Rail Transit Operational Safety Risk Assessment Based on Improved AHP and Cloud Model

Tengfei Shi[1,a], Heng Wan[1,b*], Weijie Ma[2,c], Linfeng Gan[1,d]

[1]School of Railway Transportation, Shanghai Institute of Technology, Shanghai, China
[2]Shanghai Metro First Operation Co., Ltd, Shanghai, China

[a]987288101@qq.com, [b*]hengwan@sit.edu.cn, [c]2320298967@qq.com, [d]226151109@mail.sit.edu.cn

Abstract. The safety risk assessment system for urban rail transit operations has been studied to provide support and guidance for rail transit operations. Firstly, a risk assessment index system for rail transit operations is established from four levels: station train operation, station passenger capacity, station environment, and station equipment services, providing support for the safe and reliable operation assessment of rail transit. Then, a risk assessment model for rail transit operation safety is proposed, and an improved AHP method is used to determine the weight of the indicators. Then, evaluation scores of indicators at all levels are obtained based on the cloud model assessment method, in order to evaluate the risk level of rail transit operation, providing a judgment basis for rail transit safety operation.

Keywords: rail transit; Operational risk; Improve AHP; Cloud model; risk assessment.

1 Introduction

1.1 How to Use This Template

China's urban rail transit has entered the era of net-worked operation. The scale of the road network is constantly expanding, and the passenger volume is also steadily increasing. The operational safety of urban rail transit is an important issue that urgently needs to be addressed. Building a risk assessment system for urban rail transit operational safety can effectively improve the level of railway operational safety and promote its healthy development.

Traditional evaluation methods include relative accident rate analysis [1], time series analysis [2], and regression analysis [3]. These three evaluation methods each have their own advantages and characteristics, but they all have a commonality, which is that the selection of indicator systems leads to inconsistent evaluation results. At present, there has been a lot of research on the risk assessment of rail transit operation safety in China. For example, literature [4] provides a systematic analysis of the current status of subway operation safety assessment in China and predicts future

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development. However, these studies have certain limitations, as they only focus on a certain type of safety accident or local hidden danger, and there is relatively little research on subway operation safety. Reference [5] improved the traditional SP method and overcame the impact of neglecting indicator weights. It organically combined quantitative and qualitative evaluations, and applied the improved SP to urban rail transit operation evaluation. Reference [6] adopted the methods of AHP and fuzzy theory and verified them through a set of data. Reference [7] combines the characteristics of multiple influencing factors and high operational risks in urban rail transit operation safety to construct an evaluation index system. The gain weighted comprehensive method is used to calculate the index, thus determining the critical point of safety level, and formalizing the evaluation results. However, these evaluation methods did not fully consider the uncertain factors that exist in the operation of rail transit. In response to the above issues, this project pro-poses a cloud model based operational safety risk assessment method to address the fuzziness and randomness in the operation of urban rail transit. On this basis, the improved Analytic Hierarchy Process is used to determine the weights of each indicator[8], and a cloud model is used to establish a risk assessment model for urban rail transit operation safety.

This article intends to establish a risk assessment index system for rail transit operation from four perspectives: station train operation, station passenger capacity, station environment, and station equipment services[9].Based on this, a cloud model is used to establish a rail transit operation safety risk assessment model. Taking rail transit as an example, empirical research is conduct-ed to verify the rationality of the evaluation index system and evaluation methods.You can delete our sample text and replace it with the text of your own contribution to the proceedings. However we recommend that you keep an initial version of this file for reference.

1.2 Risk assessment indicator system

Analyze the risk indicators of the existing railway transportation system. We have established a risk assessment index system for rail transit operation safety.

The first level indicator system helps to evaluate the operational status of subway stations, reflecting station operation from aspects such as train operation, station passenger capacity, station environment, and station equipment services. On this basis, in-depth analysis was conducted on the primary indicators, and secondary indicators reflecting the safety status of station operation were obtained, as shown in Table 1. For the first level indicators of station operation safety evaluation, they can be divided into main indicators and secondary indicators. The main indicator is a direct statistical indicator of the safety status of station operation, while the secondary indicator is an indirect statistical indicator related to the safety status of station operation. This article will evaluate the secondary indicators of station operation safety, including train service satisfaction, temperature difference ratio, carbon dioxide mass concentration, oxygen mass concentration, temperature difference ratio, etc., with other secondary indicators as the main indicators.2. Materials and Methods.

