Evaluation of Urban Rail Transit Service Level Based on Extension Cloud Model

Yuling Xing[1,*], Lingqiang Kong[1], Huijuan Zhou[2], Xuhui Liu[1], Haoxu Wang[1]

[1]Zhengzhou Key Laboratory of Special Vehicle Power and Control, Zhengzhou University of Science and Technology, Zhengzhou, Henan Province, 45000, China
[2]Beijing Key Laboratory of Intelligent Control Technology for Urban Road Traffic, North China University of Technology, Beijing, 100144, China

[*]Corresponding author's e-mail: 1931581232@qq.com

Abstract. Aiming at the problems of different standards and incomplete index coverage of urban rail transit evaluation system, combined with relevant standards and norms at home and abroad, a service level evaluation index system was established from the perspective of the whole process of passenger urban rail transit travel. The comprehensive weights of indicators are obtained through the weighting method combining AHP and CRITIC, and an evaluation model of urban rail transit service level based on extension cloud model is established. Based on the operation and research data of Beijing Metro Line 1, the extension cloud model is used to evaluate its service level and verify the scientificity and feasibility of the method. This method provides scientific basis for urban rail transit operation managers to evaluate service status, improve service level and improve passenger travel experience.

Keywords: urban rail transit; level of service; index system; extension cloud model

1 Introduction

With the deep integration of "Internet + rail transit", the smart city rail transit system has become a trend, the pace of urban rail transit has been significantly accelerated, and the pressure and challenges of safe operation are also increasing. For passengers, travel is no longer a simple displacement, and the requirements for service capacity and quality in all aspects of the travel process are getting higher and higher. It is an urgent problem to solve the problem of how to reasonably evaluate the service level of urban rail transit from the perspective of passengers, so as to improve the service level and operation efficiency in a targeted manner.

At present, there are many comprehensive evaluation methods used for urban rail transit. In 2017, Guo Yanyong modeled and analyzed the service level of a single subway line based on matter-element extensionology [1]. In 2019, Heike Link used data envelopment analysis and Tobit panel model to study the impact of service quality in efficiency difference analysis based on the panel data of specialized regional railway

G. Zhao et al. (eds.), *Proceedings of the 2024 7th International Symposium on Traffic Transportation and Civil Architecture (ISTTCA 2024)*, Advances in Engineering Research 241,
https://doi.org/10.2991/978-94-6463-514-0_12

services [2]. In 2020, Xiao Jichuan established a comprehensive evaluation index system for the operational vulnerability of metro stations, using the entropy weight method to achieve objective weighting, and using the TOPSIS method to evaluate the operational vulnerability of the subway transfer station through the index score of Jiahewang Station of Guangzhou Metro by an expert group [3]. Based on the perception survey of the rail transit system and 2390 passengers in Delhi, India, Jyoti Mandhani used principal component analysis to extract service quality factors, and used an integrated Bayesian network and partial least squares structural equation model to establish a service quality model to identify the hidden interrelationships between service quality factors [4]. Hua-Wen Wu constructed an evaluation index system for the operation safety of urban rail transit, and evaluated the operation safety of urban rail transit based on the cloud model and the improved CRITIC method [5]. In 2021, Li Xiaopei established an evaluation index system for urban rail transit operation safety from four aspects: personnel, equipment, environment, and management factors, and used the fuzzy comprehensive evaluation method to evaluate the operation safety of rail transit [6].

