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Investigating the Impact of Emotional Perception on Low-carbon Urban Travel: A Case Study of Wuhan Metro

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KEYWORDS

Metro Travel;
Emotional Perception;
Structural Equation Modeling (SEM);
Multi-Group Structural Equation Modeling (MSEM)

ABSTRACT

As urban metro systems play an increasingly vital role in public transportation, passengers' emotional perception has become increasingly crucial for enhancing their travel experience and quality of life. This study establishes a theoretical relational model for whole-process perception during metro travel. Structural Equation Modeling (SEM) was employed to validate the significant relationships between travel experience perceptions and passenger emotions throughout metro journeys. Furthermore, Multi-group Structural Equation Modeling (MSEM) was utilized to analyze group differences in emotional perception among populations with varying genders and travel frequencies. The findings reveal: (1) The impact mechanism demonstrates that metro passengers' travel emotions are positively influenced by pre-boarding/post-alighting perceptions, accessibility perception, and in-carriage perception, with accessibility perception exhibiting the strongest effect. (2) Group effect analysis indicates significant differences in metro travel emotional perception across gender groups and travel frequency subgroups.

1. Introduction

At the 75th United Nations General Assembly, China pledged to peak its carbon emissions by 2030 and achieve carbon neutrality by 2060. Given that transportation is a significant source of carbon emissions, the transportation sector needs to develop low-carbon transportation facilities and encourage the public to adopt green travel modes[1-2]. As a low-carbon transportation mode with large capacity, low emissions, and the ability to effectively alleviate traffic congestion, the metro has been favored by many cities. According to statistics from the Ministry of Transport of China[3] , as of September 2024, 54 cities in China have opened 313 urban rail transit lines, with an operational mileage of 10,440.5 kilometers and a monthly passenger volume of 2.58 billion.

With the continuous development of metro systems and the increase in passenger numbers, urban transportation management agencies face a dual challenge: on the one hand, they need to meet the growing basic transportation demands, and on the other hand, they need to provide high-quality and personalized travel experiences [4]. Although Chinese transportation authorities are working together to enhance the transportation service capacity of urban hubs to meet the diverse needs of the population, there are still challenges in meeting passengers' psychological and emotional needs during travel [5].

In 2019, China launched the "Healthy China Action (2019-2030)," which set a goal of raising the level of public mental health literacy to 30% by 2030 [6]. Mental health is not only of great significance to individual development but also plays a key role in the overall well-being of society. Studies have shown that more than 70% of diseases are related to negative emotions (e.g., depression, anxiety, and stress) [7]. Moreover, frequent negative emotions (such as depression, irritability, anxiety, and stress) can also lead to

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many social problems [8]. Emotions not only reflect the current psychological state and feelings but also reflect the psychological demand for a better urban environment and public services [9]. Given this, it is particularly urgent and important to explore the impact of emotional perception in urban metro travel and to enhance positive emotions in people's daily travel to promote sustainable transportation development.

This study first constructs a theoretical model of the entire process of metro travel perception. Subsequently, the study uses Structural Equation Modeling (SEM) to analyze the impact mechanism of each stage of the metro travel process on passengers' travel emotions. Meanwhile, Multi-group Structural Equation Modeling (MSEM) is employed to analyze differences among different groups, with a focus on the differences in emotional perception during metro travel among groups with different genders and travel frequencies.

In the following sections of this study, Section 2 is the literature review; Section 3, "Theoretical Research and Hypotheses," introduces the theoretical and methodological approaches and proposes the hypotheses; Section 4, "Research Design and Data Analysis," describes the sources and methods of data collection; Section 5, "Model Construction and Analysis," introduces the Structural Equation Modeling and Multi-group Structural Equation Modeling, using SEM to analyze the impact mechanism and MSEM to analyze group effects; Section 6 summarizes the results and main findings of this study, and discusses the limitations and future research prospects.

2. Literature Review

Passenger travel emotions have become a prominent research topic in the field of urban transportation. Numerous studies have explored factors influencing passenger travel emotions, including environmental perception, service quality, mode choice, and travel time, purpose, and companions.

In terms of environmental perception, Yazdanpanah and Hosseinlon [10] found that adverse weather conditions can increase passengers' negative emotions. Balaban et al. [11] demonstrated that passengers experience varying emotions when navigating public transit spaces, depending on their perception of these spaces. Cox et al. [12] revealed a significant correlation between crowding and negative emotions among UK railway passengers, while Mahudin et al. [13] developed a scale to measure railway passenger crowding and investigated its psychometric properties. Meenar et al. [14], based on a survey of bike-transit users (CTUs) in Philadelphia, USA, found that negative emotions were more prevalent than positive emotions during travel, often linked to specific geographic locations or operational management issues. Chen and Yan et al. [15] used SEM and MGWR models to show that urban architectural design, layout, and surrounding public spaces directly influence passengers' psychological states.