2 Method

The cloud model is a conceptual model proposed in reference [10]. The cloud model theory can handle uncertainty, manifested as fuzzy and random data from the perspective of membership. It has been widely used in many fields such as production and life, and has achieved good results.

2.1 Basic Concepts of Cloud

The cloud model is a fuzzy mathematical model that describes uncertain relationships, which can transform a qualitative concept into a quantitative one. Let be a quantitative domain represented by numerical values, and be a qualitative concept on . If the quantitative value , and is a random realization of the qualitative concept , and has a stable tendency towards membership , then the distribution on do-main becomes a cloud, and each becomes a cloud droplet.

Table 1. Station operation safety evaluation index

Target	Primary indicators	Secondary indicators
Safety evaluation indicators for rail transit operation	train operation	Station train delay rate
		train delay
		Station train load factor
		User satisfaction with trains
	Station passenger capacity	Gate usage rate
		Usage rate of stored value tickets
		Platform screen door failure rate
		Platform passenger density
	Station environment	temperature difference ratio
		Carbon dioxide concentration
		Oxygen concentration
		Humidity difference ratio
	Station Equipment Services	Lighting equipment failure rate
		Water pump failure rate
		Fan failure rate
		Emergency alarm device failure rate
		Sensor failure rate

$$t:T\rightarrow[0,1],\forall x\in U,x\rightarrow t(x) \tag{1}$$

The theoretical basis of cloud models is represented by three basic numerical eigenvalues, namely expectation , entropy , and hyper entropy . represents the central value of the qualitative concept, which determines the distribution position of a cloud droplet. represents the range of values for a cloud droplet ex-pressed in a qualitative concept in a register, reflecting the fuzziness and randomness of the basic concept. k is the entropy of entropy, representing the uncertainty of entropy. In cloud images, usually represents the thickness of the cloud. The greater the entropy, the thicker the cloud.

For indicators with bilateral constraints , cloud models can be used to describe them, and the cor-responding three numerical features are:

$$\begin{cases} E_x = \dfrac{H_{\min} + H_{\max}}{2}, \\ E_n = \dfrac{H_{\max} - H_{\min}}{2}, \\ \quad H_e = k, \end{cases} \tag{2}$$

In the equation, $H_{\min}$, $H_{\max}$, and H_e are generally directly given, where k is a constant that can be adjusted based on the uncertainty and randomness of the indicator [11].

2.2 Cloud Generator

There are two calculation methods for cloud models, one is done through software, and the other is done through hardware. This method is called cloud generator, which is divided into forward cloud generator and reverse cloud generator.

The forward cloud generator is the key to the transformation of cloud models from theory to practical applications. It uses characteristic parameters (E_x, E_n, E_e) to generate cloud droplets, and then transforms qualitative concepts into quantitative numerical analysis and calculation. The three numerical eigenvalues E_x, E_n, E_e and cloud droplet N representing the qualitative concept C in the one-dimensional forward cloud generator, output are the quantitative values of N cloud droplets, and $t(x)$ is the membership degree of each cloud droplet representing concept c .

The calculation formula is:

$$t(x) = \exp\frac{-(x-E_x)^2}{2E_x} \tag{3}$$

The reverse cloud generator uses quantitative data to describe the qualitative characteristics of things. It calculates the average value of samples to obtain the E_x, E_n, H_e of the cloud generator. The input of the one-dimensional reverse cloud generator is the position of n raindrops in the quantitative domain and the membership degree represented by each cloud droplet. The output is the E_x, E_n, H_e of the qualitative concept, and the number of cloud droplets is given.

3 Weight Determination

Analytic Hierarchy Process (AHP) is a method pro-posed by Professor Thomas L Saaty of the University of Pittsburgh in the 1970s to solve multi-objective decisionmaking problems. When evaluating indicators without unified standards, the corresponding level of evaluation is obtained through the evaluator's experience judgment, and the evaluation level indicators are collected for mathematical modeling[12]. The schematic diagram of AHP hierarchical structure is shown in Fig.1.