The above-mentioned comprehensive evaluation methods have their own advantages and disadvantages and applicable conditions. The TOPSIS method is a comprehensive evaluation method that uses the information of raw data to reflect the gaps between various evaluation schemes, and is suitable for comparison and selection of multiple schemes, but its own conditions are easy to cause positive and negative changes in understanding, and lack a certain degree of stability [7]. The fuzzy comprehensive evaluation method transforms the qualitative evaluation into quantitative evaluation through the membership degree theory of fuzzy mathematics, but the determination of the index weight is highly subjective, and the determination of the relative membership weight coefficient needs to be further studied. In recent years, the extendable cloud theory has been widely used in the comprehensive evaluation of electric power, construction safety, water resources, and regional ecology, which integrates the cloud model and matter-element analysis method to form the basic parameters of the normal cloud membership function, realize the measurement of the randomness and ambiguity of the evaluation level boundary, and deal with the problem of multi-index information incompatibility [7]. In this paper, a service level evaluation system is established, and combined with the index attributes in the evaluation system, the extensible cloud model is applied to the evaluation of urban rail transit service level, so as to provide scientific and reasonable guidance for urban rail transit operation managers to evaluate the service status and improve the service level.

2 Establishment of Service Level Evaluation System

2.1 Determination of Evaluation Indicators

The establishment of the evaluation system should not only understand the relevant standards and the research of existing scholars, but also consider the behavior and psychology of passengers in the process of travel in combination with the characteristics of urban rail transit. Based on my previous research [8], the influencing factors of service level were extracted from the perspective of the whole process of passenger travel, and a service level evaluation index system was established. The system includes 9 first-level indicators of entry and exit, ticket purchase, security check, ticket inspection, staircase passage, waiting, boarding, transfer, operation and management, and 26 second-level indicators of influencing factors in each link, and the index content and evaluation criteria are shown in Table 1.

Table 1. Evaluation system of urban rail transit service level

first-level indicators	Secondary indicators	Evaluation Criteria
Inbound or outbound	Walking distance from the station C_1	Numeric intervals
	Boarding guidance sign C_2	Score
Buy tickets	Passenger queuing time C_3	Numeric intervals
	Convenience of purchasing tickets C_4	Score
Security	Security queue time C_5	Numeric intervals
	Attitude of the security personnel C_6	Score
Ticket	Turnstile utilization C_7	percentage
	Gate units utilize balance C_8	percentage
	Turnstile failure rate C_9	percentage

Continued Table 1. Evaluation system of urban rail transit service level

first-level indicators	Secondary indicators	Evaluation Criteria
Up and down the channel	Walking time C_{10}	Numeric intervals
	Information Guidance C_{11}	Score
	Completeness of facilities C_{12}	Score
	Facility reliability C_{13}	percentage
Waiting	Waiting time C_{14}	Numeric intervals
	Information broadcasting C_{15}	Score
	Dynamic identity C_{16}	Score
Ride	Logo identification C_{17}	Score
	Train broadcasting C_{18}	Score
	Cabin comfort C_{19}	Score
	Ride safety C_{20}	Score
Transfer	Transfer signs C_{21}	Score
	Transfer time C_{22}	Numeric intervals
Operations management	The success rate of the last train C_{23}	percentage
	Train punctuality C_{24}	percentage
	Passenger complaint handling rate C_{25}	percentage
	Emergency handling C_{26}	Score

2.2 Weights of Evaluation Indicators

The evaluation system of urban rail transit service level involves quantitative and qualitative different attribute indicators, and in order to make a systematic evaluation of the evaluation object, it is necessary to determine the weight of each index in order to construct an evaluation model for service level evaluation. According to the evaluation index system, combined with the questionnaire survey data on the importance of indicators in my previous research results [9], the AHP and CRITIC methods were selected to carry out subjective and objective weighting of the indicators respectively, and the comprehensive index weights were obtained by coupling, so as to make the index weights more scientific and reasonable. The coupling calculation method is shown in equation (1).

$$W_i = \frac{w'_i w_i''}{\sum_{i=1}^{n} w'_i w_i''} (j = 1,2,3....n) \tag{1}$$

Where w_i' is the index weight obtained by the AHP method, and w_i'' is the index weight obtained by the CRITIC method. According to the calculation results, the weight vector of the composite index is (0.1230,0.2184,0.0236,0.0440,0.0956,0.0319, 0.0114,0.0055,0.0120,0.0038,0.0037,0.0054,0.0114,0.0831,0.0293,0.0275,0.0231,0.0 226,0.0133,0.0755,0.0725,0.0477,0.0036,0.0039,0.0011,0.0073).