Regarding service quality, Delaplace and Dobruszkes [16], using France as a case study, identified fare, convenience, and speed as key service attributes affecting passenger emotions. Alberto et al. [17] highlighted the correlation between service disruptions and negative passenger emotions. Zhai et al. [18] found that proximity to metro stations significantly enhanced passengers' positive emotions, whereas greater distances increased the likelihood of negative emotions.

In terms of mode choice, St-Louis et al. [19] demonstrated in Canada that slower modes such as walking and cycling tend to elicit more positive emotions. Páez and Whalen[20], also in Canada, found that walking and cycling commuters experienced more positive emotions compared to car and bus users. Le and Carrel [21] revealed that public transit users generally experience more negative emotions than car users but feel slightly less stress and frustration.

Concerning travel time, purpose, and companions, Morris and Guerra [22]found in the US that travel duration had little impact on passengers' emotional states. Watkins et al. [23] noted that uncertainty in travel time can cause psychological stress and irritability. Olsson et al. [24], in Sweden, found that social and recreational activities can enhance positive emotions and mitigate stress and boredom for long-distance commuters. Zhu et al. [25], using 2012–2013 US time-use survey data, explored the relationship between daily travel behavior and emotional well-being, particularly the effects of travel mode, duration, purpose, and companions. Their study showed that cycling is the most enjoyable mode, travel duration negatively correlates with happiness, dining-related trips generate the highest happiness, and traveling with family and friends enhances positive emotions. Zhang et al. [8], in China, found that the choice of travel companions influences individuals' emotional states during daily travel.

Existing literature confirms that environmental perception, service perception, mode choice, and travel time, purpose, and companions all influence passenger travel emotions. However, most studies focus on specific factors, with limited exploration of how the entire travel process affects passenger emotions. Additionally, research on the emotional impact of metro travel remains scarce. Furthermore, subjective perceptions and travel habits vary across groups due to individual differences and travel contexts, leading to diverse emotional perceptions.

To address these gaps, this study investigates the mechanisms influencing passenger travel emotions through perceptions before boarding, after alighting, accessibility, and in-carriage experiences during metro travel. It also examines group differences in emotional perception based on gender and travel frequency. By doing so, this research aims to explore the impact of metro travel on passenger emotions and promote the sustainable development of low-carbon transportation infrastructure.

3. Theoretical Analysis and Hypotheses

3.1. Theoretical Analysis

Arnold's theory of emotion posits that emotion is a "reaction to an object or situation"[26]. The necessary condition for the generation of emotion is the individual's perception of a specific stimulus event. Once perceived, the individual automatically evaluates the event, and this evaluation leads to an emotional response regarding the relevance of the stimulus to the individual's well-being, resulting in various needs and behaviors to approach or avoid the stimulus [27]. Based on Arnold's theory, we define metro travel as a "stimulus event." Passengers perceive the entire process of metro travel, and this perception automatically generates an evaluation, which in turn produces emotions.

The cognitive theory of emotion suggests that emotions and feelings are reactions to the relationship between objective reality and personal needs [28]. The person-environment fit theory indicates that an individual and their environment may achieve a state of mutual adaptation or may experience inconsistencies. When the external environment meets an individual's needs, it helps to elicit positive emotions; conversely, if the environment fails to meet these needs, it may lead to emotional problems and related negative impacts [29]. When an individual traverses a public transport space, they experience different feelings and emotions based on their perception of the space [30]. Therefore, in the perception process, we categorize the entire metro travel experience into pre-boarding and post-alighting perceptions, in-carriage perceptions, accessibility perceptions, and emotional perceptions. Since passengers' needs and environments before boarding and after alighting are essentially the same, we do not consider pre-boarding and post-alighting perceptions separately but include them together in our analysis. Thus, we measure metro travel emotions based on these four aspects of perception.

Based on Arnold's theory of emotion, we establish the path for the generation of metro travel emotions (Figure 1). By analyzing passengers' perceptions of the entire metro travel process using the cognitive theory of emotion and the person-environment fit theory, we identify the key factors. Following the path of emotion generation, we collect data on passengers' different perceptions and subjective emotions during travel through questionnaires. We then use Structural Equation Modeling (SEM) and Multi-group Structural Equation Modeling (MSEM) to analyze the collected data and explore the impact mechanisms of each stage of metro travel on passengers' travel emotions.

