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Passenger Satisfaction Analysis of an Urban Subway Based on Travel Behaviour Characteristics

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ABSTRACT
The study explores the relationship between subway passenger satisfaction and passenger travel behaviour characteristics from the perspective of subway passengers. This study takes Qingdao as an example and designs a questionnaire that includes the basic personal information and travel behaviour characteristics of passengers and evaluates their subway satisfaction. A total of 6340 valid questionnaires were obtained through the combination of online surveys and on-site random surveys. By using the fuzzy synthetic evaluation, the overall score of passenger satisfaction with the Qingdao subway is determined. According to the relationship between passenger satisfaction and travel behaviour characteristics, the chi-square test is used to select the correlation variables group. The results show that there is no significant correlation among the satisfaction of subway passengers, the main means of transportation and the availability of private cars; the frequency of taking the subway is related to the satisfaction of subway passengers; and the purpose of travelling and the reasons for choosing the subway are significantly related to the satisfaction of subway passengers. Finally, based on the analysis of the differences in satisfaction under different conditions, some suggestions were proposed to improve the satisfaction of subway passengers.

KEYWORDS
fuzzy synthetic evaluation; chi-square test; passenger satisfaction; travel behaviour characteristics; subway.

1. INTRODUCTION

As an important component of urban public transportation, the subway plays an irreplaceable role in improving the travel efficiency of urban residents and alleviating traffic congestion. With the continuous improvement and expansion of the subway network, the number of subway passengers is also increasing, which makes the study of subway passenger satisfaction and its influencing factors particularly important.

Since the construction of the first subway in the world in London in 1863, urban rail transit has gone through more than 100 years of history. Scholars from various countries have conducted extensive research on the subway industry, with early studies mainly focusing on safety and management. In recent years, theories related to passenger satisfaction have only begun to be applied from the highway, bus, taxi, railway industry [1–4] to the urban subway industry. Friman et al. [5] conducted an e-mail survey of residents in metropolitan areas of Sweden, using the maximum likelihood method provided in LISREL VIII to propose and estimate a model to study the factors influencing the service satisfaction of public transport users. Stradling et al. [6] used the six-step method of the consumer satisfaction system in economics to conduct three studies on travel modes,

demonstrating the role of this method in measuring, understanding and influencing the satisfaction with traffic modes. Habib et al. [7] used the survey data of public transportation customer satisfaction to model the reasons for the selection of public transportation It was found that the satisfaction of bus passengers is different according to age, income and travel purpose. Nwachukwu [8] randomly selected 300 bus passengers for a questionnaire survey. That study used descriptive statistics, correlation analysis, principal component analysis, regression analysis and other methods to analyse the obtained data and to determine the overall satisfaction with the bus and the factors that influence satisfaction. Singh [9] assessed passenger satisfaction with public bus transport services in the city of Lucknow, India and identified the priority of service quality improvement to increase passenger satisfaction. At present, research on subway passenger satisfaction mainly focuses on evaluation methods and indicator selection. Kesten and Öğüt [10] proposed a practical method for monitoring the performance of public transportation systems, which summarises 22 indicators for 6 different measurement standards. Mouwen [11] demonstrated the impact of customer characteristics on public transport satisfaction. Shen [12] et al. validated the causal relationship path coefficient between passenger satisfaction and its influencing factors using a structural equation model based on partial least squares. Nezir [13] provided an overall SQ evaluation outline to measure the performance of Istanbul's multi cycle RT line by proposing a combination method of statistical analysis, trapezoidal fuzzy numbers and TOPSIS. Liu and Huang [14] analysed the characteristics and the advantages and disadvantages of the customer satisfaction index models in Sweden, America, Europe and China, and determined that the ACSI model is more suitable for subway satisfaction research. Azmi [15] et al. surveyed the passengers of electric trains at Kuala Lumpur Central Station, using the partial least squares method to analyse the questionnaire data. The results show that the service quality dimension is the factor that affects passenger satisfaction. Pan et al. [16] investigated subway passengers through online surveys and on-site random surveys. A chi-square test was used to analyse the correlation between the basic information of subway passengers and their psychological and behavioural responses. Xu et al. [17] adopted a combination of Bayesian network, structural equation modelling and importance-performance analyses to evaluate and improve the service quality of crowded subways from the point of service components. Ibrahim et al. [18] tested the influencing factors of light rail satisfaction using structural equation modelling, and the results showed that perceived quality and perceived value have a significant and direct impact on passenger satisfaction. Li et al. [19] used a comprehensive evaluation method for subway station satisfaction based on passenger perception to evaluate satisfaction from the perspective of passengers, obtaining the desired level of passenger satisfaction, reflecting the differences and consensus of the passengers' perception. Li et al. [20] used DHHLTS to depict the uncertain satisfaction evaluation information given by passengers, improved the k-means++ algorithm, clustered the large group of passengers for satisfaction evaluation information aggregation and extended AQM to acquire the passenger satisfaction ranking of rail transit lines. Verma [21] et al. studied and understood the factors influencing service quality satisfaction and commuter willingness to continue using subway services from the perspective of passengers in Bangalore. Based on the perception of 700 subway passengers, factor analysis and regression modelling were conducted. The developed model showed that subway operation and safety (MOS) and passenger convenience (PE) were the most influential, while anxiety (A) had a negative impact on the overall service quality satisfaction and loyalty intention (SQLI) of the Bangalore subway. Meanwhile, a small number of scholars have conducted research on satisfaction based on the different characteristics of passengers. Based on the different socio-economic and travel characteristics of passengers, Obsie [22] et al. used factor analysis and ordered logit models to conclude that safety assurance, ticketing system, travel information, congestion level, frequency, cleanliness and comfort are the most important factors affecting user satisfaction. Ibrahim [23] used Kuala Lumpur's light rail service as a case study to investigate the impact of passenger gender and age on the perception of LRT service quality and overall satisfaction. It was found that there were significant differences in the factors affecting passenger satisfaction in terms of gender and age. Guo [24] et al. explored a passenger satisfaction index system with a wider coverage and constructed a structural equation model. The study found that convenience, cleanliness, comfort and perceived value all have a positive and direct impact on passenger satisfaction. Papagiannakis and Yiannakou [25] conducted a survey and analysis using the Chennai subway as an example and found that male commuters used subway services more than female commuters.