2.3 Evaluation Grade Division

The classification of urban rail transit service level and the selection of thresholds are also very important. The index system established in this paper includes quantitative and qualitative indicators, and the service level of urban rail transit is divided into 1-5 levels by referring to the classification standards of TCRP and other relevant urban rail transit station facilities and line operation, which represent excellent, good, average, poor and very poor, respectively. Among them, the qualitative indicators give the scoring principle, and the 5-point system is used for grading. Such indicators include signs, information broadcasting, passenger services, facilities, driving safety, etc. The thresholds for each level of quantitative indicators are based on relevant criteria and expert recommendations. Table 2 describes the thresholds for specific indicator levels.

Table 2. Indicator levels and thresholds

Index	L_1	L_2	L_3	L_4	L_5
C_1	[0,300)	[300,500)	[500,800)	[800,1000)	[1000,1500)
C_2	(4,5]	(3,4]	(2,3]	(1,2]	[0,1]
C_3	[0,30)	[30,60)	[60,90)	[90,120)	[120,300)
C_4	[0,20)	[20,40)	[40,60)	[60,90)	[90,120]
C_5	[0,10)	[10,30)	[30,60)	[60,120)	[120,300]

C_6	(4,5]	(3,4]	(2,3]	(1,2]	[0,1]
C_7	[0.9,1]	[0.8,0.9)	[0.6,0.8)	[0.4,0.6)	[0,0.4)
C_8	[0.8,1]	[0.6,0.8)	[0.4,0.6)	[0.2,0.4)	[0,0.2)
C_9	[99.9,100]	[99.5,99.9)	[99,99.5)	[97,99)	[0,97)
C_{10}	[0,108)	[108,172)	[172,210)	[210,326)	[326,600]
C_{11}	(4,5]	(3,4]	(2,3]	(1,2]	[0,1]
C_{12}	(4,5]	(3,4]	(2,3]	(1,2]	[0,1]
C_{13}	[99.9,100]	[99,99.9)	[98.5,99)	[97,98.5)	[0,97)
C_{14}	(10,30]	(30,120]	(120,180]	(0,10]	(180,600]
C_{15}	(4,5]	(3,4]	(2,3]	(1,2]	[0,1]
C_{16}	(4,5]	(3,4]	(2,3]	(1,2]	[0,1]
C_{17}	(4,5]	(3,4]	(2,3]	(1,2]	[0,1]
C_{18}	(4,5]	(3,4]	(2,3]	(1,2]	[0,1]
C_{19}	(4,5]	(3,4]	(2,3]	(1,2]	[0,1]
C_{20}	(4,5]	(3,4]	(2,3]	(1,2]	[0,1]
C_{21}	(4,5]	(3,4]	(2,3]	(1,2]	[0,1]
C_{22}	[10,60)	[60,180)	[180,240)	[240,360)	[360,520]
C_{23}	[99,100]	[80,99)	[60,80)	[40,60)	[0,40)
C_{24}	[99.9,100]	[99.4,99.9)	[98.5,99.4)	[97,98.5)	[0,97)
C_{25}	[99,100]	[95,99)	[90,95)	[85,90)	[0,85)
C_{26}	(4,5]	(3,4]	(2,3]	(1,2]	[0,1]

3 Service Level Evaluation

3.1 Principles of the Extendable Cloud Model

The cloud model was proposed by Professor Li Deyi. The distributed membership of any element x on the domain U is denoted as $u(x)$, and each x with membership is denoted as a cloud drop$(x, u(x))$, and the membership function forms the shape of the cloud, which is called the cloud model. The numerical characteristics of the cloud are (E_x, E_n, H_e). E_x represents the expected spatial distribution of cloud droplets in the domain, entropy E_n represents the degree of dispersion of cloud droplets, and superentropy H_e is a measure of the uncertainty of entropy, which is the thickness of a cloud droplet. The meaning of its numerical features is shown in Figure 1.