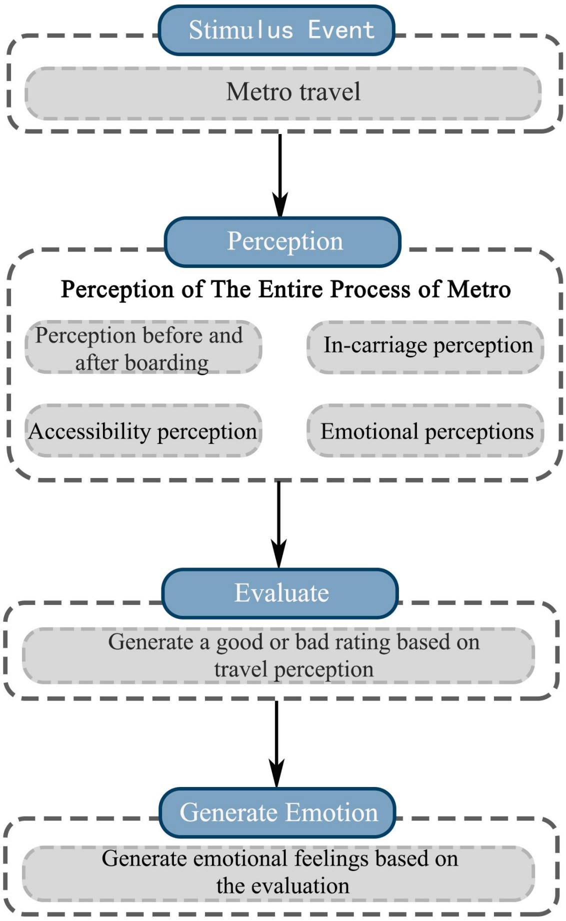

Figure 1 | Path Diagram of Metro Travel Emotion Generation

3.2. Variable Selection

Based on the cognitive theory of emotion and the person-environment fit theory mentioned in the methodology above, we consider the environment and needs of passengers before boarding and after alighting. The perceptions before boarding and after alighting include fare, station entry process, supporting facilities, waiting time, and environmental space. These factors are included as measurement variables to construct the evaluation framework for pre-boarding and post-alighting perception experiences.

Similarly, considering the environment and needs of passengers inside the carriage, the perceptions of passengers inside the carriage include crowding level, temperature, and carriage environment. These factors are included as measurement variables to construct the evaluation framework for in-carriage perception experiences.

Considering the need for accessibility, the perceptions of accessibility include transfer convenience, connections with other transportation modes (e.g., shared bicycles, buses, walking), and detour (i.e., the distance traveled by metro is greater than that by car). These factors are included as measurement variables to construct the evaluation framework for accessibility perception experiences.

For travel emotion perception, emotional state, satisfaction, and willingness to use are included as measurement variables to construct the evaluation framework for emotional perception experiences. The specific measurement items are shown in Table 1.

In addition, descriptive variables were also established. Descriptive variables measured a range of socio-demographic attributes and travel situations, which help to understand the travel patterns of different groups of people. These attributes include gender, age, number of times taking the metro per week, and purpose of travel. The number of times taking the metro per week is measured in four aspects: 1. Daily, 2. 3–5 times per week, 3. 1–2 times per week, 4. Very rarely. The purpose of travel is measured in seven aspects: 1. Commuting to work, 2. Going to school, 3. Tourism, 4. Shopping, 5. Visiting friends, 6. Entertainment, 7. Others. All other socio-demographic data are continuous variables.

Thus, the questionnaire design includes five dimensions, namely descriptive variables, emotional perception, pre-boarding and post-alighting perceptions, accessibility perception, and in-carriage perception. Except for the descriptive variables, a 5-point Likert scale was used to rate the statements, ranging from 1 (Strongly Disagree) to 5 (Strongly Agree).

3.3. Research Hypotheses

3.3.1. Hypotheses on Impact Mechanisms

The perception before boarding and after alighting refers to the experiences that passengers have before they start their metro journey and after they finish it. This process involves a series of procedures, such as purchasing tickets, undergoing security checks, passing through turnstiles, perceiving the station space environment, and using the supporting facilities within the station. Studies have shown that when the environment, services, ticketing, and supporting facilities in the metro station are well-man-

Table 1 | Measurement Variable Settings

Divisor	Quantity	Content
Emotional Perceptions	3	On this subway ride, I felt comfortable emotionally. During this subway trip, I felt satisfied with all kinds of objective conditions. I would like to keep taking the Wuhan subway.
Preboarding/Post-alighting Perceptions	5	I feel satisfied with the fare of this subway trip. I am satisfied with the process of entering the subway station (including ticket purchase, security check, passing the gate, etc.). I am satisfied with the facilities (toilets, waiting seats, vending machines, etc.) at the subway station. I am satisfied with the waiting time for this trip. I felt comfortable with the environmental hygiene in the station during this trip.
Accessibility Perception	3	I am satisfied with the convenience of transferring to other routes during this trip. I was satisfied with the convenience of connecting the subway station with other modes of transportation (shared bikes, buses, etc.). The detour (the distance traveled by subway is greater than the distance traveled by car) was acceptable to me.
In-carriage Perception	4	I am satisfied with the safety of the subway during this trip. I found the congestion in the subway car acceptable during this trip. The temperature of the carriage made me feel comfortable. I felt comfortable with the sanitary conditions of the carriage this time.

aged, passengers' positive emotions are enhanced [16,31]. Therefore, we propose Hypothesis H1: The perception before boarding and after alighting has a positive effect on passengers' emotions. Reasonable travel costs, convenient station entry procedures, well-equipped supporting facilities, and appropriate waiting times can lead to more positive emotions among passengers.