At present, there is a lack of unified standards for the establishment of the evaluation index system for subway passenger satisfaction. Research is mostly limited to qualitative analysis or quantitative analysis of satisfaction using structural equation models, which limits the reliability of the statistical results. Structural equation modelling is a multivariate statistical technique that combines regression analysis, factor analysis and analysis of variance. It is widely used in quantitative research, but it mainly simulates linear relationships and

cannot accurately describe the potential effects between variables in nonlinear relationships, which may lead to inaccurate prediction and diagnosis. When constructing the evaluation index system for subway passenger satisfaction, this study takes into account the living conditions and needs of modern people, and adds dimensions such as train operation and window services to ensure the scientific and comprehensive evaluation. In terms of evaluation methods, a fuzzy comprehensive evaluation method combining qualitative and quantitative methods was adopted to evaluate complex variables with multiple factors and levels, in order to more accurately point out the improvement direction of the subway system and improve passenger satisfaction. With the development of the subway system, the relationship between changes in passenger travel demand, growth in the scale of the subway network and travel satisfaction is not yet clear. Therefore, considering the impact of passenger travel characteristics on subway services is an important direction of this study.

Taking Qingdao, China, as an example, this study explores the impact of passenger travel behaviour on subway satisfaction. First, passengers have positive or negative feelings about subway travel based on the purpose and frequency of subway travel; thus, these factors affect the satisfaction of subway passengers. Second, whether passengers own private cars or other main means of transportation also affects the emotional awareness and emotional feelings of passengers, thus promoting or inhibiting subway satisfaction. This study clarifies whether the current passenger travel behaviour has an impact on subway satisfaction, provides a new basis for the consideration of subway satisfaction, reflects the basic principle of people-oriented design in the process of urban transportation and urban development and takes personal vital interests as an important basis for policy-making to promote the improvement of subway satisfaction, thus contributing to the harmonious and stable development of society.

2. QUESTIONNAIRE DESIGN

Questionnaire design is the key to investigation and research and directly affects the value of the collected information and the validity of the data. The questionnaire is divided into four parts according to the research purpose, research content and design principles.

2.1 Questionnaire design

The satisfaction survey questionnaire is designed in two parts: passenger travel behaviour characteristics and satisfaction evaluation. The passenger travel behaviour characteristics include whether the respondents have private cars, the major means of transport for travel, the frequency of subway ride, the purpose of travel and the reasons for choosing subway travel. The satisfaction evaluation part includes three dimensions: train operation satisfaction, window service satisfaction and equipment and facilities satisfaction. It is expanded to form a three-level indicator consisting of 13 specific evaluation indicators, while forming the questions on the survey questionnaire.

The questionnaire is divided into four parts according to the research purpose, research content and design principles. The first part is the screening questionnaire, which contains three questions: (1) whether the respondent is a subway employee; (2) whether the respondent has ever taken the subway; and (3) the age of the respondent. The questionnaire did not include subway employees, persons who have not taken the subway and minors under the age of 18 years. The second part is about the characteristics of travel behaviour, which includes five topics: (1) the main means of transport used; (2) the main purpose of the respondent's choice to travel by subway (including this trip); (3) the reasons why the respondent chose to travel by subway; (4) whether the respondent has a private car; and (5) the frequency of the respondent's subway rides this year. The third part is the subway passenger satisfaction survey, which has 13 topics. The fourth part is the basic passenger information section, which contains five topics: (1) gender; (2) age; (3) education level; (4) occupation; and (5) monthly income.

In the design of the questionnaire, this study uses a Likert scale of five levels to quantify the passenger satisfaction indicators. Passengers score each indicator to express their satisfaction with the subway. The evaluation criteria for each factor are as follows: very satisfied (5), satisfied (4), generally satisfied (3), dissatisfied (2) and very dissatisfied (1).

This survey adopted the combination of on-site random surveys and online surveys. The passenger satisfaction survey plan was developed in advance. During the period from 1 October to 15 October 2023, 195 people/day were dispatched to complete the on-site random passenger satisfaction survey and 4975 questionnaires were obtained. From 12 October to 29 October 2023, the online passenger satisfaction survey was completed by using the online questionnaire of the APP network of Qingdao Metro and 1558

questionnaires were obtained. To ensure the quality of the questionnaire, the on-site random questionnaires and online questionnaires were screened individually, and the missing responses and other incomplete questionnaires were screened and eliminated. There were 4827 valid questionnaires from the offline surveys and 1550 valid questionnaires from the online surveys. The total number of valid questionnaires was 6340.

2.2 Reliability analysis

To avoid errors, it is necessary to test the reliability of the collected questionnaires before analysing the data. Reliability represents the consistency or stability of the scale, that is, the reliability of the questionnaire data in reflecting the actual situation. Cronbach's alpha coefficient is often used in reliability estimation. When the alpha coefficient is greater than or equal to 0.9, the intrinsic reliability of the questionnaire is extremely high; when the alpha coefficient is between 0.8 and 0.9, the intrinsic reliability of the questionnaire is acceptable; when the alpha coefficient is greater than or equal to 0.7 and less than 0.8, the questionnaire has some design problems, but it still has some reference value; and when the alpha coefficient is less than 0.7, there are many problems in the design of the questionnaire and revising the questions or increasing or decreasing the number of questions should be considered.

Cronbach's alpha coefficient is the most commonly used reliability coefficient. The formula for calculating this coefficient is as follows:

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum_{i=1}^{k} Var(i)}{Var}\right) \tag{1}$$

where α is the reliability coefficient, k is the total number of items assessed in the scale, $Var(i)$ is the intractable variance of the score of the i^{th} item and Var is the variance of the total number of items.

Using the SPSS software to analyse the reliability of the subway passenger satisfaction evaluation part, the reliability analysis alpha coefficient value is 0.982, which shows that the questionnaire has high internal reliability.

