COMPREHENSIVE SERVICE QUALITY EVALUATION OF PUBLIC TRANSIT BASED ON EXTENSION CLOUD MODEL

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Abstract:

Prioritizing the development of public transit and enhancing its attractiveness is an important way to solve the problem of urban traffic congestion and achieve sustainable development. To improve the service quality and overall operational efficiency of urban public transit, an evaluation index system related to the comprehensive experience of passengers, service supply quality of public transit enterprises, and supervision of management departments was introduced from both the demand and the supply of public transit travel services. Based on the data distribution characteristics of the boxplot in statistics, the evaluation level and corresponding value range of each index were determined, and the comprehensive weight of the index was determined using the linear weighting method combining the analytic hierarchy process and the entropy weight method, so as to reduce the influence of single weighting method on the evaluation results of comprehensive service quality of public transit. An evaluation method of public transit comprehensive service quality based on the extension cloud model was established. The evaluation results of the model were obtained by calculating the cloud affiliation and comprehensive certainty, and a reliability factor was used to test the evaluation results, which solved the problem of randomness and fuzziness in the process of comprehensive service quality evaluation of public transportation and made the evaluation results closer to the reality. Finally, the established comprehensive evaluation model was applied to a city for example analysis, and the corresponding evaluation level was obtained as good. The value of the reliability factor in the model was less than 0.01, indicating that the model has good applicability and a certain application value for the comprehensive service quality evaluation of public transit. The evaluation method fully considered a variety of evaluation indicators, specified the evaluation level of comprehensive service quality of public transit, and the evaluation results provide a theoretical basis for public transport enterprise to make targeted improvement measures.

Keywords: traffic engineering, public transit, comprehensive evaluation, extension cloud model, portfolio optimization, cloud affiliation

To cite this article:

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1. Introduction

Traffic congestion caused by the rapid development of cities has been perplexing urban managers and citizens for a long time. How to build a "people-oriented" public transit travel system from the perspective of passenger demand and a green and environmentally friendly protection travel mode for people at all levels has become the key to solving the problem. (Lai et al., 2020) proposed an evaluation method for public transit service quality based on passenger energy cost according to the heart rate, acceleration, and speed automatically collected by the experimenter while walking in the subway transfer station. (Awasthi et al., 2011) proposed a comprehensive evaluation method for the service quality of an urban transportation system based on SERVQUAL and fuzzy TOPSIS. (Liou et al., 2014) proposed a new information fusion model that solved the subordination relationship between various standards using the weighted nonlinear regression analysis method and realized the evaluation of the service quality of the public transport system. (Sendek & Pyza, 2018) established a passenger satisfaction evaluation model for Ningbo public transit by combining the advantages of the analytic hierarchy process (AHP), entropy weight method, and fuzzy comprehensive evaluation method. (Moslem et al., 2020) proposed a method combining AHP and the best worst method to evaluate public transit service quality. (Sercan & Selçuk, 2014) constructed a public transportation system service evaluation index system, including 22 evaluation indexes in six aspects: time, cost, accessibility, comfort, safety and service quality. (Morton et al., 2016) identified three potential factors that affect passenger satisfaction, namely convenience, environment in bus and ease of service. (Stojic et al., 2020) used correlation analysis, factor analysis and regression analysis to analyze the factors influencing passenger satisfaction based on the young user group. (Rajsman & Škorput, 2022) proposed a multi-criteria transportation service quality evaluation model based on passenger satisfaction to determine differences between reached level of the quality of transport service of individual bus carriers and propose possible improvements to the business. (Moslem & Celikbilek, 2020) proposed an integrated grey Analytic Hierarchy Process and grey Multi Objective Optimization Method by Ratio Analysis technique to evaluate the public transport service quality. (Soza-Parra et al.,

2019) proposed that crowding has a negative and non-linear impact on how passengers evaluate their travel satisfaction through a post-service satisfaction survey of bus and metro users. (Sam et al., 2018) Used the SERVQUAL methodology to analyse the core public bus transport users' service quality expectations and perceptions and pointed out that the bus service reliability and responsiveness were key to explain the bus service quality in the city. (Chocholac et al., 2020) proposed that respondents were more satisfied with the quality of services performed by the urban public transport companies, but the perception of individual service quality factors varied from one user group to another. (Noor & Foo, 2014) pointed out that comfort, convenience, and safety are the main factors influencing passenger satisfaction. (Rajsman & Škorput, 2022) proposed a multi-criteria model for evaluating the quality of transport services by the method of measuring passenger satisfaction based on the disaggregated approach and linear programming modeling (Kisilowski & Stypułkowski, 2021) established a service quality assessment index system for public transit enterprises from four aspects: bus passenger demand, bus enterprise service, enterprise authority, and regional characteristics. (Deng & Qin, 2020) established a passenger satisfaction evaluation index system based on AHP and fuzzy comprehensive evaluation method with six aspects of the economy, convenience, comfort, speed, safety, and punctuality as the first-level indicators. Based on the above research results, most of the current research content is to study the public transit service quality evaluation or passenger satisfaction evaluation separately, and does not combine the two for comprehensive evaluation. Moreover, few research results involve the evaluation of management departments. Most of the evaluation methods in the above studies use analytic hierarchy process, fuzzy comprehensive evaluation method and data envelopment analysis, and these methods cannot adequately express the fuzziness in the evaluation process, which makes the correlation between the evaluation methods and evaluation indicators weak, and there is a certain deviation between the evaluation results of the model and reality. Therefore, based on the problems existing in the above research, this paper introduces an evaluation index system related to the comprehensive experience of passengers, quality of service supply of