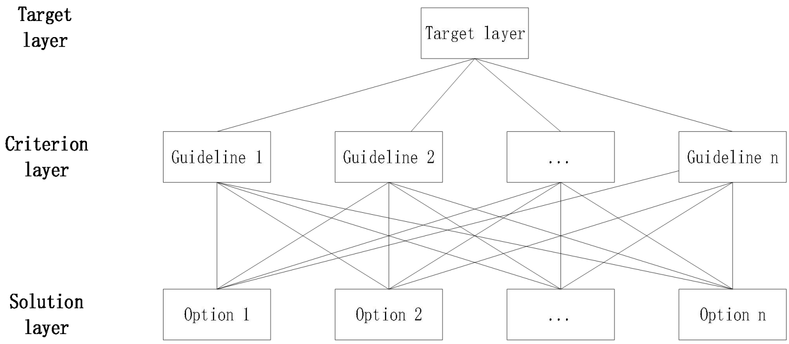

Fig. 1. Schematic diagram of AHP hierarchical structure.

The safety assessment indicators for rail transit operation are mainly divided into four aspects: station train operation, station passenger capacity, station environment, and station equipment services. Therefore, these four indicators have been determined as the first level indicators for rail transit operation safety assessment.

The AHP-OWA weighting method is an improved Analytic Hierarchy Process (AHP OWA) method that ranks the weights in order after passing consistency checks on the weights of indicators at all levels[13]. Then, the OWA operator is used to avoid data instability caused by maximum and minimum values. The steps are as follows:

3.1 Obtain initial weights using the AHP method

The AHP algorithm assigns weights to rail transit operational safety risk assessment indicators by inviting experts to obtain the initial weights q_i of the indicators.

3.2 Extreme weakening

The OWA weighting method mainly uses binomial coefficients to weaken and adjust the extreme value of weights to obtain absolute weights. The formula is as follows:

$$u_i' = \frac{c_n^k}{\sum_{k=0}^{n} c_n^k} q_i \tag{4}$$

Where: $\sum_{k=0}^{n} c_n^k$ is the sum of binomial; n is the number of indicators that require weight adjustment.

3.3 OWA Adjust Weights

The adjusted weight u_i' can be obtained by combining the binomial coefficient and weight and normalizing them.

$$u_i = \frac{u_i'}{\sum_{i=1}^{n} u_i'} \tag{5}$$

4 Safety Assessment

According to the principle of cloud models, data from various evaluation indicators are treated as cloud droplets, and the cloud model feature parameters are calculated. The feature parameters are input into the forward cloud generator to obtain a comprehensive evaluation result. The overall characteristics of the cloud cluster formed by the comprehensive evaluation result reflect the operational safety status of urban rail transit. The evaluation process is as follows:

4.1 Determine the risk assessment index system

Taking into account the various attributes of rail transit risk assessment, representative comprehensive assessment indicators are selected to construct a rail transit risk assessment indicator system. The station operation safety risk assessment index system consists of four first level indicators and 17 second level indicators, as shown in Table 1.

4.2 Determine the evaluation level scale cloud

According to the operational safety standards of rail transit stations, the risk assessment levels of rail transit operation are divided based on expert opinions. The level boundary is fuzzified using a cloud model to calculate the cloud feature parameters of the standard cloud for rail transit operation safety risk level, as shown in Table 2.

The obtained feature parameters are input into a forward cloud generator to obtain a practical scale cloud for rail transit operation safety risk assessment, as shown in Fig.2.

4.3 Determine indicator weights

The first level indicators of the rail transit risk assessment index system are weighted using AHP-OWA. Compare each statistical indicator in pairs to form ajudgment matrix, calculate the consistency ratio CR of the judgment matrix, realize the weakening adjustment of the weight mechanism through OWA weighting, and combine the binomial coefficient with the initial weight to obtain the rail transit risk indicator weight, as shown in Table 3.

4.4 Determine the evaluation result cloud

Calculate the actual cloud digital feature parameters of each indicator data in the actual evaluation plan. Input digital features into a reverse cloud generator to generate the corresponding cloud parameter matrix, i.e. Z .

$$Z = \begin{Bmatrix} a_{11} \\ a_{12} \\ \cdots \\ a_{45} \end{Bmatrix} = \begin{Bmatrix} E_{x11} & E_{n11} & H_{e11} \\ E_{x12} & E_{n12} & H_{e12} \\ \cdots & \cdots & \cdots \\ E_{x45} & E_{n45} & H_{e45} \end{Bmatrix} \tag{6}$$

Based on the obtained weights and indicator cloud parameter matrix, the cloud model for evaluating the operational safety of urban rail transit can be expressed as:

4.5 Compare evaluation results

By comparing the comprehensive evaluation cloud map generated by the forward cloud generator with the evaluation level scale cloud map, the evaluation results can be obtained based on the range W and shape of the Z comparison cloud map

$$C = W * Z \tag{7}$$

5 Case Analysis

This article evaluates and analyzes Shanghai Metro Line 10, which connects Minhang District, Hongqiao Railway Station, and Hangzhong Road Station to Pudong New Area. It is an L-shaped line for Shanghai Metro operation. It has prominent characteristics such as strong representativeness, high operating mileage, multiple stations, and long operating time, which is the reason why we chose Line 10 for empirical research.