3. FUZZY COMPREHENSIVE EVALUATION ANALYSIS OF SUBWAY PASSENGER SATISFACTION

The fuzzy comprehensive evaluation method is a derivative of fuzzy mathematics, which is mainly applied to the comprehensive evaluation of complex problems. The evaluation of customer satisfaction involves many factors, which must be considered from many perspectives when constructing the index system of customer satisfaction. The evaluation has many levels and uncertainties.

The steps of fuzzy comprehensive evaluation are as follows. Step 1: Establish a fuzzy set. In the Assessment Index Set $U = \{U_1, U_2, ..., U_n\}$, U_i is the i$^{\text{th}}$ index in the criterion layer of the evaluation index system. In $U_i = \{U_{i1}, U_{i2}, ..., U_{ij}\}$, U_{ij} is the j^{th} index under the i^{th} index of the criterion layer. By establishing evaluation set $V = \{y_1, y_2, ..., y_m\}$, y_m is the m^{th} rating. By determining the weight allocation to U_i as a_i, the weight set of criterion level indicators is $A = \{a_1, a_2, ..., a_n\}$. The weight of U_{ij} to U_i is a_{ij}, where a_i represents the weight of factor i^{th} in U, and the sum of all a_i is 1. Step 2: According to the evaluation level, the membership vector $r_{ij} = \{r_{ij1}, r_{ij2}, ..., r_{ijh}\}$, where $r_{ijh} = V_{ijh} / n$, n is the total number of passengers surveyed and V_{ijh} is the number of passengers whose evaluation index U_{ij} is V_h, The evaluation membership matrix R is obtained. Step 3: Calculate the first-level fuzzy comprehensive evaluation and the second-level fuzzy comprehensive evaluation. Step 4: According to the fuzzy comprehensive evaluation formula $B = A \bullet R$ and the principle of maximum degree of membership, the final evaluation results are obtained.

3.1 Establishment of the comprehensive evaluation set

The advantage of a fuzzy comprehensive evaluation is that the result is in the form of a vector rather than a specific numerical point, which can more accurately reflect the ambiguity of things themselves. The comprehensive evaluation set is a fuzzy evaluation vector in the fuzzy comprehensive evaluation and can reflect the information of the degree of membership of each evaluation grade of the evaluated object in the

form of a numerical value. Since each passenger's experience and feelings about subway service are different, the evaluation attitude is different, and it is not easy to count and measure. In this model, the evaluation level is set as follows:

$$V = \{Very\ dissatisfied, Dissatisfied, Generally\ satisfied, Satisfied, Very\ satisfied\} = \{1\ 2\ 3\ 4\ 5\}$$

The evaluation of subway passenger satisfaction requires the construction of a satisfaction index system, which is divided into three levels in this paper. The first-level index is subway passenger satisfaction, and the second-level index has three levels, which are train operation, window service, equipment and facilities. The third-level index is the specific content of the second-level index. The three-level indicators are the specific questions in the subway passenger satisfaction questionnaire that obtain the information about satisfaction. See *Table 1* below for the index system of the questionnaire.

Table 1 – Satisfaction evaluation index system and weight values

First-level indicators	Secondary indicators	Secondary index weight	Three-level indicators	Three-level index weight
Satisfaction of subway passengers	Train operation	0.3868	1. Train departure intervals are acceptable	0.3757
			2. Easy boarding and acceptable in-car congestion	0.2143
			3. Punctual arrival of trains	0.1518
			4. Train runs smoothly and parking position is accurate	0.1181
			5. The first and last train hours are acceptable	0.1401
	Window services	0.3148	1. Unobstructed and orderly organisation and guidance of passenger flow in subway stations	0.1552
			2. Subway staff exhibits a friendly attitude, efficient service and decent appearance	0.1955
			3. Subway station and train environments clean and signals stable	0.1204
			4. Subway stations and trains have clear orientation, rich display contents and accurate information	0.3141
			5. Subway ticket-buying facilities are complete and efficient	0.2148
	Equipment and facilities	0.2984	1. Station and train service facilities are in good condition and easy to use (including current limiting auxiliary facilities, elevators, toilets, seats, carriage handrails/handles/rings, etc.)	0.476
			2. Facilities are convenient and available (such as wheelchairs and umbrellas)	0.2966
			3. Commercial equipment and facilities are easy to use (e.g. advertisements, vending machines/ATMs, shops, etc.)	0.2274

3.2 Determining the weight of indicators

This study uses the AHP method to determine the weight of each index of the subway passenger satisfaction evaluation. The determination of the weight by the AHP method includes three steps. Step 1: Compare the importance of each evaluation index factor to the evaluation target and assign the rating index factor, which is the element of the judgment matrix, constituting the judgment matrix. Step 2: Determine the weight of each element. Step 3: Check the consistency of the judgment matrix. Usually, when people compare many factors under subjective consciousness, they cannot guarantee the consistency of the judgment criteria, so there are estimation errors. Therefore, to test the consistency of the judgment matrix, it is necessary to calculate the random consistency ratio: $CR = CI / RI$. When $CR < 0.1$, the consistency of the judgment matrix is considered to be acceptable; otherwise, the elements of the judgment matrix should be adjusted until they pass the consistency test. Through the above steps, the weights of all the levels of the indicators of subway passenger satisfaction are calculated as shown in *Table 1*.

3.3 Fuzzy relational matrix

After sorting the original data obtained from the questionnaire, the degree of membership of the three-level indicators is calculated according to the steps of the abovementioned fuzzy comprehensive evaluation, as shown in *Table 2* below.