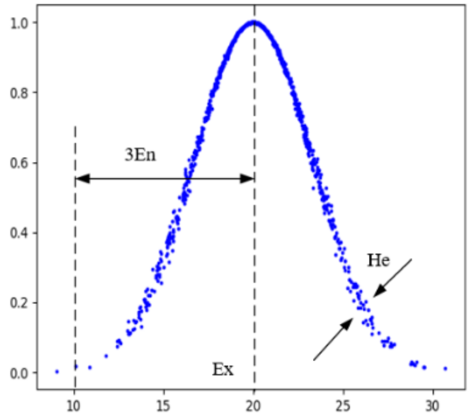

Fig. 1. Schematic diagram of the three numerical features of the cloud model.

Matter-element analysis unifies the name P, feature C_i, and eigenvalue X of the evaluation thing to form the basic element $R = (P, C_i, X)$ of the thing, where Xrepresents the limit value of the evaluation index, which is the determined value. The division of the actual service level cut-off value X is fuzzy and random, so the cloud model eigenvalue (E_x, E_n, H_e) is substituted for X to form an ordered triplet (thing name, thing feature, cloud cover value) [10], and the cloud extension model is denoted as shown in equation 2.

$$R = \begin{bmatrix} P & C_1 & x_1 \\ & C_2 & x_2 \\ & \cdots & \cdots \\ & C_i & x_3 \end{bmatrix} = \begin{bmatrix} p & C_1 & (E_{x1}, E_{n1}, H_{e1}) \\ & C_2 & (E_{x2}, E_{n2}, H_{e2}) \\ & \cdots & \cdots \\ & C_i & (E_{xi}, E_{ni}, H_{ei}) \end{bmatrix} \tag{2}$$

3.2 Extensible Cloud Model Calculations

The generation algorithm of the cloud can be implemented either in software or in hardware, called a cloud generator. The forward cloud generator is the process from qualitative concept to quantitative representation, and the reverse cloud generator is the process from quantitative representation to qualitative concept. The hierarchical standard cloud is implemented with a one-dimensional forward cloud generator, and its algorithm principle is shown in Figure 2.

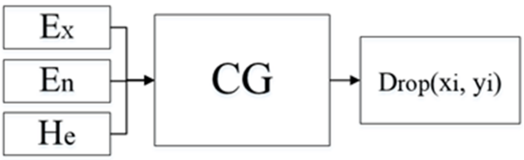

Fig. 2. Forward Cloud Generator.

If the indicator value is x∈ (a, b), then the three numeric eigenvalues of the cloud model E_x, E_n, H_e, as shown in equation (3).

$$\left\{\begin{array}{c} E_x = (a+b)/2 \\ E_n = (b-a)/6 \\ H_e = C(C \text{ is generally taken as "}0-0.2\text{" }) \end{array}\right\} \quad (3)$$

Calculation of the Correlation Degree of the Metric μ_{il}.

The Metric correlation calculation methods can be divided into two categories. In the case where the value of the index to be evaluated is determined, the value x_i can be regarded as a cloud droplet, which can be brought into the forward cloud generator to produce a random number $E_n'$with an expectation of E_n and a standard deviation of H_e, which obeys the standard normal distribution. Since E_n' is randomly generated, in order to improve the confidence level, t needs to be repeated (here t is taken 1000 times) to obtain the mean E_n'', then the correlation degree of the indicator as shown in equation (4).

$$u_{il} = \exp\left[-\frac{(x-E_x)^2}{2(E_n'')^2}\right] \quad (4)$$

For the uncertain evaluation index, the fuzzy transformation of the characteristic interval value is required. The correlation degree of the index is the ratio of the intersection and union of the index interval and the hierarchical cloud interval [10].