public transport enterprises and supervision of management departments from two aspects of public transport travel service demand and supply. Analytic hierarchy process and entropy weight method are used for combined weighting. Using the advantages of qualitative and quantitative analysis of matter-element extension theory and the uncertain reasoning characteristics of normal cloud model, a comprehensive service quality evaluation method of public transport based on extension cloud model is established to solve the problems of uncertainty in the evaluation process.

The paper is outlined as follows. In Sect. 2, we construct an evaluation index system related to the comprehensive experience of passengers, quality of service supply of public transport enterprises, and supervision of management departments. In Sect. 3, we use AHP and entropy weight method for combined weighting to determine the comprehensive weight of evaluation indicators, and then based on extension cloud model to comprehensively evaluate the quality of public transport services. In Sect. 4, the established comprehensive evaluation model is applied to a city for example analysis to verify the applicability and application value of the model. Finally, Sect. 5 concludes the paper.

2. Evaluation index system of public transit comprehensive service quality considering service supply and demand

To achieve high-quality public transit travel and improve its attractiveness to passengers, it is first necessary to establish a corresponding evaluation index system for the comprehensive service quality of public transit, and then further evaluate its advantages and disadvantages on this basis and determine its corresponding problems. From the specific meaning of "quality", as an external evaluation, "quality" is to feel the services provided by public transport enterprises from the perspective of passenger demand and management department; "quality" is the fundamental and characteristic of things, and refers to the service quality provided by public transport enterprises. According to the selection principle of evaluation indicators, this study constructs an evaluation index system related to the comprehensive experience of passengers, service supply quality of public transport enterprises, and supervision of management departments from the

two aspects of public transit travel service demand and supply, as shown in Figure 1.

2.1. Passenger comprehensive experience indicators

The purpose of passengers traveling by public transit is generally commuting, shopping, tourism, and so on. The demand for public transit travel is mainly reflected in speed, convenience, economy, comfort, safety, punctuality, etc.

(1) Rapidity: This refers to the rapidity of public transit and the time consumed by passengers when traveling by public transit. Its evaluation indexes are the average operating speed of buses in peak hours and average travel time consumption of passengers.

(2) Convenience: This refers to the convenience of passengers choosing public transit, and is also the basic requirement for service quality provided by public transport enterprises. Its evaluation indicators are the average transfer coefficient of passengers, non-cash utilization rate of public transit, and sharing rate of public transit motorized trips.

(3) Economy: Passengers' perception of the fares set by public transport enterprises, and their evaluation indicators are passenger rates and bus card preferential policies.

(4) Comfort: This refers to the degree of comfort experienced by passengers when traveling by public transit, and its evaluation indicators are the public transit peak load rate, temperature and humidity in the bus, and seat comfort.

(5) Safety: This refers to the safety degree of passengers in the process of taking public transit; that is, the perception of safety obtained by passengers by using public transit vehicles. The evaluation indicators were the public transportation liability accident rate and safe operation interval mileage (Stanevičiūtė & Grigonis, 2018).

(6) Punctuality: This refers to the punctuality of vehicle arrival, and its evaluation indicators are the punctuality rate of public transit and deviation in the vehicle arrival time (Öztürk, 2021).

2.2. Service supply quality indicators of public transport enterprises

As a public welfare service enterprise, the main purpose of public transport enterprises is to realize the displacement of passengers and better meet their

travel demand. The service quality provided by public transport enterprises is mainly reflected in routes, stations, vehicles, transportation services, etc.

(1) Line capacity supply: This reflects the transportation capacity of urban public transit, and its evaluation indicators include the coverage rate of the bus operation line network, bus line repetition coefficient, bus lane setting rate, and bus priority intersection ratio.

(2) Station capacity supply: This index measures the rationality of the number of public transportation stations and depots. Its evaluation indicators are the coverage rate of public transport stations, bus entry rate, vehicle pile ratio, real-time prediction rate of

bus arrival information, and the setting rate of bus bay stops.

(3) Vehicle capacity supply: This is an indicator that reflects whether the number of vehicles provided by public transport enterprises can meet passenger travel demand to the greatest extent. Its evaluation indicators are the number of public transit vehicles per 10,000 people, ratio of green buses, and average age of public transit vehicles.