Table 2 – Degree of membership of three-level indicators

Three-level indicators	Very dissatisfied	Dissatisfied	Generally satisfied	Satisfied	Very satisfied
1. Train departure intervals are acceptable	0.0002	0.0002	0.0261	0.2538	0.7197
2. Easy boarding and acceptable in-car congestion	0.0003	0.0003	0.0089	0.2683	0.7222
3. Punctual arrival of trains	0	0	0.0002	0.1784	0.8214
4. Train run smoothly and parking position is accurate	0	0	0.001	0.2435	0.7555
5. The first and last train hours are acceptable.	0.0002	0.0003	0.0083	0.2527	0.7385
6. Unobstructed and orderly organisation and guidance of passenger flow in subway stations	0	0.0001	0.0019	0.2344	0.7636
7. Subway staff exhibit a friendly attitude, efficient service and decent appearance.	0	0.0002	0.0025	0.2323	0.765
8. Subway station and train environments clean and signals stable	0	0	0.0011	0.2319	0.767
9. Subway stations and trains have clear orientation, rich display contents and accurate information.	0	0	0.0008	0.2284	0.7708
10. Subway ticket-buying facilities are complete and efficient	0	0	0.0013	0.2289	0.7698
11. Station and train service facilities are in good condition and easy to use (including current limiting auxiliary facilities, elevators, toilets, seats, carriage handrails/handles/rings, etc.).	0	0	0.0016	0.2334	0.765
12. Facilities are convenient and available (such as wheelchairs and umbrellas).	0	0	0.0033	0.2349	0.7618
13. Commercial equipment and facilities are easy to use (e.g. advertisements, vending machines/ATMs, shops, etc.).	0.0002	0	0.0032	0.2377	0.7589

3.4 First-level fuzzy comprehensive evaluation

Based on the fuzzy evaluation set of three-level indexes, the membership matrix of B_1 train operation satisfaction, B_2 window service satisfaction and B_3 equipment and facilities satisfaction are obtained as R_1, R_2 and R_3, respectively. The fuzzy comprehensive evaluation formula $B = A \bullet R$ is used to obtain the single-factor fuzzy comprehensive evaluation of the two-level indexes that affect subway passenger satisfaction, taking B_1 train operation as an example:

$$\begin{aligned} B_1 &= A_1 \bullet R_1 \\ &= \begin{pmatrix} 0.3757 & 0.2143 & 0.1518 & 0.1181 & 0.1401 \end{pmatrix} \begin{bmatrix} 0.0002 & 0.0002 & 0.0261 & 0.2538 & 0.7197 \\ 0.0003 & 0.0003 & 0.0089 & 0.2683 & 0.7222 \\ 0 & 0 & 0.0002 & 0.1784 & 0.8214 \\ 0 & 0 & 0.001 & 0.2435 & 0.7555 \\ 0.0002 & 0.0003 & 0.0083 & 0.2527 & 0.7385 \end{bmatrix} \\ &= \begin{pmatrix} 0.0002 & 0.0002 & 0.013 & 0.2441 & 0.7425 \end{pmatrix} \end{aligned} \quad (2)$$

In this way, the fuzzy comprehensive evaluation vectors of B_2 and B_3 are calculated as follows:

$$B_2 = \begin{pmatrix} 0 & 0.0001 & 0.0014 & 0.2306 & 0.7679 \end{pmatrix} \quad (3)$$

$$B_3 = \begin{pmatrix} 0 & 0 & 0.0025 & 0.2348 & 0.7627 \end{pmatrix} \quad (4)$$

To summarise, the degree of membership of secondary indicators is obtained, as shown in *Table 3* below.

Table 3 – Degree of membership of secondary indicators

Secondary indicators	Very dissatisfied	Dissatisfied	Generally satisfied	Satisfied	Very satisfied
Overall satisfaction with train operation	0.0002	0.0002	0.013	0.2441	0.7425
Overall satisfaction with window services	0	0.0001	0.0014	0.2306	0.7679
Overall satisfaction of equipment and facilities	0	0	0.0025	0.2348	0.7627

3.5 Second-level fuzzy comprehensive evaluation

After transforming the secondary index fuzzy evaluation set into the secondary evaluation matrix, the comprehensive evaluation value is calculated.

$$B = A \bullet R = \begin{pmatrix} 0.3868 & 0.3148 & 0.2984 \end{pmatrix} \begin{bmatrix} 0.0002 & 0.0002 & 0.0130 & 0.2441 & 0.7425 \\ 0 & 0.0001 & 0.0014 & 0.2306 & 0.7679 \\ 0 & 0 & 0.0025 & 0.2348 & 0.7627 \end{bmatrix} = \begin{pmatrix} 0.0001 & 0.0001 & 0.0062 & 0.2371 & 0.7565 \end{pmatrix} \quad (5)$$

Therefore, the passenger satisfaction value of the Qingdao Metro can be calculated.

$$E = BV^T = \begin{pmatrix} 0.0001 & 0.0001 & 0.0062 & 0.2371 & 0.7565 \end{pmatrix} \begin{pmatrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{pmatrix} = 4.7498 \quad (6)$$

Through the above calculation, the fuzzy comprehensive evaluation set of the first-level index “Degree of subway passenger satisfaction” is obtained as follows:

$$B = \begin{pmatrix} 0.3868 & 0.3148 & 0.2984 \end{pmatrix} \quad (7)$$

B is the membership vector of the evaluation index set to the evaluation set, which is the final result of the fuzzy comprehensive evaluation. According to the principle of maximum degree of membership, the maximum degree of membership is 0.3868, and the corresponding evaluation grade is “generally satisfactory”. In addition, according to the formula, the overall satisfaction of Qingdao Metro passengers is calculated to be 4.75, indicating that the overall satisfaction level of most passengers is “satisfactory”.

In order to further prove the applicability of the above satisfaction method, this study compares the method with the structural equation model often used in passenger satisfaction evaluation research. The AMOS26.0 software was used to test and analyse the overall degree of satisfaction with train operation, the overall degree of satisfaction with window services and the overall degree of satisfaction with equipment and facilities. The comparison of the evaluation results obtained is shown in *Table 4* below.

Table 4 – Comparison of the evaluation results of the two models

Secondary indicators	Fuzzy integrated evaluation model	Structural equation model
Overall satisfaction with train operation	More satisfactory	More satisfactory
Overall satisfaction with window services	More satisfactory	More satisfactory
Overall satisfaction of equipment and facilities	Generally satisfactory	More satisfactory

According to *Table 4*, the evaluation results obtained by the fuzzy comprehensive evaluation method and the structural equation model are basically the same, which verifies the applicability and effectiveness of this

method in satisfaction evaluation. In addition, compared with structural equation modelling, the fuzzy comprehensive evaluation method has enormous potential in passenger satisfaction analysis. By constructing a fuzzy evaluation matrix and a fuzzy weight matrix, this method can visualise complex information, providing decision-makers with an intuitive way to understand the weights and evaluation results of various indicators, facilitating subsequent analysis of passenger satisfaction and proposing suggestions that can improve passenger intention and satisfaction.

