, 0.4170)^T, \; x^+ = (0.2595, 0.1812, 0.1440, 0.4160)^T .$$

We can calculate $k = 0.917$ and $m = 1.066$ using Formula (2). The weight obtained using Formulas (3) and (4) is $W = (0.2519, 0.1820, 0.1496, 0.4163)$.

Weight values of other indicators can be obtained similarly (Table 1).

3.2 Analysis of the Evaluation Process based on Multilevel Fuzzy Mathematics

3.2.1 Basic definition

3.2.1.1 Establishing the factor set

Let U be the set of influencing factors, that is, a set of factors that affect the evaluation object.

$$U = \{U_1, U_2, \cdots, U_i, \cdots, U_m\}, \; U_i = \{u_{i1}, u_{i2}, \cdots, u_{ij}, \cdots, u_{ip}\},$$

where U_i represents the No. i subset and u_{ij} denotes the No. j influence factor of the No. i subset.

3.2.1.2 Establishing the evaluation set

The evaluation set is composed of different kinds of evaluation results that the evaluator may obtain from the evaluation object and expressed as V,

$$V=\{v_1,v_2,\cdots,v_n\},$$

where V_i represents the No. i evaluation result and n represents the total number of evaluation results, $i = 1,2,\ldots,n$.

The set defines the selection range of the evaluation results of a certain factor. The evaluation element can be either a qualitative expression or a quantitative score.

3.2.1.3 Establishing the weight set

The weight of each factor is given according to the importance of each factor in every layer. Let the weight set of factors at each level be

$$W=\{W_1,W_2,\cdots,W_i,\cdots,W_m\},\ W_i=\{w_{i1},w_{i2},\cdots,w_{ij},\cdots,w_{ip}\},$$

where W represents the fuzzy weight of the criterion layer and W_i represents the fuzzy weight of the No. i factor layer.

3.2.2 Evaluation steps [7]

3.2.2.1 One-level fuzzy comprehensive assessment model

Any factor is assessed according to the evaluation set V, and the judgment matrix of any factor is obtained as follows:

$$R_{ij}=\{r_{ij1},r_{ij2},\cdots,r_{ijk},\cdots,r_{ijn}\},$$

where r_{ijk} is the degree of subordination of the k-level evaluation that corresponds to the No. j factor of the No. i subset and $r_{ijk}\in[0,1]$. The judgment matrix of the No. i subset is expressed as follows:

$$R_i=(r_{ijk})_{j\times n},$$

where the number of rows of the matrix R_i is equal to the number of u_{ij} subfactors of U_i and the number of columns of the matrix R_i is equal to n, which is the number of elements of the evaluation set. The single-factor fuzzy evaluation set, that is, the one-level fuzzy comprehensive evaluation model, is obtained via the fuzzy operation on R and W as follows:

$$B_i=W_i\circ R_i=\{b_{i1},b_{i2},\cdots,b_{in}\},$$

where "$\circ$" denotes the synthesis method of W and R, that is, the combination of fuzzy operators.

3.2.2.2 Two-level fuzzy comprehensive evaluation model

The one-factor fuzzy evaluation set B_i is the one-factor evaluation set for the No. i subset U_i and also constitutes the judgment matrix R of the second-level fuzzy comprehensive evaluation.

$$R = \begin{bmatrix} B_1 \\ B_2 \\ \vdots \\ B_m \end{bmatrix} = \begin{bmatrix} r_{i11} & r_{i12} & \cdots & r_{i1n} \\ r_{i21} & r_{i22} & \cdots & r_{i2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{ij1} & r_{ij2} & \cdots & r_{ijn} \end{bmatrix},$$

and then the two-level fuzzy comprehensive evaluation model can be expressed as follows:

$$B = R \circ W = \{b_1, b_2, \cdots, b_i, \cdots, b_n\},$$

where b_i indicates the degree to which the evaluated subject has a rating level of v_i.

If $\sum_{i=1}^{n} b_i \neq 1$, then the matrix is normalized. According to the principle of maximum membership degree, the evaluation grade vi corresponding to the largest bi is selected as the result of the comprehensive evaluation.

4. Example Analysis

The operation safety audit and evaluation of a high-speed railway terminal in northwest China is taken as an example. The evaluation standard consists of the following evaluation grades: {Poor, Very Poor, General, Good, Excellent}.

4.1 Create the Evaluation Set

The expert group composed of safety evaluation experts and operation managers of the high-speed railway terminal combined various evaluation indicators to score the operational security situation of the high-speed railway terminal and take the proportion of the number of relevant experts who approve of a certain indicator evaluation level to all the participants as the index evaluation value [8] (Table 2).