(4) Transportation service capacity supply: This reflects the size of public transit capacity, and its evaluation indicator is the average departure frequency of public transit in peak hours.
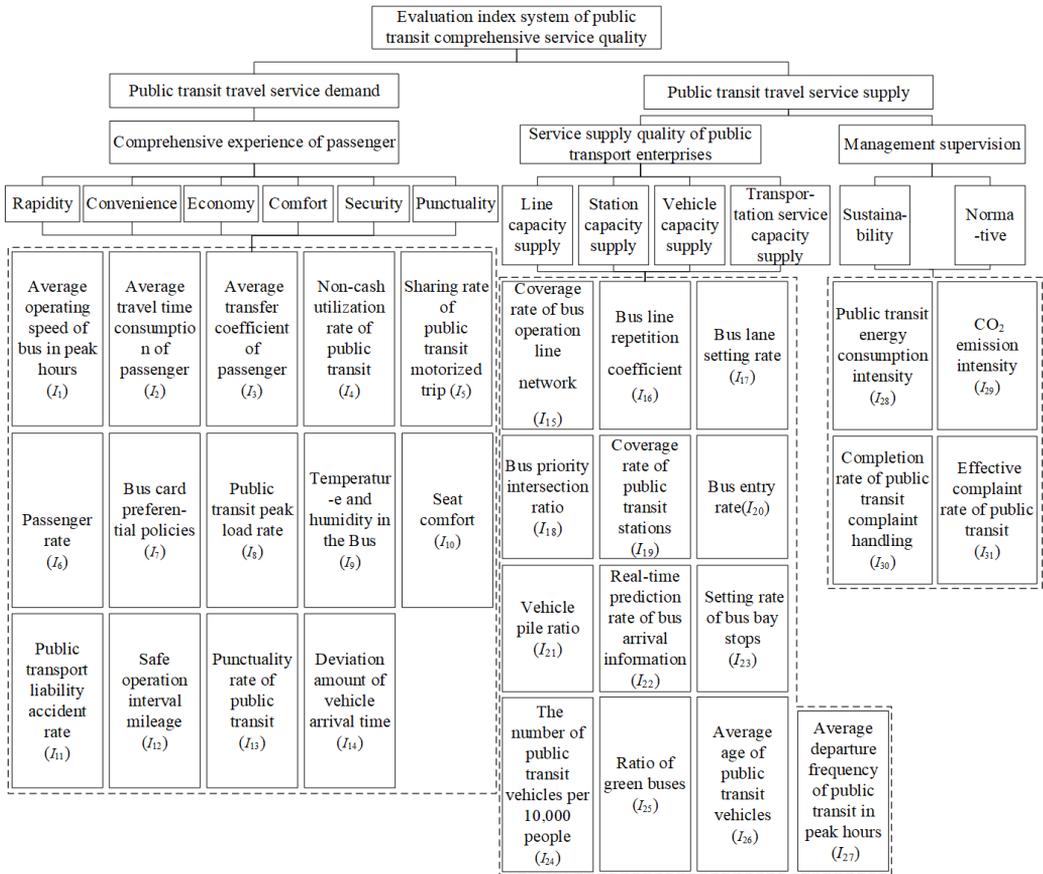

Fig. 1. Index system for evaluating the comprehensive service quality of public transit considering service supply and demand

2.3. Supervision indicators of management department

Strengthening the supervision of public utilities by management departments and realizing the rational allocation of resources can ensure the sustainability and standardization of the operation of public transport enterprises.

(1) Sustainability: The sustainable development of urban public transit focuses on the protection of the urban ecological environment and the optimal utilization of resources while promoting the construction and development of transport system. The evaluation indicators are public transport energy consumption intensity and CO2 emission intensity.

(2) Normative: This refers to the degree of attention that bus companies attach to the problems reflected by passengers and the overall feelings of passengers brought by the services provided by public transport enterprises in terms of service attitude, route setting, sanitary environment, infrastructure equipment, etc. The evaluation indicators are the completion rate of public transit complaint handling and the effective complaint rate of public transit.

3. Evaluation model of public transport comprehensive service quality

After determining the evaluation index system for public transport comprehensive service quality, the weights of the indicators must be reasonably allocated to reflect the accuracy of the evaluation results more accurately. Considering the shortcomings of the single weighting method, this study adopts the AHP in the subjective weighting method and the entropy weighting method in the objective weighting method to determine the subjective and objective weights of the evaluation indicators, respectively. In addition, it uses the linear weighting method to optimize the combination of the AHP and entropy weight method to obtain the comprehensive weight of the evaluation index.

3.1. Analytic hierarchy process
3.1.1. Construction of judgment matrix
The construction of the judgment matrix is the focus of the AHP. Usually, the 9-scale method is used to compare each element of the same layer that belongs to each element of the previous layer to obtain the judgment matrix B_{ij}, where $b_{ij}=1/b_{ji}$.

$$B_{ij} = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1q} \\ b_{21} & b_{22} & \cdots & b_{2q} \\ \vdots & \vdots & \ddots & \vdots \\ b_{q1} & b_{q2} & \cdots & b_{qq} \end{bmatrix} \quad (1)$$

where b_{ij} represents the importance of the *ith* element and *jth* element relative to a factor in the previous layer; q is the order of the judgment matrix, that is, the number of indexes contained in each judgment matrix.