4. THE RELATIONSHIP BETWEEN PASSENGER TRAVEL BEHAVIOUR AND SATISFACTION

From the perspective of subway passengers, this paper explores whether passenger travel behaviour has an impact on subway passenger satisfaction and elucidates the impact of different travel behaviours on subway passenger satisfaction. From the perspective of subway passenger satisfaction, comprehensively considering the difference in subway satisfaction under different travel behaviours to promote the improvement in subway satisfaction is conducive to the urban development of urban traffic.

4.1 Statistics of passenger travel behaviour characteristics

According to the travel behaviour characteristics of subway passengers, a questionnaire survey is conducted using five questions: whether the respondent has a private car, the main means of transportation, the frequency of taking the subway, the purpose of travel and the reasons for choosing the subway. See *Table 5* for the statistical analysis of the travel characteristics of the respondents.

Table 5 – Travel behaviour characteristics of respondents

Travel characteristics	Category	Frequency	Percentage
Whether the respondents have private cars	Yes	3626	57.2%
	No	2714	42.8%
Major means of transport for travel	Subway	5360	39.7%
	Bus	4384	32.5%
	Taxi/online ride-hailing	1445	10.7%
	Bicycles (including electric bicycles)	422	3.1%
	Private car	1886	14.0%
Frequency of subway ride	One time two or more months	544	8.5%
	1–3 times a month	1390	21.7%
	1–2 times a week	1613	25.2%
	Three or more times a week	2793	43.6%
Purpose of travel	Commuting to and from work	3257	31.0%
	Going to and from school	405	3.9%
	Going out to work	2988	28.4%
	Shopping and visiting friends	1988	18.9%
	Travel	1452	13.8%
	Other	421	4.0%
Reasons for choosing subway travel	No traffic jams, time is guaranteed	5048	30.7%
	Safety and stability	2951	17.9%
	Convenient	4053	24.6%
	Reasonable price	1629	9.9%
	Good driving environment (including public security)	1634	9.9%
	Good comprehensive service	1119	6.8%
	Other	15	0.1%

1) Whether the respondents have private cars. Of the 6340 respondents, 57.27% have private cars and 42.8% do not have private cars. With the development of society, an increasing numbers of people own private cars and the phenomenon of ground traffic congestion is becoming increasingly more serious. People who have private cars will also choose to travel by subway, so there is no obvious gap between the number of subway passengers who have private cars and those who do not.
2) The main means of transportation for the respondents. According to the survey data, 5360 people choose the subway as the main means of transportation, representing the largest number of people in the five modes of transportation with the response rate accounting for 39.7%, followed by public transport with the response rate accounting for 32.5%. The number of people who choose private cars, taxis and ride-hailing is not different, accounting for 14% and 10.7%, respectively, and the number of people who choose bicycles (including electric bicycles) is the lowest, accounting for 3.1%. These findings show that the majority of subway passengers mainly choose buses and subways. Since passengers may choose any combination of subway, bus, taxi/online ride-hailing, bicycles and private car as their main transport modes, the sum of percentages is not 1.
3) The frequency of subway rides. The results show that the most frequent passengers are those who take the subway more than three times a week, accounting for 44.1%; 25.4% take the subway more than once or twice a week; 21.9% take the subway more than once a month; and 8.6% take the subway one time two or more months.
4) The purpose of travel. The purpose of passengers' travel in this survey is divided into six categories: commuting to work, going to school, going out to work, shopping, visiting friends, tourism and others, accounting for 51.4%, 6.4%, 47.1%, 31.4%, 22.9%, and 6.6%, respectively. These findings demonstrate that the majority of subway passengers commute to work. The sum of the percentages is not 1 because passengers may travel for multiple purposes at a time.
5) The reason why the respondents choose subway travel. The most important reason is that there are no traffic jams and the time is guaranteed, accounting for 30.7%; the second reason is convenience and safety, accounting for 24.6% and 17.9%, respectively. The proportions of respondents choosing reasonable price, good riding environment and comprehensive service are equivalent, accounting for 9.9%, 9.9% and 6.8%, respectively. Since subway passengers mostly commute to and from work and go out to handle affairs, they have a high demand for punctuality; therefore, they choose not to be stuck in traffic, and the subway schedule is usually guaranteed. The reason why the proportion choosing reasonable price options is low is that a large proportion of subway passengers take public transport as the main means of transportation, and the price of public transport is lower than that of the subway. The percentages do not equal 100% because there is more than one reason why passengers choose the subway.

4.2 Cross-analysis of travel behaviour characteristics and subway passenger satisfaction

The survey variables were analysed for correlation, assuming that there was no correlation between the variables, and the significance level was set as 0.01 and 0.05. If the probability *p-value* is less than the significance level, the original hypothesis was rejected and there was a significant difference between the sample from the overall distribution and the expected distribution. If the probability *p-value* is greater than the significance level, the original hypothesis is accepted and there is no significant difference between the sample from the overall distribution and the expected distribution, including the following three situations: A. If $p<0.01$, reject the original hypothesis; there is significant difference between the two variables. B. If $0.01\leq p<0.05$, reject the original hypothesis and there is a difference between the two variables. C. If $p\geq 0.05$, accept the original hypothesis; there is no significant difference between the two variables.

In this questionnaire, "whether the respondents have private cars" and "frequency of taking the subway" in the passenger travel characteristic section are single-choice topics. In the SPSS software, the data about satisfaction with the trains, window service, and equipment and facilities are tested by the chi-square test, while the data about the "main means of transportation", "the purpose of travel" and the "reasons for choosing the subway" are the multiple-choice topics. The chi-square test is different from the chi-square test for single-choice questions. First, in the SPSS software, a common multichoice item contingency analysis table containing variables and frequencies is generated. According to the results of the contingency table, a new data file containing variables and weights is generated. The weights of variables are the frequencies. The weights of variables are weighted variables and each element is weighted. The weighted data are used for contingency

analysis and chi-square test [26]. The chi-square test results of passenger travel behaviour characteristics are shown in *Table 6* below.