Let N be the intersection of the indicator and the hierarchical cloud interval.

$$N = (E_x - 3E_{n1}', E_x + 3E_{n1}') \cap (E_x - 3E_{n2}', E_x + 3E_{n2}') \quad (5)$$

Let M be the union of the indicator and the hierarchical cloud interval.

$$M = (E_x - 3E_{n1}', E_x + 3E_{n1}') \cup (E_x - 3E_{n2}', E_x + 3E_{n2}') \quad (6)$$

The correlation between the indicator and each level is as follows.

$$u_{il} = N/M \quad (7)$$

According to the correlation calculation method of the above two types of indicators, the correlation matrix of the object to be evaluated is as follows.

$$U = \begin{bmatrix} u_{11} & u_{12} & \cdots & u_{1l} \\ u_{21} & u_{22} & \cdots & u_{2l} \\ \cdots & \cdots & \cdots & \cdots \\ u_{i1} & u_{i2} & \cdots & u_{il} \end{bmatrix} \quad (8)$$

where i is the number of indicators, and l is the number of evaluation grades.

Determine the Rating Level.

The comprehensive evaluation vector is calculated by the index correlation degree U and the index weight W.

$$B = W \times U = (b_1, b_2, b_3, b_4 \ldots\ldots b_l) \tag{9}$$

The weighted average method was used to obtain the comprehensive evaluation score r.

$$r = \sum_{l=1}^{5} b_l f_l \,/\, \sum_{l=1}^{5} b_l \tag{10}$$

f_l is the score corresponding to each grade in the evaluation grade. In this paper, the service level from L_1 to L_5 is scored at 5, 4, 3, 2, 1, and the final score is shown in Table 3.

Table 3. Rating scores.

Evaluation Rating	L_1	L_2	L_3	L_4	L_5
Score is judged	[4.5,5]	[3.5,4.5)	[2.5,3.5)	[1.5,2.5)	[0,1.5)

4 Instance Verification

4.1 Data Research

In order to verify the scientific rationality of the evaluation model, combined with the specific survey data, the service level of the extension cloud model was evaluated. The survey is the travel process of passengers transferring from Octagon Amusement Park Station to Gongzhufen Station to Line 10 during the morning peak of 7:00-8:00 on weekdays in November 2022. Among them, the facilities and operation indicators were obtained by the Beijing Transportation Development Research Institute, and the other indicators were obtained from field research according to the qualitative index evaluation principles and scoring criteria and quantitative index calculation formulas, as shown in Table 4.

Table 4. Passenger travel survey datas from Bajiao Amusement Park Station to Gongzhufen Station

Index (per unit)	Survey values	Index (per unit)	Survey values
C_1(m)	[66,698]	C_{14}	[0,162]
C_2	4	C_{15}	4
C_3(s)	[0,22]	C_{16}	5
C_4(s)	[2,56]	C_{17}	5
C_5(s)	[0,12]	C_{18}	5
C_6	4	C_{19}	3
C_7	0.62	C_{20}	5

C_8	[0.90,0.96]	C_{21}	4
C_9	99.99%	C_{22}(s)	[116,125]
C_{10}	[60,70]	C_{23}(%)	100%
C_{11}	4	C_{24}(%)	99.97%
C_{12}	4	C_{25}(%)	100%
C_{13}	100%	C_{26}	5

4.2 Definition of Service Level Levels

According to the threshold of service level classification and the calculation method of cloud model level cloud eigenvalue, the numerical characteristics of the index service level level standard cloud are obtained, where the H_e is taken as 0.01. The forward cloud generator was programmed with Python software, and the eigenvalues of the standard cloud of each index level were entered, and the index level evaluation cloud was drawn. The standard clouds of grades 1-5 of each index are represented by "red, orange, green, blue, and violet" in the same coordinate axis. The abscissa is the indicator value, and the ordinate represents the membership degree of the indicator value in different levels of the region. Taking index C1 as an example, the standard cloud of the index grade is shown in the figure 3 below.