4.2 One-level Fuzzy Comprehensive Evaluation

According to the formula:

$$B_i = R_i \circ W_i = \begin{bmatrix} r_{i11} & r_{i12} & \cdots & r_{i1n} \\ r_{i21} & r_{i22} & \cdots & r_{i2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{im1} & r_{im1} & \cdots & r_{imn} \end{bmatrix} \circ (w_{i1}, w_{i2}, \cdots, w_{im}) = (\mathrm{b}_{i1}, \mathrm{b}_{i2}, \cdots, \mathrm{b}_{in}),$$

we can obtain:

$$B_1 = R_1 \circ W_1 = \begin{bmatrix} 0 & 0.1 & 0.2 & 0.4 & 0.3 \\ 0 & 0.1 & 0.4 & 0.4 & 0.1 \\ 0.1 & 0.1 & 0.3 & 0.4 & 0.1 \\ 0.1 & 0.1 & 0.2 & 0.4 & 0.2 \\ 0 & 0.1 & 0.2 & 0.4 & 0.3 \end{bmatrix} \circ (0.1691, 0.2291, 0.2676, 0.2015, 0.1327)$$

$$= (0.0469, 0.1000, 0.2726, 0.4000, 0.1805).$$

For the same reason,

$$B_2 = (0.1193, 0.1308, 0.4268, 0.1578, 0.1653),$$

$$B_3 = (0.0723, 0.2069, 0.4000, 0.2073, 0.1135),$$

$$B_4 = (0.0739, 0.1837, 0.3919, 0.3000, 0.1205).$$

Table 2. Expert assessment set of operation safety of the high-speed railway passenger station

		Index	Index evaluation set				
			Poor	Very poor	General	Good	Excellent
Operational security management of the high-speed railway terminal (U)	Personnel capability level (U_1)	Physical and mental condition of staff (U_{11})	0	0.1	0.2	0.4	0.3
		Staff security concept and sense of responsibility (U_{12})	0	0.1	0.4	0.4	0.1
		Level of professional knowledge and skills of staff (U_{13})	0.1	0.1	0.3	0.4	0.1
		Level of staff emergency response capacity (U_{14})	0.1	0.1	0.2	0.4	0.2
		Level of staff engagement (U_{15})	0	0.1	0.2	0.4	0.3
	Equipment operation level (U_2)	Completeness of equipment (U_{21})	0.2	0.1	0.5	0.1	0.1
		Advanced level of equipment (U_{22})	0.1	0.1	0.5	0.1	0.2
		Daily maintenance and maintenance of equipment (U_{23})	0	0.1	0.2	0.4	0.3
		Equipment management level (U_{24})	0.1	0.3	0.3	0.2	0.1
	Environmental security level (U_3)	On-site production and operation environment (U_{31})	0.2	0.3	0.4	0.1	0
		Level of security inspection in and out of the station (U_{32})	0	0.2	0.4	0.3	0.1
		Security environment inside and outside the station (U_{33})	0	0.1	0.4	0.2	0.3
		Workers' daily living environment (U_{34})	0	0.1	0.4	0.3	0.2
	Organizational management level (U_4)	Construction of safety production system and management system (U_{41})	0.1	0.1	0.4	0.3	0.1
		Safety management agency effectiveness (U_{42})	0	0.1	0.3	0.3	0.3
		Investment degree of special funds for safety production (U_{43})	0	0.3	0.3	0.3	0.1
		Education and training of production safety and management personnel (U_{44})	0.1	0.2	0.4	0.3	0
		Construction level of station emergency management mechanism (U_{45})	0.1	0.2	0.3	0.3	0.1

4.3 Two-level Fuzzy Comprehensive Evaluation

The comprehensive evaluation system of the high-speed railway terminal operation security management is divided into two layers, and the second-level fuzzy comprehensive evaluation is only the synthesis according to all the factors U_i (i=1,2,3,4) of the first level. The single-factor evaluation matrix of the second-level fuzzy comprehensive evaluation should be the first-level fuzzy comprehensive evaluation matrix:

$$R = \begin{bmatrix} 0.0469 & 0.1000 & 0.2726 & 0.4000 & 0.1805 \\ 0.1193 & 0.1308 & 0.4268 & 0.1578 & 0.1653 \\ 0.0723 & 0.2069 & 0.4000 & 0.2073 & 0.1135 \\ 0.0739 & 0.1837 & 0.3919 & 0.3000 & 0.1205 \end{bmatrix},$$

and $W = (0.2519, 0.1820, 0.1496, 0.4163)$. Then,

$B = W \circ R = (0.0751, 0.1564, 0.3693, 0.2854, 0.1427)$. After normalization,
$B' = (0.0730, 0.1520, 0.3589, 0.2774, 0.1387)$.