Table 6 – Chi-square test of travel behaviour characteristics and satisfaction

Traffic behaviour characteristics of passengers between groups	***p-value***		
	A1 Satisfaction of train operation	**A2 Window service satisfaction**	**A3 Equipment and facilities satisfaction**
Whether the respondents have private cars	0.866	0.610	0.893
Frequency of subway ride	0.037	0.000	0.001
Purpose of travel	0.000	0.000	0.000
Major means of transport for travel	0.791	0.975	0.989
Reasons for choosing subway	0.002	0.000	0.000

Whether the respondents have private cars and satisfaction analysis

The impact of private cars on satisfaction is shown in *Figure 1*. There is no significant difference between the average satisfaction of passengers with and without private cars in terms of equipment and facilities, while in terms of train operation satisfaction and window service satisfaction, the satisfaction of passengers without private cars is lower than that of passengers with private cars. This result occurs mainly because for subway passengers with private cars, the punctuality and comfort, adaptability, price and time efficiency of taking a subway are better than those of driving private cars.

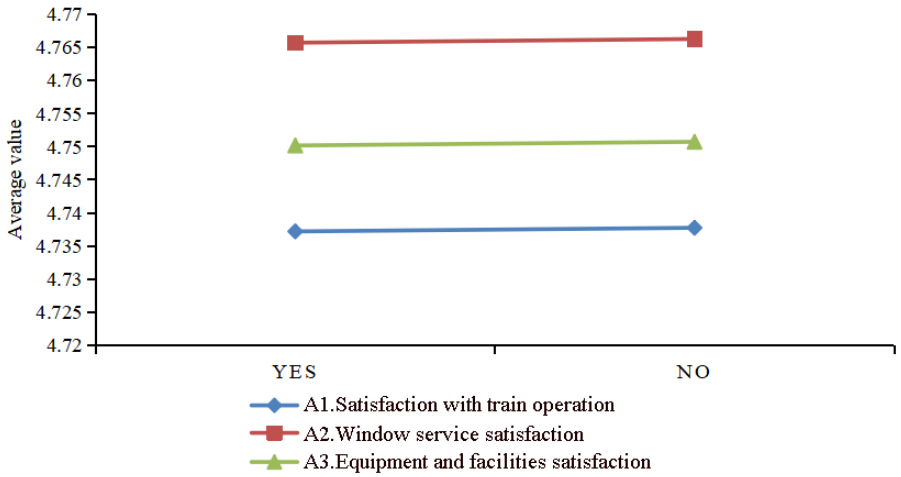

Figure 1 – Whether the respondent has a private car and satisfaction

Frequency and satisfaction of passengers on the subway

The analysis results of the impact of subway frequency on satisfaction are shown in *Figure 2*. The passengers who take the subway three times or more have the highest satisfaction with train operation, window service and equipment and facilities. With the decrease in subway frequency, the average satisfaction is also reduced. This result mainly occurs because the passengers who take subway less frequently are not familiar with the subway lines and the environment. To a large extent, familiarity affects the score of satisfaction. For the satisfaction of train operation, most of the passengers who take the train three times or more are commuters, and the commute time is in the early peak and late peak times. The departure interval during the early peak and the late peak is short, while most of the passengers who take the subway once or twice a week are shopping and visiting friends, with high requirement for train arrival time. However, the travel time of these less frequent passengers is mainly at times of relatively low passenger flow with a long departure interval, so their satisfaction with the train operation is low. The passengers who take the subway with a frequency of 1–3 times

a month are mainly tourists, and the time requirement is low, so even if the travel time is in the flat peak with a large departure interval, it has little impact on the train satisfaction score.

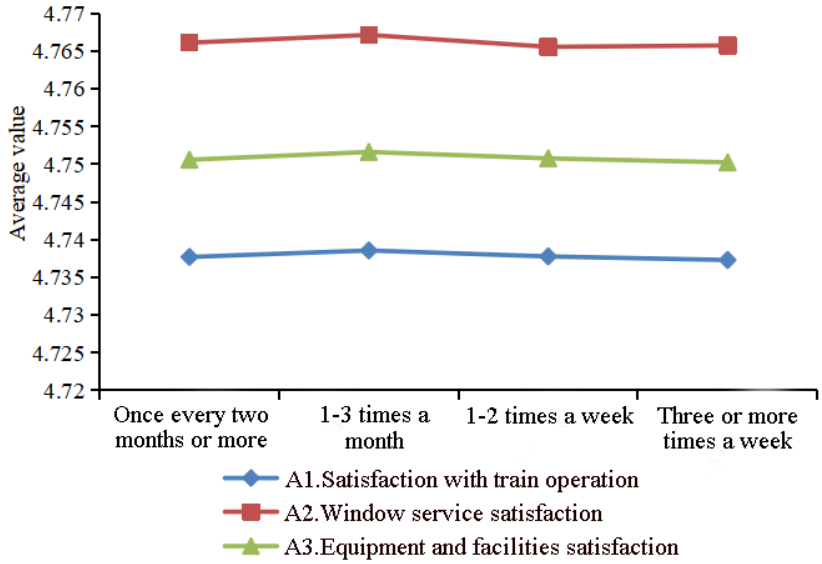

Figure 2 – Frequency and satisfaction with subway ride

Travel purpose and satisfaction

According to the relationship between the purpose and satisfaction of subway passengers, the analysis results are shown in *Figure 3* below. Regarding the satisfaction with train operation, window service and equipment and facilities, the satisfaction of the abovementioned passengers who commute and go out is higher than the satisfaction with the train operation because these passengers have higher requirements for the punctuality of the train and the interval between departures; the commute time of these passengers is in the early and late peaks, which are crowded, so the passengers who commute and go out to work are less satisfied with the trains. For shopping, visiting friends and traveling, most passengers take the subway at the peak of departure intervals, so the satisfaction with train operation is lower than the satisfaction with windows and equipment and facilities. It is worth noting that the satisfaction of shoppers with the window service is similar to the satisfaction with equipment and facilities, while the satisfaction of tourists with the equipment and facilities is lower than the satisfaction with the window service. This result mainly occurs because tourists are not familiar with the distribution of subway equipment and facilities, and carrying luggage requires more waiting seats. There is no significant difference in the satisfaction with train operation, window service and equipment and facilities among the abovementioned passengers who go to school. These passengers are mainly young people with a higher educational background who exhibit strong adaptability to the environment.