3.1.2. Calculation of index weights
According to the obtained judgment matrix, calculate the sum y_i' of indexes in each row of the judgment matrix, and then normalize y_i' according to Equations (2) - (3) to obtain the weight w_i' of each evaluation index.

$$y_i' = \sum_{j=1}^{q} b_{ij}, \quad i = 1, 2, \dots, q \quad (2)$$

$$w_i' = \frac{y_i'}{\sum_{i=1}^{q} y_i'} \quad (3)$$

where w_i' represents the subjective weight of the *ith* evaluation index.

3.1.3. Consistency test
When comparing multiple elements, it is difficult to ensure complete consistency only based on people's subjective judgments. It is necessary to test whether the index judgment matrix is reliable through consistency judgment. The consistency indexes of the test are shown in Equations (4) - (5):

$$CI = \frac{\lambda_{max}}{q - 1} \quad (4)$$

$$CR = \frac{CI}{RI} \quad (5)$$

where *CI* is the consistency index of judgment matrix; λ_{max} is the maximum eigenvalue of the judgment matrix; *RI* is the average random consistency index corresponding to the *q*-order matrix, and the corresponding value can be obtained from Table 1 (Podolski et al., 2011).

Table 1. Average random consistency index

Order q	1	2	3	4	5	6	7	8	9	10	11
RI	0.00	0.00	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49	1.52

The random consistency ratio CR is calculated according to Equation (5), and when $CR \leq 0.1$, the judgment matrix is considered to pass the consistency test; when $CR > 0.1$, the consistency of the judgment matrix is considered to fail the test, and the judgment matrix should be appropriately revised until the judgment matrix has good consistency.

3.2. Entropy weight method

The information entropy is often used as a quantitative index of the information content of a system. The greater the information entropy, the greater the uncertainty of the information, which can be further used as the objective of system equation optimization or the judgment basis for parameter selection. (Harte & Newman, 2014). The calculation process of the entropy weight method includes the following three steps:

(1) Calculate the entropy value e_i of the index;
(2) Calculate the coefficient of variation h_i of the index;
(3) Calculate the entropy weight $w_i^{''}$ of the index. Among them, the entropy value e_i, coefficient of variation h_i, and entropy weight $w_i^{''}$ of ith index are calculated by Equations (6)-(8):

$$e_i = -\frac{1}{\ln v} \sum_{j=1}^{v} f_{ji} \ln f_{ji}, \quad f_{ji} = \frac{p_{ji}}{\sum_{j=1}^{v} p_{ji}} \quad (6)$$

$$h_i = 1 - e_i \quad (7)$$

$$w_i^{''} = \frac{h_i}{\sum_{i=1}^{n} h_i} \quad (8)$$

where P_{ji} represents the rating value of the *jth* expert on the *ith* index; v represents the number of experts; n represents the number of evaluation indexes; w_i" represents the objective weight of the *ith* evaluation index.

3.3. Determination of Comprehensive Weight

Let the weight obtained by AHP be $w_i^{'}$ (i=1, 2,…, n) and the weight obtained by entropy weight method be $w_i^{''}$ (i=1, 2,…, n). The comprehensive weight w_i

was obtained using the linear weighting method, and the calculation method is shown in Equation (9):

$$w_i = aw_i^{'} + bw_i^{''} \quad (9)$$

where w_i represents the comprehensive weight of the *ith* evaluation index; a represents the weighting coefficient of the subjective weight, and b represents the weighting coefficient of the objective weight.

To make the weight distribution result more reasonable, this study used the difference coefficient method to determine the values of a and b (Yao et al., 2018). The calculation Equation is shown in Equation (10):

$$\begin{cases} a = \frac{n}{n-1} \left(\frac{2}{n} \sum_{i=1}^{n} iP_i - \frac{n+1}{n} \right) \\ b = 1 - a \end{cases} \quad (10)$$

where n represents the number of evaluation indicators; P_i represents the corresponding component of the *ith* indicator after the subjective weight vector is sorted from small to large.