Accessibility perception refers to an individual's subjective feeling about the ease of reaching a destination. The quality of accessibility depends on the convenience with which people can experience services and activities [32]. Studies have indicated that during transfers, transfer areas often cause more negative emotions [30].Good accessibility can enhance passengers' overall sense of well-being [33]. Therefore, we propose Hypothesis H2: Accessibility perception is positively correlated with passengers' travel emotions. When passengers feel that transfers are inconvenient, connections with other modes of transportation (such as shared bicycles, buses, etc.) are poor, and the travel distance by metro is greater than that by car (i.e., detour), they are likely to experience more negative emotions.

In-carriage perception involves passengers' emotional experiences inside the carriage. Studies have shown that when facing crowded carriages, delays, or uncomfortable environments, passengers' emotions tend to become negative [30]. The environmental conditions of the vehicle, such as crowding level, noise level, and temperature, can affect passengers' psychological feelings [32]. Therefore, we propose Hypothesis H3: In-carriage perception is positively correlated with passengers' travel emotions. When passengers have a positive evaluation of the environment and conditions inside the carriage, their travel emotions are also more likely to be positive.

3.3.2. Hypotheses on Group Differences

Existing research has demonstrated significant differences in travel emotion perception among different groups. Regarding gender, Fong and Shaw [34] found that women's emotional responses during travel experiences differ from those of men. Other studies have shown that women's emotional response mechanisms during travel may be more complex, influenced by various factors such as travel purpose, personal emotional state, and social relationships [35]. In terms of travel frequency, Ma and Chen [36] found that increased travel frequency is generally positively correlated with emotional well-being. Frequent travelers tend to experience more positive emotions, which is closely related to their improved quality of life. Travel provides an opportunity to escape daily stress, thereby enhancing travelers' emotional states. Additionally, some studies have identified an interaction effect between gender and travel frequency. The impact of travel frequency on emotional benefits varies between genders. Although both men and women can derive emotional benefits from travel, women's motivations for psychological relaxation and cultural learning during travel may make their emotional experiences more positive with increased travel frequency [37].

Therefore, the following hypotheses are proposed:

H4: There are significant differences in metro travel emotion perception between genders and travel frequencies.

H5: There are significant differences in metro travel emotion perception among different travel frequencies.

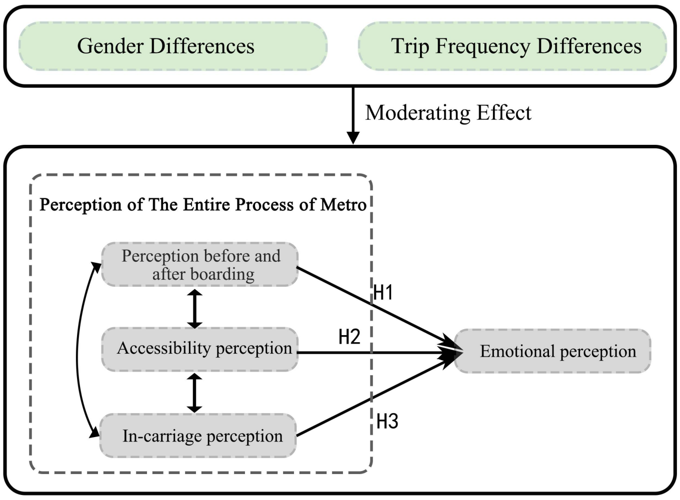

Figure 2 | Theoretical Model Diagram

Based on the research hypotheses presented in this section, a theoretical model is constructed as shown in Figure 2.

4. Research Design and Data Analysis

4.1. Research Design and Data Collection

Data were collected through offline questionnaires distributed in Wuhan City in July 2024. Wuhan, the central city of China's central region and an important comprehensive transportation hub nationwide, is a rapidly developing city with a permanent population of 12.3265 million (according to the 7th National Population Census of Wuhan). It is also the capital city of Hubei Province. As of June 2024, Wuhan Metro had 12 operational lines with a total operating mileage of 486 kilometers. On June 24, 2024, the total passenger volume of Wuhan Metro's network exceeded 10 billion.

The 12 operational lines of Wuhan Metro were selected as the research subjects. Random sampling surveys were conducted among passengers on these 12 lines, with small gifts (valued at less than 5 Chinese yuan) provided as incentives for participation. A total of 500 questionnaires were distributed. After preliminary processing of the 500 returned questionnaires, including the removal of incomplete responses and those with contradictory answers, 402 valid datasets were obtained.

4.2. Variables

4.2.1. Descriptive Statistics of the Sample

Table 2 reflects the socio-demographic attributes and travel situation data. In terms of gender distribution, male respondents slightly outnumber females. Regarding age