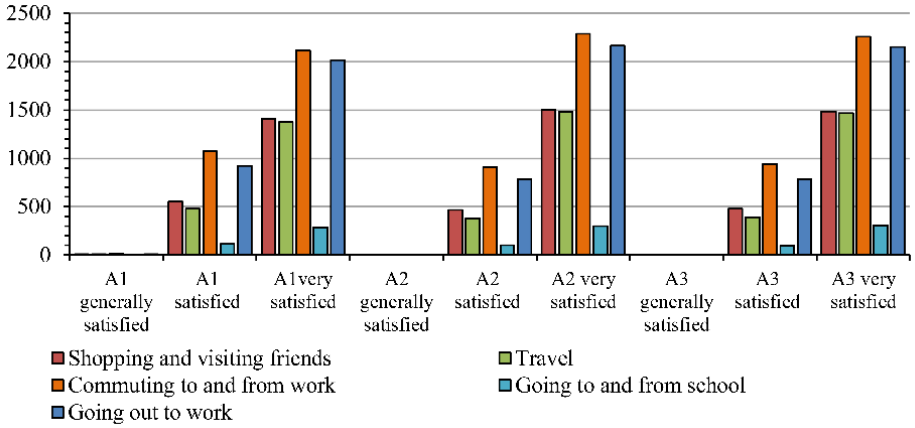

Figure 3 – Purpose and satisfaction with travel

Major transportation means and satisfaction

According to the relationship between the major means of transportation and satisfaction, the analysis results are shown in *Figure 4*. Passengers who use ride-hailing and buses as the main means of transportation have similar satisfaction with window service and equipment and facilities, and this satisfaction level is higher than the satisfaction with train operation. This proportion of passengers mainly commute and go out to work and have higher requirements for the departure intervals, so their satisfaction with train operation is lower. The passengers who take taxis, use online ride-hailing services, drive cars and ride bicycles (including electric bicycles) as the main means of transportation have relatively lower experience with the subway, and there is no significant difference in their satisfaction with train operation, window service and equipment and facilities.

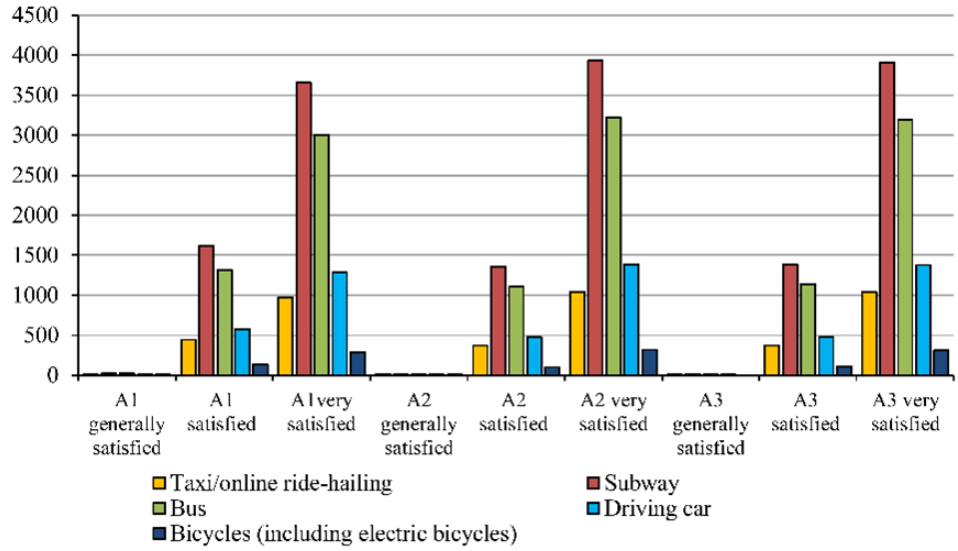

Figure 4 – Main transportation and satisfaction

Reasons and the satisfaction with choosing subway travel

The analysis results of the relationship between choosing subway travel reasons and satisfaction are shown in *Figure 5*. The reason for choosing the subway is that the passengers who require no traffic jam, guaranteed time, convenience, safety and stability, and good riding environment are more satisfied with the window service and equipment than with the train operation, mainly because these passengers pay more attention to the departure interval, smooth operation and congestion of the subway, and these three aspects belong to the third level of train operation satisfaction evaluation indicators. Passengers who choose the reasonable price and good comprehensive service as the reasons for subway travel show little difference in satisfaction with train operation, window service, and equipment and facilities.