According to the maximum membership degree principle, the operational security management of the high-speed railway terminal is evaluated as “General” safety status.

5. Conclusion

The high-speed railway passenger station is a new type of urban comprehensive transportation hub that evolved from the railway passenger station. Compared with the ordinary railway passenger station, the high-speed railway passenger station adopts a large number of new technologies and equipment, which has new characteristics in transportation organization, passenger service, and station management, such as complex building structure, numerous internal equipment, compact layout, wide traffic radiation, large passenger flow, and more hidden trouble points [4]. The safe operation of the passenger station is the first condition to ensure its development and construction. Analyzing and evaluating the risk of the high-speed railway passenger station scientifically and effectively are necessary.

- A comprehensive evaluation index system for the operational security management of the high-speed railway terminal consisting of 4 criteria and 18 specific indicators is constructed. The high-speed railway terminal can refer to the indicator system for evaluating its security management level, and railway management departments can also use the index system for auditing the operational security of the high-speed railway terminal.
- IEM is introduced to determine the weight of each indicator because of the excessive number of indicators available in the system. The operational security of the high-speed railway terminal is comprehensively evaluated on the basis of the fuzzy comprehensive evaluation model and combined with the expert scoring method. The combination of qualitative analysis and quantitative research effectively avoids the shortcomings of individual experts’ subjective judgment errors that can lead to large deviations in the evaluation results, thereby improving the scientificity and accuracy of the evaluation results.
- Risk factors, such as terrorist attacks, severe weather, and building fires, were excluded from the process of selecting evaluation indicators because of space limitations. Four levels of indicators, namely, personnel capacity, station equipment, station environment, and organizational management, were primarily investigated in this study. Risk factors in the operational security management of the high-speed railway terminal should be comprehensively considered in the follow-up study while applying computer programming to improve the calculation efficiency, convenience, and practicability of the evaluation method.

Acknowledgement

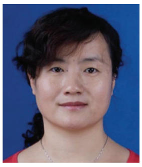
This work was supported by the National Natural Science Foundation of China (No. 51969011 and 51669010) and the University Innovation Fund Project in Gansu Province of China (No. 2020B-108).

References

[1] Y. Zhuang, “A study on safety risk assessment and control optimization of high speed railway passenger terminal based on fuzzy petri network,” Beijing Jiaotong University, Beijing, China, 2018.
[2] D. Elms, “Rail safety,” *Reliability Engineering & System Safety*, vol. 74, no. 3, pp. 291-297, 2001.
[3] L. Small, “Rail safety,” *The Arup Journal*, vol. 2004, no. 1, pp. 10-11, 2004.
[4] L. Zhen, “Analysis of passenger safety risk in large-scale high-speed railway,” Southwest Jiaotong University, Chengdu, China, 2014.
[5] Y. Zhang, “Research on passenger safety early warning management system of railway passenger station,” Beijing Jiaotong University, Beijing, China, 2016.
[6] Y. Wang and G. Hao, “Comprehensive evaluation of airport operation safety based on IEM and vague sets theory,” *Bulletin of Science and Technology*, vol. 32, no. 1, pp. 210-214, 2016.
[7] D. Du, Q. Pang, and Y. Wu, *Contemporary Comprehensive Evaluation Methods and Case Selection*, 3rd ed. Beijing, China: Tsinghua University Press, 2018.
[8] L. Wang, L. Yun, and Z. Xu, “Multi-Hierarchical Gray Correlation Analysis Applied in the Selection of Green Building Design Scheme,” *Industrial Safety and Environmental Protection*, vol. 42, no. 4, pp. 93-96, 2016.

Li Wang https://orcid.org/0000-0001-9290-2690

He received his B.S. degree at the School of Civil Engineering in Lanzhou Jiaotong University in 2004 and M.S. degree at the School of Traffic and Transportation in Lanzhou Jiaotong University in 2011. At present, he is a lecturer at the School of Traffic and Transportation of Lanzhou Jiaotong University in Lanzhou, China.



Chunling Jin https://orcid.org/0000-0002-8068-0055

She received her B.S degree at the North China University of Water Resources and Electric Power in 2000 and M.S. degree at the Lanzhou Jiaotong University in 2005. At present, she is a professor at the School of Civil Engineering of Lanzhou Jiaotong University in Lanzhou, China.

Chongqi Xu https://orcid.org/0000-0001-8654-5244

He respectively received his B.S. and M.S. degrees at the School of Traffic and Transportation of Lanzhou Jiaotong University in 1995 and 2011. At present, he is a senior engineer at the School of Traffic and Transportation of Lanzhou Jiaotong University in Lanzhou, China.