3.4. Evaluation model of public transport comprehensive service quality based on extension cloud

3.4.1. Extension cloud theory

Extenics has a wide range of applications, and it can be used to transform incompatible evaluation indexes into fusion problems. In extenics, the matter-element model $R = (N, C, V)$ is used as the basic element to describe things. where N, C, and V represent the name, characteristics, and characteristic value of the thing, respectively (Cigoli & Metere, 2016). In the traditional matter-element extension model, the value of V is usually regarded as a definite value representing the measured value or limit value of the index, ignoring the fuzziness and randomness of objective things. Therefore, using the cloud model has the advantage of dealing with the double uncertainty of things. The normal cloud model can be represented by three eigenvalues: expectation E_x, entropy E_n, and super-entropy H_e (Yang et al., 2018). Expectation E_x represents the

cloud distribution center value corresponding to the cloud drop at a certain evaluation level, which reflects the classification level of the evaluation index of public transit comprehensive service quality; entropy E_n represents the value range of a certain evaluation level, reflecting the randomness of data collection in the evaluation process; super-entropy H_e represents the randomness of the membership degree of a certain evaluation level, which reflects the correlation between the randomness and fuzziness of the evaluation index level. The extension cloud model uses the normal cloud model (E_x, E_n, H_e) to replace eigenvalue V in the matter-element extension theory to realize a mathematical description of the randomness and fuzziness in the evaluation process. The extension cloud model is expressed as follows:

$$R = \begin{bmatrix} M & C_1 & (E_{x1}, E_{n1}, H_{e1}) \\ & C_2 & (E_{x2}, E_{n2}, H_{e2}) \\ & \vdots & \vdots \\ & C_n & (E_{xn}, E_{nn}, H_{en}) \end{bmatrix} \tag{11}$$

where M represents the city to be evaluated; C_i represents the ith evaluation index of public transit comprehensive service quality ($i = 1, 2, 3, ..., n$); (E_{xi}, E_{ni}, H_{ei}) represents the cloud description of each level of public transit comprehensive service quality evaluation index C_i.

3.4.2. Calculation of characteristic parameters

The critical values of each evaluation level corresponding to the evaluation index i of public transit comprehensive service quality are H_{max} and H_{min}, respectively. The calculation formula of parameters E_x, E_n, and H_e is shown in Equation (12):

$$\begin{cases} E_x = (H_{max} + H_{min}) / 2 \\ E_n = (H_{max} - H_{min}) / 2.355 \\ H_e = \lambda \cdot E_n \end{cases} \tag{12}$$

where λ represents a constant determined according to the degree of fuzziness, and its value is generally 0.1 (Wu et al., 2020).

3.4.3. Determination of cloud affiliation of extension cloud model

Consider each index value x as a cloud drop, generate a normally distributed random number with expected value E_n and standard deviation H_e, and the

number of given cloud drops is N. Finally, calculate the cloud affiliation μ between each index value x and the normal cloud model. The calculation formula is shown in Equation (13):

$$\mu = exp\left\{ \frac{-(x - E_x)^2}{2(E_n')^2} \right\} \tag{13}$$

where μ represents the affiliation between index value x and the extension cloud model, and E_n' represents the random number that obeys normal distribution.

According to Equation (13), the cloud affiliation between each evaluation index value and the normal cloud model can be calculated, and a comprehensive judgment matrix U can be obtained.

$$U = \begin{bmatrix} \mu_{11} & \mu_{12} & \cdots & \mu_{1m} \\ \mu_{21} & \mu_{22} & \cdots & \mu_{2m} \\ \vdots & \vdots & & \vdots \\ \mu_{n1} & \mu_{n2} & \cdots & \mu_{nm} \end{bmatrix} \tag{14}$$

where μ_{ij} represents the cloud affiliation between the public transit comprehensive service quality evaluation index C_i and the jth normal cloud model. j represents the evaluation level of the public transit comprehensive service quality ($j = 1, 2, ..., m$).

3.4.4. Determination of the evaluation level of public transport comprehensive service quality

According to the comprehensive weight value obtained above and combined with the comprehensive judgment matrix, the comprehensive certainty Q and comprehensive evaluation score R of the public transport comprehensive service quality evaluation can be calculated as follows:

$$Q = [w_1\ w_2 \ldots w_n] \cdot \begin{bmatrix} \mu_{11} & \mu_{12} & \cdots & \mu_{1m} \\ \mu_{21} & \mu_{22} & \cdots & \mu_{2m} \\ \vdots & \vdots & & \vdots \\ \mu_{n1} & \mu_{n2} & \cdots & \mu_{nm} \end{bmatrix} \tag{15}$$

$$R = \frac{\sum_{j=1}^{m} b_j f_j}{\sum_{j=1}^{m} b_j} \tag{16}$$

where b_j represents the value of the jth component corresponding to vector Q, f_j represents the score value of evaluation level j.

Because there is randomness in solving the affiliation degree, it needs to be solved multiple times to

reduce the influence of random factors. The expectation value E_{xr}, entropy E_{nr}, and reliability factor θ of the comprehensive judgment score are calculated, as shown in Equation (17):

$$\begin{cases} E_{xr} = \sum_{i=1}^{l} R_i(x) / l \\ E_{nr} = \sqrt{\dfrac{1}{l-1} \sum_{i=1}^{l} [R_i(x) - E_{xr}]^2} \\ \theta = \dfrac{E_{xr}}{E_{nr}} \end{cases} \quad (17)$$

where l represents the number of operations, which is considered as 1500 in this study; R_i represents the comprehensive judgment score obtained by the *ith* calculation; θ represents the dispersion degree of the evaluation results, and its value is inversely proportional to the reliability (Zhu et al., 2021).