Table 2 | Statistics of Socio-Demographic Attributes and Travel Situations

Sample Information	Options	Quantity	Percentage
Gender	Man	241	60
	Woman	161	40
Age	Ages 0-14	7	1.7
	Ages 15-24	241	60.0
	Ages 25-34	108	26.9
	Ages 35-44	26	6.5
	Ages 45-54	10	2.5
	Ages 55-64	7	1.7
	Aged 65 and above	3	0.7
Number of Times Taking the Metro per Week	Daily use	41	10.2
	3-5 times per week	126	31.3
	1-2 times per week	158	39.3
	Very rarely	77	19.2
Purpose of Travel	Visiting friends	32	8.0
	Shopping	36	9.0
	Traveling	28	7.0
	Commuting to work	72	17.9
	Going to school	83	20.6
	Entertainment	115	28.6
	Other	36	9.0

distribution, young people aged 15–34 are the main force in metro travel, accounting for 60% of the total sample. Passengers in this age group are usually more active and have higher travel demands, including commuting to school, work, and social activities. Fewer passengers are aged 0–14 and 65 and above, which may be related to the relatively lower travel demands and activity ranges of these age groups. In terms of metro usage frequency, passengers who travel 1–2 times per week are the most numerous, accounting for 39.3%. This indicates that the metro is a regularly used mode of transportation for many passengers. Passengers who travel 3–5 times per week also constitute a significant proportion, highlighting the important role of the metro in urban transportation. Regarding travel purposes, commuting to work and school are the main purposes, accounting for 38.5% of the total sample. This emphasizes the key role of the metro in urban daily commuting. The data analysis results reveal a balanced distribution of the survey sample across various basic attributes, effectively avoiding sample bias and ensuring the representativeness and diversity of the statistical results.

4.2.2. Reliability and Validity Testing

The reliability of the questionnaire was assessed using Cronbach's alpha coefficient, with the analysis conducted using SPSS. As shown in Table 3, the overall reliability coefficient of the questionnaire scale is 0.954, indicating a high level of reliability for the entire questionnaire. Typically, a Cronbach's alpha coefficient greater than 0.7 is considered acceptable, while a value greater than 0.8 is regarded as good. The Cronbach's alpha coefficients for each dimension of the scale range from 0.865 to 0.921, all exceeding the standard value of 0.6. Therefore, the internal consistency reliability of the survey questionnaire is good, and its reliability is strong.

To assess the structural validity of the data, Bartlett's test of sphericity and the KMO (Kaiser-Meyer-Olkin) test were employed to evaluate the suitability of using factor analysis. The KMO value is an indicator of the correlation between variables; the closer it is to 1, the stronger the correlation between variables, and thus the more suitable for factor analysis. As shown in Table 4, the KMO value of the scale is 0.949 (>0.7), and Bartlett's test of sphericity yields a p-value of 0.000 (<0.01). This indicates that the correlations between variables are significant and suitable for exploratory factor analysis.

Excluding the items of descriptive variables in the sample, the principal component analysis method of exploratory factor analysis was used. According to the total variance explained, the first four principal components cumulatively accounted for 78.543% of the total variance, a proportion significantly higher than the minimum acceptable standard (at least 50%). This indicates that most of the data variation can still be explained, and they have a strong explanatory power over the data as a whole. Therefore, four common factors can be extracted, which correspond exactly to the four dimensions in the questionnaire, proving the rationality of the questionnaire's setting of four dimensions. In the factor analysis, the factor loadings of each item ranged from 0.611 to 0.798, exceeding the threshold of 0.5. Thus, the model data also performed well in terms of structural validity, and the quality of the model data passed the test.

4.2.3. Correlation Analysis

The correlation between travel emotions, pre-boarding and post-alighting perceptions, accessibility perceptions, and in-carriage perceptions was examined using Pearson's correlation coefficient method. As shown in Table 5, all correlation coefficients were statistically significant (p<0.001), indicating that the relationships between these variables are significant.

Table 3 | Reliability Test of the Questionnaire

Total *alpha*	Dimension *alpha*
0.954	α_1=0.875
	α_2=0.921
	α_3=0.885
	α_4=0.865

Note: Dimension 1: Travel Emotion is denoted as α_1; Dimension 2: Pre-boarding and Post-alighting Perception is denoted as α_2; Dimension 3: Accessibility Perception is denoted as α_3; Dimension 4: In-carriage Perception is denoted as α_4.

Table 4 | KMO and Bartlett's Test of Sphericity for the Scale

KMO		**0.949**
Bartlett's Test of Sphericity	Approximate Chi-Square	4881.833
	Degrees of Freedom	105
	Significance	0.000

Table 5 | Correlation Analysis

Correlation	Emotional perception	pre-boarding/post-alighting perceptions	Accessibility perception	In-carriage perception
Emotional perception	1	0.749**	0.767**	0.716**
pre-boarding/post-alighting perceptions	0.749**	1	0.755**	0.679**
Accessibility perception	0.767**	0.755**	1	0.688**
In-carriage perception	0.716**	0.679**	0.688**	1

Note: ** indicates ***p*<.001**, the correlation is significant.