5.1 Data processing

On the basis of knowing the safety level standard of rail transit operation risk, the cloud parameter solution formula under bilateral constraints based on normal distribution is adopted, and the level boundary is fuzzified through the cloud model. The assessment level boundary value has the same membership degree of 0.5. The calculated characteristic parameters of the standard cloud model of rail transit operation safety risk level are shown in Table 2.

Table 2. Standard cloud model characteristic parameters of rail transit operation safety risk leve

Comprehensive evaluation level		Characteristic parameter	
	E_x	E_n	H_e
Very safe	91.3	6.3	0.64
Safe	76.4	6.3	0.64
Unsafe	55.6	6.3	0.64
Dangerous	21.3	17.1	1.68

Input the characteristic parameters of each level of cloud model into the forward cloud generator to obtain the evaluation standard cloud for rail transit, as shown in Fig.2.

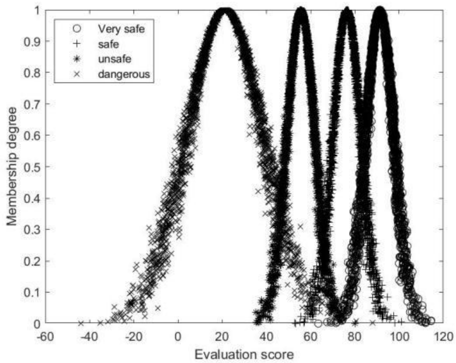

Fig. 2. Rail transit operation safety risk assessment index cloud map.

5.2 Calculation of Evaluation Index Weights

The evaluation indicators for rail transit operation management mainly include station train operation, station passenger capacity, station environment, and station equipment services, which are determined as the first level indicators for rail transit operation risk assessment. The AHP-OWA weighting method is used to weight the first level indicators of the rail transit risk assessment index system. Compare the same level indicators in pairs to form a judgment matrix, and calculate the consistency ratio of the judgment matrix to be $CR = 0.056 < 0.1$, which can pass the consistency test. The OWA weighting is used to realize the weakening adjustment of the extreme value of the weight, and the binomial coefficient is combined with the initial weight to obtain the primary index weight. The specific weighting results are shown in Table 3.

Table 3. Weights of indexes at all levels of rail transit operation safety evaluation

Primary indicators	Weight	Secondary indicators	Weight
		Station train delay rate	0.052
		train delay	0.051
train operation	0.237	Station train load factor	0.058
		User satisfaction with trains	0.076
		Gate usage rate	0.060
		Usage rate of stored value tickets	0.071
Station passenger capacity	0.245	Platform screen door failure rate	0.061
		Platform passenger density	0.053
		temperature difference ratio	0.046
		Carbon dioxide concentration	0.062
Station environment	0.222	Oxygen concentration	0.051
		Humidity difference ratio	0.063
		Lighting equipment failure rate	0.045
		Water pump failure rate	0.053
Station Equipment Services	0.296	Fan failure rate	0.062
		Emergency alarm device failure rate	0.057
		Sensor failure rate	0.079

5.3 Analysis of evaluation results

Input the indicator data and weight data into the reverse cloud generator to obtain the corresponding indicator set cloud parameter matrix, namely Z. The obtained matrix is combined with the weight W to obtain the cloud parameters of the Shanghai Metro Line 10 indicator system according to formulas 6 and 7. The cloud parameters of the evaluation results of each secondary and primary indicator are shown in Table 4.

Input the obtained cloud model parameters of all levels of indicators into the forward cloud generator to obtain cloud maps of all levels of indicators. Taking train operation indicators as an example, place the obtained evaluation result cloud map into the cloud map of rail transit evaluation standards. A more intuitive evaluation result level is shown in Fig.3.