3.5. Process for evaluating the comprehensive service quality

This study uses the linear weighting method to combine AHP and entropy weight method to comprehensively determine the weight of each evaluation index, and realizes the comprehensive evaluation of public transport service quality based on extension cloud model. The evaluation process is shown in Figure 2.

4. Case analysis
4.1. Data sources

Based on the current data of public transit comprehensive service quality in a certain city, this study makes a comprehensive evaluation. The relevant data for each evaluation index are obtained through the "Statistical Report of Passenger Transportation in Cities (Counties)", "China Urban Construction Statistical Yearbook" and third-party survey agencies using questionnaires.

4.2. Data sources

In this study, the 31 evaluation indexes of public transit comprehensive service quality was divided into four evaluation levels: excellent, good, average, and poor. That is, the value of n in the above is 31, and the value of m is 4. The score values corresponding to evaluation levels 1–4 are 1, 2, 3, and 4, respectively. Based on the index data of 44 typical cities in

China, according to the quartiles of boxplots in statistics, SPSS software was used to determine the value ranges of four different levels of each evaluation index, in which the upper quartile, median, and lower quartile represent the critical values of different levels. The division results are presented in Figure 3 and Table 2.

4.3. Evaluation index weight calculation

The subjective and objective weights of each evaluation index were calculated using the AHP and entropy weight method, respectively. The obtained subjective weights were arranged in order from small to large, and the difference coefficient method was used to calculate the weighting coefficient of the subjective and objective weights. The calculation results are as follows: a =0.516 and b=0.484. Finally, the comprehensive weights of each evaluation index were obtained using Equation (9), as shown in Table 3.

4.4. Result analysis

According to the level of public transit comprehensive service quality evaluation indicators, MATLAB programming software was used to calculate the digital eigenvalues of the normal cloud model of each evaluation index, and the cloud drop diagram of the evaluation index was generated based on the extension cloud model. Because of the limited space, only the cloud drop diagrams of the average travel time consumption of passengers and the non-cash utilization rate of public transit are represented here, and the results are shown in Figure 4 and 5. After obtaining the cloud drop diagrams of the urban public transport comprehensive service quality evaluation index, the cloud affiliation of each evaluation indicator was obtained by substituting the relevant data into Equations (13)–(14) for calculation. According to the obtained membership matrix and index comprehensive weight, the comprehensive certainty of the city's public transport comprehensive service quality is obtained by substituting Equation (15). According to the principle of maximum certainty, the level with the greatest certainty is the evaluation level of the city's public transit comprehensive service quality. The corresponding reliability factor θ is calculated using Equations (16)-(17), and the results are shown in Table 4.

As can be observed in Table 4, the maximum value of the comprehensive certainty is 0.548, which indi-

cates that the evaluation level of public transit comprehensive service quality in the city is good, and the credibility factor $\theta = 0.006 < 0.01$ in the model indicates that the evaluation result is credible, and the model has good applicability to the problem of comprehensive service quality evaluation of public transit.
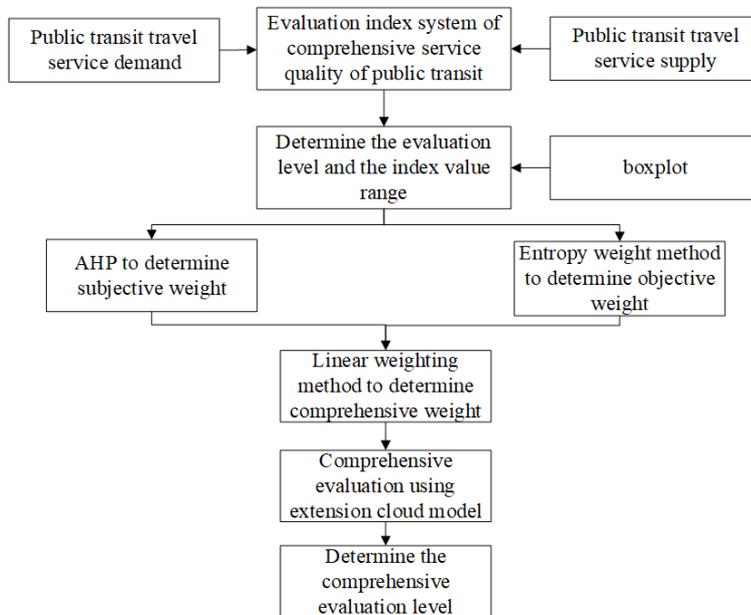