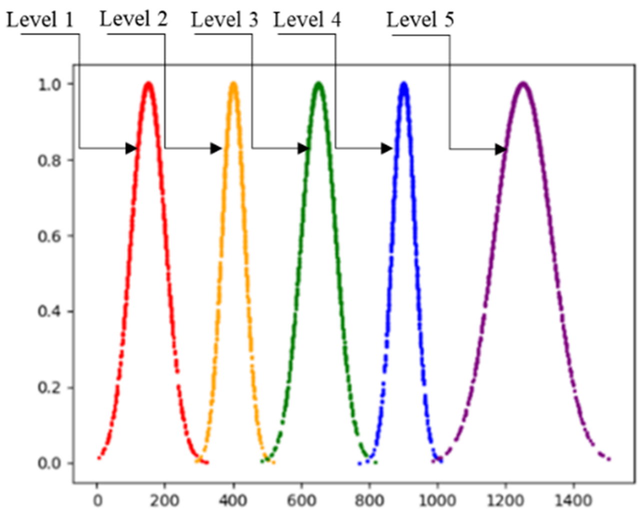

Fig. 3. Standard cloud of walking distance outside the station C_1.

Due to the ambiguity of the actual indicators to be evaluated, the correlation matrix U should be calculated according to the level relevance in equation (11).

$$U=\begin{bmatrix}0.3352 & 0.3165 & 0.2698 & 0.0000 & 0.0000\\ 0.0124 & 0.0126 & 0.0000 & 0.0000 & 0.0000\\ 0.7333 & 0.0000 & 0.0000 & 0.0000 & 0.0000\\ 0.3214 & 0.3571 & 0.2759 & 0.0000 & 0.0000\\ 0.8333 & 0.0667 & 0.0000 & 0.0000 & 0.0000\\ 0.0122 & 0.0126 & 0.0000 & 0.0000 & 0.0000\\ 0.0000 & 0.0000 & 0.1000 & 0.0000 & 0.0000\\ 0.3000 & 0.0000 & 0.0000 & 0.0000 & 0.0000\\ 0.1946 & 0.0008 & 0.0000 & 0.0000 & 0.0063\\ 0.0926 & 0.0000 & 0.0000 & 0.0000 & 0.0000\\ 0.0124 & 0.0126 & 0.0000 & 0.0000 & 0.0000\\ 0.0125 & 0.0120 & 0.0000 & 0.0000 & 0.0000\\ 0.1050 & 0.0016 & 0.0000 & 0.0000 & 0.0063\\ 0.1235 & 0.5556 & 0.2333 & 0.0617 & 0.0000\\ 0.0124 & 0.0127 & 0.0000 & 0.0000 & 0.0000\\ 0.0123 & 0.0000 & 0.0000 & 0.0000 & 0.0000\\ 0.0124 & 0.0000 & 0.0000 & 0.0000 & 0.0000\\ 0.0124 & 0.0000 & 0.0000 & 0.0000 & 0.0000\\ 0.0000 & 0.0124 & 0.0125 & 0.0000 & 0.0000\\ 0.0124 & 0.0000 & 0.0000 & 0.0000 & 0.0000\\ 0.0124 & 0.0126 & 0.0000 & 0.0000 & 0.0000\\ 0.0000 & 0.0750 & 0.0000 & 0.0000 & 0.0000\\ 0.0145 & 0.0041 & 0.0000 & 0.0000 & 0.0000\\ 0.5388 & 0.0009 & 0.0000 & 0.0000 & 0.0063\\ 0.0143 & 0.0000 & 0.0000 & 0.0000 & 0.0003\\ 0.0126 & 0.0000 & 0.0000 & 0.0000 & 0.0000\end{bmatrix} \tag{11}$$

Next, the correlation degree of the comprehensive evaluation grade B was calculated in equation (12).

$$B = W \times U = (0.1767,\quad 0.1155,\quad 0.0660,\quad 0.0051,\quad 0.0002) \tag{12}$$