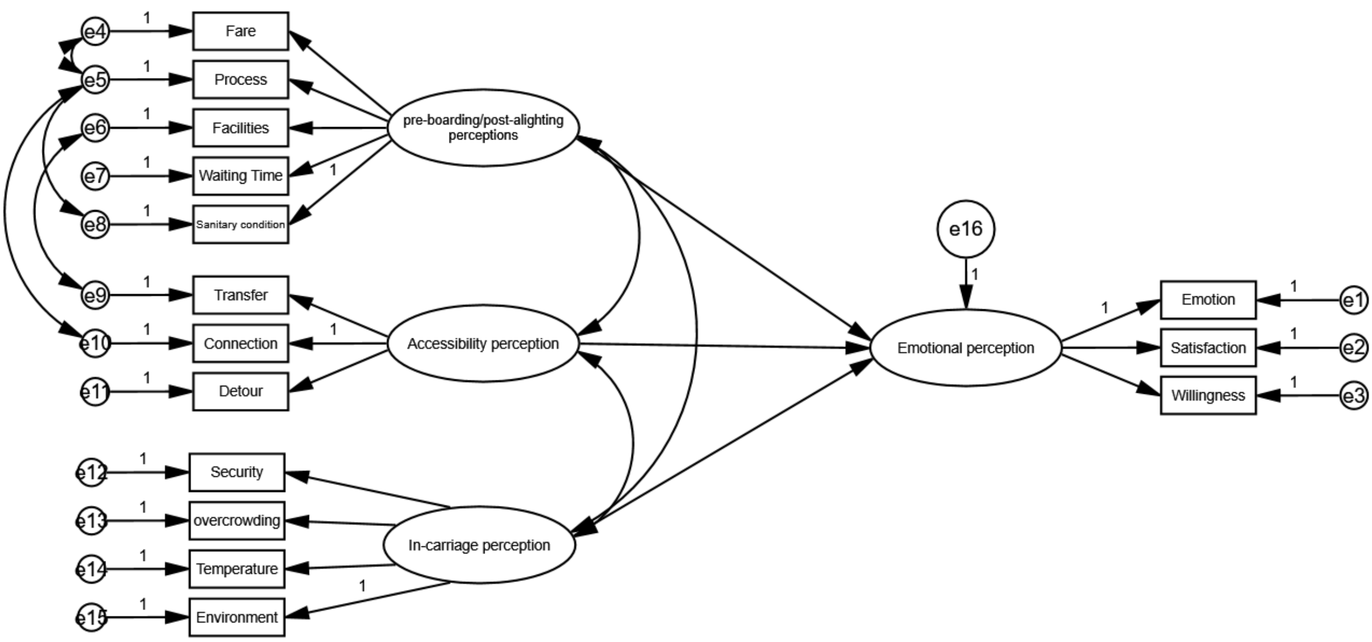

Figure 3 l Path Diagram of the SEM Model

5. Model Construction and Analysis

5.1. Construction of Structural Equation Modeling (SEM)

This study employs Structural Equation Modeling (SEM) for data analysis. SEM is capable of simultaneously resolving the complex relationships between endogenous and exogenous variables and calculating the direct, indirect, and total effects of these variables. SEM is used to test a set of theory-driven hypotheses, aiming to measure the fit between the hypothesized conceptual model composed of observed indicators and latent constructs and the data[33] .

Based on existing literature and theoretical knowledge, we designed and constructed a theoretical conceptual model for the entire process of metro travel perception to explore the interrelationships among different variables. In this process, we first established the measurement models for latent variables, which are based on theoretical hypotheses and used for preliminary analysis of the correlations between latent variables. Subsequently, we conducted path analysis to further investigate the relationships between these variables and constructed the Structural Equation Model accordingly.

The SEM model was constructed using AMOS 24.0 software, where ellipses represent latent variables and rectangles represent measurement indicators. We considered three exogenous latent variables—perception before boarding and after alighting, accessibility perception, and in-carriage perception—and one endogenous latent variable—travel emotion. The three measurement indicators for travel emotion, the five measurement indicators for perception before boarding and after alighting, the three measurement indicators for accessibility perception, and the four measurement indicators for in-carriage perception are

Table 6 l Goodness-of-Fit Test for the SEM Model

Statistical Test Metric	Standard or Critical Value for Fit	Test Result	Model Fit Judgment
Chi-Square(χ^2)	p>0.05（Not Significant）	348（p<0.001）	Fit Indices Reference Statistics
CMIN/DF	<5	4.139	Yes
RMR	<0.05	0.024	Yes
RMSEA	<0.08	0.088	No
GFI	>0.90	0.898	No
AGFI	>0.80	0.854	Yes
TLI	>0.90	0.932	Yes
IFI	>0.90	0.946	Yes
NFI	>0.90	0.930	Yes
CFI	>0.90	0.946	Yes