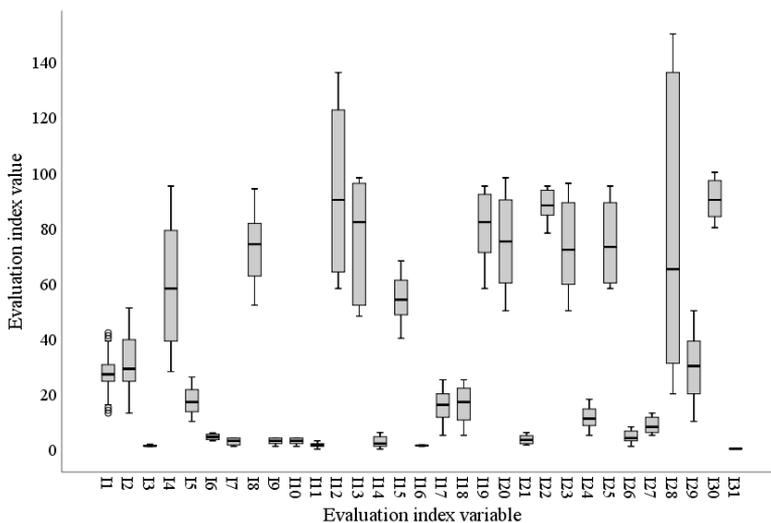Fig. 2. Process for evaluating the comprehensive service quality of public transit

Fig. 3. Boxplot of each evaluation index

Table 2. Grading standard of each evaluation index

Evaluation Indicators	Evaluation level			
	Excellent	Good	Average	Poor
Average operating speed of buses in peak hours (km/h)	≥31	[28, 31)	[25, 28)	<25
Average travel time consumption of passengers (min)	<25	[25, 30)	[30, 40)	≥40
Average transfer coefficient of passengers	<1.16	[1.16, 1.32)	[1.32, 1.5)	≥1.5
Non-cash utilization rate of public transit (%)	≥80	[60, 80)	[40, 60)	<40
Sharing rate of public transit motorized trip (%)	≥22	[18, 22)	[14, 18)	<14
Passenger rates (%)	<3.5	[3.5, 4.5)	[4.5, 5.5)	≥5.5
Bus card preferential policies	≥4	[3, 4)	[2, 3)	<2
Public transit peak load rate (%)	<63	[63, 75)	[75, 82)	≥82
Temperature and humidity in the bus	≥4	[3, 4)	[2, 3)	<2
Seat comfort	≥4	[3, 4)	[2, 3)	<2
Public transit liability accident rate (times/million km)	<1	[1, 1.5)	[1.5, 2)	≥2
Safe operation interval mileage (10,000 km/time)	≥125	[100, 125)	[65, 100)	<65
Punctuality rate of public transport (%)	≥96	[84, 96)	[52, 84)	<52
Deviation amount of vehicle arrival time (min)	<1	[1, 3)	[3, 5)	≥5
Coverage rate of bus operation line network (%)	≥62	[55, 62)	[49, 55)	<49
Bus line repetition coefficient	<1.2	[1.2, 1.3)	[1.3, 1.4)	≥1.4
Bus lane setting rate (%)	≥20	[16, 20)	[12, 16)	<12
Bus priority intersection ratio (%)	≥22	[17, 22)	[11, 17)	<11
Coverage rate of public transit stations (%)	≥92	[83, 92)	[71, 83)	<71
Bus entry rate (%)	≥90	[75, 90)	[60, 75)	<60
Vehicle pile ratio	<2	[2, 3.5)	[3.5, 5)	≥5
Real-time prediction rate of bus arrival information (%)	≥94	[89, 94)	[85, 89)	<85
Setting rate of bus bay stops (%)	≥90	[75, 90)	[60, 75)	<60
The number of public transit vehicles per 10,000 people (standard platform per 10,000 people)	≥15	[12, 15)	[9, 12)	<9
Ratio of green buses (%)	≥90	[75, 90)	[60, 75)	<60
Average age of public transit vehicles (year)	<3	[3, 5)	[5, 7)	≥7
Average departure frequency of public transit in peak hours (vehicle / h)	≥12	[8, 12)	[6, 8)	<6
Public transit energy consumption intensity (g of standard coal/person-km)	<32	[32, 86)	[86, 137)	≥137
CO_2 emission intensity (g/person-kilometer)	<20	[20, 30)	[30, 40)	≥40
Completion rate of public transit complaint handling (%)	≥97	[92, 97)	[85, 92)	<85
Effective complaint rate of public transit (times / million person times)	<0.1	[0.1, 0.15)	[0.15, 0.2)	≥0.2