From the cloud chart of indicators at all levels, it can be seen that the first level indicator station train operation indicators perform the best, with an evaluation level between "safe" and "very safe", and a high score, indicating that the station train operation safety performance is relatively excellent. The evaluation level of station passenger capacity, station environment, and station equipment service is between "safe" and "very safe", and the score is close to the "safe" level. The low score of station environmental indicators indicates that the station needs further improvement in terms of station environment.

By calculating the scores and weights of various indicators at all levels, the comprehensive cloud parameters for rail transit operation safety risk assessment are obtained, as shown in Table 5. The obtained cloud model parameters are input into the forward cloud generator to obtain the comprehensive evaluation

Table 4. Rail transit operation safety at all levels of index cloud parameters

Primary indicators	E_x	E_n	H_e	Secondary indicators	E_x	E_n
				Station train delay rate	91.67	2.228
				train delay	91.67	1.114
train operation	83.57	2.188	0.813	Station train load factor	71.67	1.95
				User satisfaction with trains	81.67	3.064
				Gate usage rate	78.33	2.785
				Usage rate of stored value tickets	95	1.671
Station passenger capacity	78.51	2.342	1.07	Platform screen door failure rate	68.33	2.785
				Platform passenger density	68.33	2.228
				temperature difference ratio	81.67	2.785
				Carbon dioxide concentration	85	1.671
Station environment	77.1	2.267	1.124	Oxygen concentration	78.33	2.228
				Humidity difference ratio	65	2.507
				Lighting equipment failure rate	75	2.507
				Water pump failure rate	88.33	3.621
Station Equipment Services	77.73	2.338	0.854	Fan failure rate	71.67	2.228
				Emergency alarm device failure rate	85	1.671
				Sensor failure rate	71.67	1.95

Table 5. Integrated cloud parameters for rail transit operation safety risk assessment

Risk assessment of rail transit operation safety	E_x	E_n	H_e
	79.16	2.288	0.958

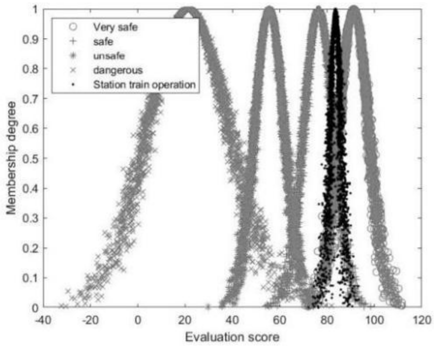

Fig. 3. Rail transit operation safety risk assessment station train operation index cloud map.

cloud map, and the obtained comprehensive evaluation cloud map is placed in the standard cloud map for rail transit operation safety risk assessment, to more intuitively see the level of rail transit operation safety risk assessment. As shown in Fig.4.

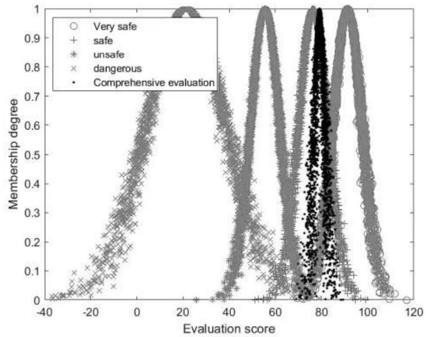

Fig. 4. pIntegrated cloud map of rail transit operation safety risk assessment.

The comprehensive evaluation score of Shanghai Metro Line 10 is calculated to be 79.16. As shown in Fig.4, cloud droplets are located between "safe" and "very safe". It can be seen that the safety risk assessment performance of this station operation is relatively excellent.

6 Conclusion

The safe operation of urban rail transit is crucial to the safety of every citizen, and ensuring the safety of urban rail transit is very important. Due to the large number of daily operations and passenger capacity, it is crucial to conduct a safety assessment of urban rail transit.

(1) Taking Shanghai Metro Line 10 as an example, based on on-site research, a safety evaluation index system for urban rail transit was constructed from four aspects.

(2) The improved AHP method and cloud model were used to evaluate the safety of rail transit operation in four aspects: train operation, train capacity, station environment, and station equipment condition. From the evaluation results, it can be seen that the safety of Shanghai Metro Line 10 is good, with a relatively low score for station environment, which requires further improvement.

In addition, the operating environment of urban rail transit is complex, with a large number of personnel.The equipment is extensive, and the indicator system constructed in the article needs further improvement.

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