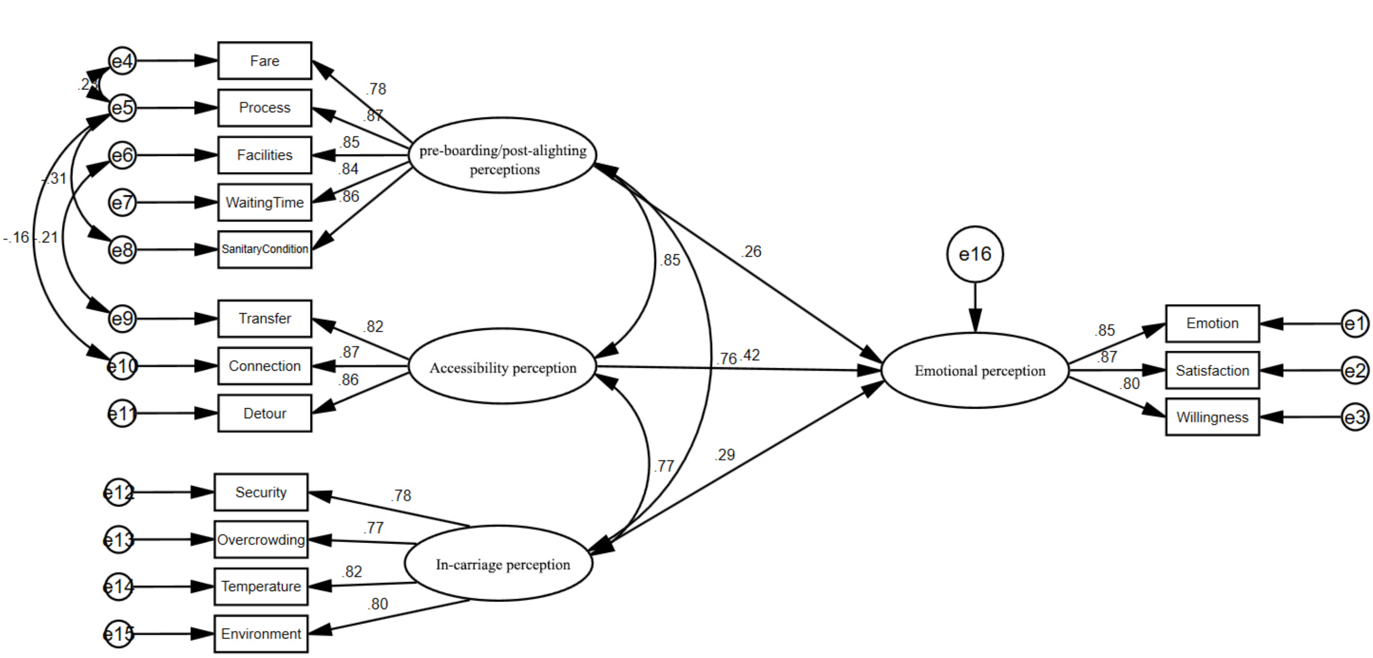

Figure 4 I Revised SEM Model and Path Diagram

shown in Figure 3. The circular e1 to e16 represent the measurement errors for each measurement indicator. In the constructed Structural Equation Model, the three exogenous latent variables and one endogenous latent variable are interconnected through three hypothesized paths. These paths represent our expected influences between the variables, and the model construction aims to verify whether these expectations align with the actual data.

A goodness-of-fit test was conducted on the constructed SEM model. The goodness-of-fit indices are shown in the table. Table 6 indicates that the Root Mean Square Error of Approximation (RMSEA) is 0.088, which exceeds the acceptable threshold of 0.08. Additionally, the Goodness-of-Fit Index (GFI) is 0.898, slightly below the standard value of 0.90. These results suggest that the constructed model requires further refinement.

When a model fails to meet the fit criteria, variables with high Modification Indices (MI) can be removed to refine the model. A high MI value (typically greater than 10) indicates a strong correlation,

suggesting the need to release paths with large MI values to improve the model's fit. In this study, the MI values between e4 and e5, e5 and e8, e5 and e10, and e6 and e9 were found to be significant. Therefore, correlation paths between these residuals were added to enhance the model's fit.

The revised SEM is shown in Figure 4. The results of the goodness-of-fit test after revision are shown in Table 7, and all fit indices indicate that the model fits well. Therefore, it can be concluded that the model is well-fitted overall.

Table 7 I Goodness-of-Fit Test for the Revised SEM Model

Statistical Test Metric	Standard or Critical Value for Fit	Test Result	Model Fit Judgment
Chi-Square(χ^2)	p>0.05（Not Significant）	280（p<0.001）	Fit Indices Reference Statistics
CMIN/DF	<5	3.498	Yes
RMR	<0.05	0.022	Yes
RMSEA	<0.08	0.079	Yes
GFI	>0.90	0.916	Yes
AGFI	>0.80	0.874	Yes
TLI	>0.90	0.946	Yes
IFI	>0.90	0.959	Yes
NFI	>0.90	0.944	Yes
CFI	>0.90	0.959	Yes

5.2. Structural Equation Modeling (SEM) Analysis and Hypothesis Path Testing

The relationships between model variables are determined by the signs of the standardized path coefficients, which indicate the positive or negative correlations between variables. The absolute values of the path coefficients are used to assess the strength of the influence between two variables; the larger the absolute value, the greater the impact one variable has on the other along the path. The standardized path coefficients for the revised SEM paths, as shown in Figure 3, are presented in Table 8.