Table 3. Weight of each evaluation index

| Evaluation indexes	I_1	I_2	I_3	I_4	I_5	I_6	I_7	I_8
Subjective weight	0.022	0.048	0.043	0.003	0.048	0.056	0.052	0.006
Objective weight	0.009	0.047	0.002	0.037	0.049	0.006	0.033	0.026
Comprehensive weight	0.016	0.048	0.023	0.019	0.048	0.032	0.043	0.016
Evaluation indexes	I_9	I_{10}	I_{11}	I_{12}	I_{13}	I_{14}	I_{15}	I_{16}
Subjective weight	0.001	0.019	0.019	0.038	0.044	0.018	0.046	0.040
Objective weight	0.040	0.037	0.052	0.042	0.027	0.042	0.006	0.053
Comprehensive weight	0.020	0.028	0.035	0.040	0.036	0.030	0.027	0.046
Evaluation indexes	I_{17}	I_{18}	I_{19}	I_{20}	I_{21}	I_{22}	I_{23}	I_{24}
Subjective weight	0.029	0.053	0.036	0.022	0.021	0.054	0.008	0.059
Objective weight	0.042	0.054	0.033	0.046	0.011	0.032	0.046	0.046
Comprehensive weight	0.035	0.053	0.035	0.034	0.016	0.043	0.026	0.053
Evaluation indexes	I_{25}	I_{26}	I_{27}	I_{28}	I_{29}	I_{30}	I_{31}	-
Subjective weight	0.009	0.050	0.055	0.022	0.055	0.015	0.009	-
Objective weight	0.019	0.051	0.021	0.007	0.015	0.046	0.023	-
Comprehensive weight	0.014	0.050	0.039	0.015	0.036	0.030	0.016	-
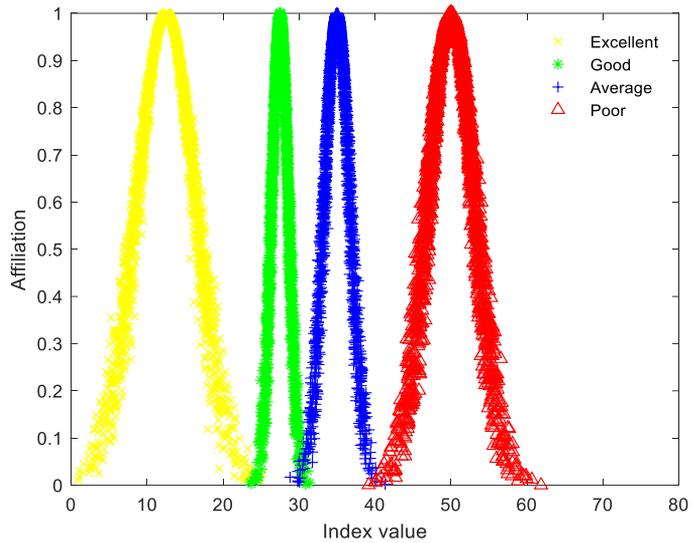
Fig. 4. Cloud drop diagram of average travel time consumption of passengers
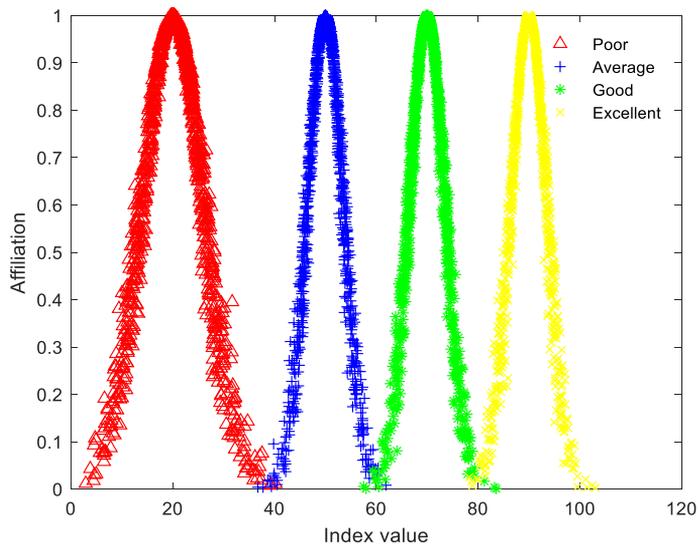

Fig. 5. Cloud drop diagram of non-cash utilization rate of public transit

Table 4. Evaluation results for the comprehensive service quality of public transit in a city

Evaluation level	Excellent	Good	Average	Poor	Evaluation results	Credibility
Comprehensive certainty	0.125	**0.548**	0.308	0.019	Good	0.006

5. Conlusion

In this study, we introduced an evaluation index system related to the comprehensive experience of passengers, service supply quality of public transport enterprises, and supervision of management departments from the two aspects of public transit travel service demand and supply to evaluate the comprehensive service quality of public transit. A combination of subjective and objective weighting methods is used to comprehensively determine the index weight. Based on the matter-element extension theory and the normal cloud model, an evaluation method for public transport comprehensive service quality based on the extension cloud model is established. The practicality of the model was verified through empirical analysis, and the credibility factor of the model was less than 0.01, indicating that the evaluation results were credible. Public transport enterprises can make targeted improvement measures based on the outstanding problems existing in the evaluation results to enhance the attractiveness of public transit for passenger travel. Because the value of the parameter H_e in the extension cloud model established in this study has a certain subjectivity and limitations, research on the randomness of the comprehensive service quality evaluation index of public transportation can be strengthened in subsequent research to reduce the subjectivity of the value of the parameter H_e and make evaluation result more accurate.

Acknowledgement

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