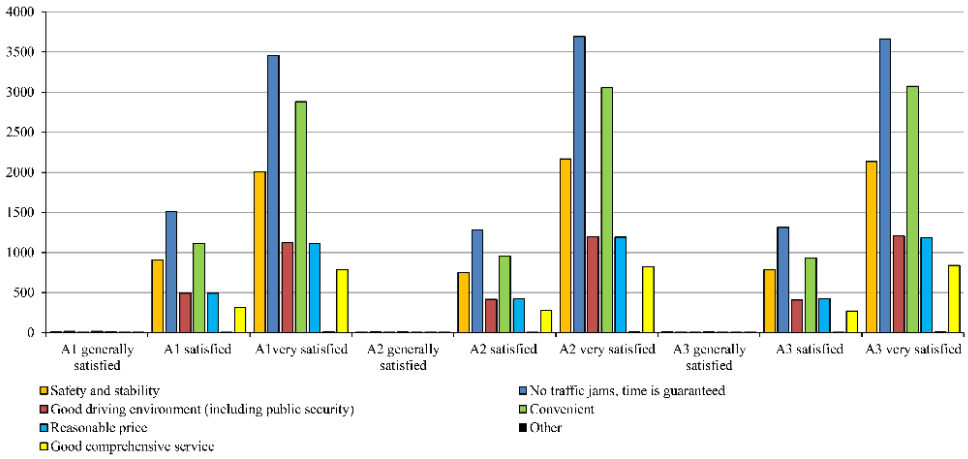

Figure 5 – The reasons for and satisfaction with subway travel

5. CONCLUSION

The evaluation index system of this study starts from the characteristics of passenger travel behaviour, fully considering the comprehensiveness and scalability of the evaluation. The indicators used have strong objectivity, and the design of evaluation indicators allows for dynamic adjustment with changes in passenger demand, ensuring the relevance and pertinence of evaluation results. Therefore, the evaluation system of this study not only has application value in the local area, but also can provide reference for subway passenger satisfaction research in other regions. This paper studies the relationship between the characteristics of passenger travel behaviour and the degree of satisfaction of subway passengers. By designing questionnaires and analysing the correlation of the results, we draw the following conclusions based on the analysis of the differences in degree of satisfaction under different conditions, such as whether passengers have private cars, travel frequency, travel purpose, main means of transportation and the reasons for choosing subway travel:

1) Whether there is a private car has no significant correlation with the satisfaction of subway passengers, but the satisfaction of passengers who have a private car with the train, window service and facilities are lower than that of passengers with a private car.
2) The subway frequency is related to the satisfaction of subway passengers. It is worth mentioning that the passengers who take the subway 1–2 times a week report low satisfaction due to the large interval between flat peak departures. In addition, the satisfaction with train operation, window service and equipment and facilities all decrease with the decrease in travel frequency. It is suggested that the subway companies should pay attention to these passengers and adopt corresponding measures. For instance, enhance the cultural atmosphere of the subway through subway cultural activities, art exhibitions and other means, attracting infrequent subway passengers to experience subway travel. For the issues of departure interval and waiting time, it is suggested to closely track the changes in passenger flow on each route, adjust the train schedule in a timely manner, further compress the running interval on routes with conditions, and shorten the waiting time for passengers.
3) There is a significant correlation between the purpose of travel and the satisfaction of subway passengers. For the purpose of going to school and leaving school, the passengers' satisfaction with train operation, window service and facilities are equal. Passengers who have commuting, business trip, shopping and tourism as their travel purposes are more satisfied with window services, equipment and facilities than with train operation. This proportion of passengers is the largest, and the subway operations department can be based on the characteristics of the increase in passenger flow, humane adjustment of the departure time, a reasonable allocation of the number of trains running measures to improve the degree of satisfaction.
4) There is no significant correlation between the satisfaction of subway passengers and the main means of transportation. There are no significant differences in satisfaction with train operation, window service and equipment among the passengers who take taxis, use online ride-hailing services, drive cars and ride bicycles (including electric bicycles). The satisfaction of the passengers who take the subway and public transport as the main means of transportation is similar to the satisfaction with equipment and facilities, which is higher than the satisfaction with train operation. It is suggested that the subway should introduce preferential measures suitable for these passengers to improve satisfaction.
5) There is a significant correlation between the reasons for choosing subway travel and the satisfaction of subway passengers. The reason for choosing the subway is that the passengers with no traffic jam, guaranteed time, convenience, safety and stability, and good riding environment are more satisfied with the window service and equipment than with the train operation. The passengers who select reasonable prices and good comprehensive service as the reasons for choosing the subway trip show little difference in satisfaction with the train operation, window service and equipment and facilities.

6. FUTURE WORK

These conclusions are based on the analysis of the questionnaire completed by subway passengers about their feelings and experiences, which is consistent with the actual situation. Future research can be considered from the following aspects.

1) By using the comprehensive fuzzy evaluation method, the passenger satisfaction with Qingdao Metro is "generally satisfactory", and the overall satisfaction score is 4.75. This result shows that the passengers of Qingdao Metro are positive about the service of Qingdao Metro. The survey respondents of this study include local residents of Qingdao. The majority of residents in Qingdao express pride in the subway

system, although a small portion may exhibit uncritical praise and a lack of objective perspective towards the subway. This could potentially cause respondents to overlook minor flaws or issues in subway services, or lead passengers to be more forgiving of some shortcomings. As a result, evaluation result may be influenced by local protective sentiment, slightly skewing towards a positive direction. In future applications of the evaluation indicators from this study, it is recommended to make appropriate adjustments and verifications considering the cultural, economic and technological variations in different regions.

2) This study used fuzzy comprehensive evaluation and structural equation model to compare and analyse passenger satisfaction evaluation results. In future research, a combination of fuzzy comprehensive evaluation, structural equation model and ordered probit model can be used to collect data from multiple perspectives for comparative analysis, yielding more rational and reliable evaluation results.
3) In future research work, additional factors such as transfer frequency and transfer distance could be considered when selecting model variables. These factors can be incorporated into the analysis of the impact of passenger travel behaviour characteristics model variables on passenger satisfaction.

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潘福全，程帅，张丽霞，杨晓霞，杨金顺

基于出行行为特征的城市地铁乘客满意度分析

摘要：
本文从地铁乘客的角度出发，探究地铁乘客满意度与乘客出行行为特征的关系，以中国青岛为例，设计了包含乘客个人基本信息、出行行为特征、地铁满意度评价的调查问卷。采用网络在线调查和现场随机调查两种方式结合，本次调查共获得 6340 份有效调查问卷。利用模糊综合评价法计算得出青岛市地铁总体满意度得分，针对地铁乘客满意度与乘客出行行为特征的关系，运用统计学方法选取相关性变量组进行卡方检验。结果表明：出行主要交通工具、是否有私家车与地铁乘客满意度无显著相关关系；乘坐地铁频率与地铁乘客满意度有关；出行目的、选择地铁出行原因与地铁乘客满意度有显著相关关系。最后根据满意度在不同条件下的差异分析得出的结论，提出了一些可以提高地铁乘客满意度的建议。

关键词：
模糊综合评价法；卡方检验；乘客满意度；出行行为特征；地铁