Finally, the comprehensive evaluation score r was calculated in equation (13).

$$r = \frac{\sum_{l=1}^{5} b_l f_l}{\sum_{l=1}^{5} b_l} = \frac{5\times0.1767+4\times0.1155+3\times0.0660+2\times0.0051+1\times0.0002}{0.1767+0.1155+0.0660+0.0051+0.0002} = 4.2748 \tag{13}$$

According to the final calculation results, the comprehensive evaluation score is in the range of [3.5, 4.5), and the service level of Beijing Metro Line 1 during the morning peak period is level 2 according to the grade score table. The Beijing Municipal Transportation Commission will carry out the 2022 Beijing Urban Rail Transit Service Quality Evaluation in accordance with the "Urban Rail Transit Service Quality Evaluation Specification". The evaluation content includes three parts: passenger satisfaction, service guarantee ability and key indicators of operation service, with a benchmark score of 1000 points. Among the 22 participating lines announced, the scores of Beijing Metro Line 1 are all at the upper middle level. The results of this evaluation are consistent with the results verified by the research examples, which proves the rationality of the evaluation method.

5 Conclusion

According to the relevant standards and specifications of urban rail transit, considering the travel needs and behavioral characteristics of passengers, a service level evaluation index system is established. Combined with the index attributes in the evaluation system, the extendable cloud model is innovatively applied to the evaluation of urban rail transit service level, and the measurement of randomness and ambiguity of the service level evaluation level boundary is realized. The feasibility of the model is verified by the actual survey data, which provides scientific guidance for urban rail transit operation managers to evaluate the service status and improve the service level.

Due to the rapid development of the intelligence of the urban rail transit system, the establishment of its service level evaluation system needs to be further updated and refined, and the convenience of the implementation of the evaluation method needs to be studied, so as to better serve the passengers' public transportation and improve the passenger travel experience.

References

1. Guo Y Y, Liu P, WU Y, et al. (2017) Evaluation Method for Service Level of Urban Rail Transit and Its Application. J. Journal of Hefei University of Technology, ,40(03):384-389.
2. Heike Link. (2019) The impact of including service quality into efficiency analysis: The case of franchising regional rail passenger serves in Germany. J. Transportation Research Part A: Policy and Practice, (119):284-300.
3. Xiao J C, Xing Y. (2020) A vulnerability assessment method for subway station operation based on entropy-weighted TOPSIS model. J. Journal of Transportation Engineering and Information, 18(02):163-169.
4. JYoti Mandhani, Jogendra K N, Manoranjan P. (2020) Interrelationships among service quality factors of Metro Rail Transit System: An integrated Bayesian networks and PLS-SEM approach. J. Transportation Research Part A: Policy and Practice, (140):320-336.
5. Hua-Wen Wu, Jin Z and Jing Z. (2020) Urban rail transit operation safety evaluation based on an improved CRITIC method and cloud model[J]. Journal of Rail Transport Planning & Management, (16).
6. Li X P, Duan Z Y and Sun L. (2021) Comprehensive Evaluation of Operation Safety of Urban Rail Transit Based on Fuzzy Comprehensive Evaluation. J. Heilongjiang Jiaotong Keji, 44(02):204-207+209.
7. Zhang Z J, Chen F L, Long A H, et al. (2020) Evaluation of Water Resources Security in Arid Area Based on Extension Cloud Model- A Case Study of Shihezi Reclamation Area. J.Arid Zong Research, 37(04):847-856.
8. Zhou H J, Xing Y L. (2020) Level of Service Evaluation System Based on the Entire Journey of Passenger Travel on Rail Transit.J.Journal of Transportation Engineering, 20(06)：44-50.
9. Chen J J. (2017) Research on comprehensive evaluation and application of construction safety based on extensible cloud theory. D. Wuhan University of Science and Technology.
10. Tan Z B. (2019) Research on tunnel traffic safety evaluation based on extendable cloud model. D. Huazhong University of Science and Technology.