The results reveal significant relationships between metro passengers' travel emotions and their perceptions of different travel stages. Specifically, accessibility perception has a significant positive impact on travel emotions (standardized path coefficient = 0.42); pre-boarding and post-alighting perceptions also have a positive impact on travel emotions (standardized path coefficient = 0.26); and in-carriage perception has a positive impact on travel emotions as well (standardized path coefficient = 0.29). The differences in the impact of pre-boarding and post-alighting perceptions and in-carriage perception on travel emotions are not significant. The standardized coefficients between accessibility perception and pre-boarding and post-alighting perceptions and in-carriage perception are 0.85 and 0.77, respectively, indicating a very significant influence.

Based on the above findings, accessibility perception has the most significant impact on travel emotions, reflecting contemporary residents' high emphasis on the accessibility of public transportation. A well-designed metro network can provide convenient connections, reduce the number of transfers and walking distances, thereby enhancing passengers' travel emotions. Wuhan, a densely populated and geographically extensive city, is divided into three main areas (Wuchang, Hanyang, Hankou) by the Yangtze River and the Han River. This unique geographical feature poses higher demands on transportation connectivity. In such an urban environment, the metro, as a key and rapid mode of public transportation, plays a decisive role in alleviating traffic congestion and improving travel efficiency. Therefore, residents are particularly sensitive to the accessibility of the metro, paying close attention to the connections between the metro and residential areas, commercial districts, educational institutions, and tourist attractions during their travels. These factors directly affect their travel convenience and time costs, which in turn influence passengers' travel emotions.

5.3. Multi-Group Structural Equation Modeling (MSEM) Analysis

The purpose of multi-group structural equation modeling (MSEM) is to evaluate whether the theoretical model proposed by researchers is equivalent across different sample groups or if there are significant differences [38]. This paper employs MSEM to conduct differential analysis on two dimensions: gender and travel frequency. In terms of gender, due to the interaction of physiological factors and socio-cultural influences, there are certain psychological differences between men and women, and these differences are also reflected in their experiences with public transportation. Regarding travel frequency, it is divided into frequent users and occasional users. Based on the samples collected in this study, individuals who use the metro daily or 3–5 times per week are categorized as frequent users, while those who use it 1–2 times per week or very rarely are classified as occasional users. Occasional users account for 58.5% of the total sample, which is close to the proportion of frequent users, making it suitable for multi-group analysis. On the other hand, frequent and occasional users of the metro have different focal points regarding the construction and services of the metro. For example, frequent users may place greater emphasis on the punctuality, crowding levels, and transfer convenience of the metro, while occasional users may be more concerned with the convenience of ticket purchasing and the clarity of station guidance. Therefore, this paper selects these two

Table 8 | Interpretation of the Paths in the Revised Model

Path	Hypothesis Explanation	Standardized Path Coefficient	p	Direction of Influence	Validation Result
H1	Perception before boarding and after alighting has an impact on travel emotions.	0.26	***	Positive	Valid
H2	Accessibility perception has an impact on travel emotions.	0.42	***	Positive	Valid
H3	In-carriage perception has an impact on travel emotions.	0.29	***	Positive	Valid

Note: *** indicates that the path significance level *P* value is less than 0.01.

representative dimensions to analyze the differences between groups.

The results of the multi-group analysis are shown in Table 9. In terms of the impact mechanism, the multi-group test results are basically consistent with the main model results, all showing positive impacts. However, the accessibility perception for women is not significant. The specific analysis is as follows:

In the gender dimension, the path coefficient for men regarding the impact of accessibility perception on travel emotions is 0.492, while it is not significant for women. This indicates that men place greater emphasis on the accessibility of the metro, and accessibility perception has a more significant impact on men's travel emotions. In daily travel and commuting, men tend to focus more on travel efficiency, and inefficient travel can lead to more negative emotions for them. The path coefficient for women regarding the impact of pre-boarding and post-alighting perceptions on travel emotions is 0.435, while for men, it is 0.208. This suggests that women pay more attention to pre-boarding and post-alighting perceptions, including ticket prices, station environmental hygiene, entry procedures, and supporting facilities and services. These perceptions have a more significant impact on women's travel emotions. The path coefficients for men and women regarding the impact of in-carriage perception on travel emotions are 0.302 and 0.259, respectively. The slightly higher path coefficient for men indicates that in-carriage perception has a more significant impact on men's travel emotions.

In the travel frequency dimension, for the group that frequently uses the metro, the path coefficient for the impact of accessibility perception on travel emotions is 0.459, which is higher than the path coefficient of 0.330 for the group that occasionally uses the metro. This suggests that frequent users place slightly more importance on accessibility perception, which has a more significant impact on their travel emotions. Frequent users, who mostly commute for work or school, tend to focus more on the accessibility and efficiency of the metro. The path coefficients for the impact of pre-boarding and post-alighting perceptions and in-carriage perception on travel emotions are 0.257 and 0.269 for frequent users, and 0.325 and 0.313 for occasional users, respectively. This indicates that occasional users are more affected by pre-boarding and post-alighting perceptions and in-carriage perception in terms of travel emotions. Occasional users tend to pay more attention to ticket purchasing, station guidance clarity, entry procedures, station environment, and supporting facilities.

6. Conclusion and Outlook

6.1. Conclusion

This study proposes a theoretical relational model for the entire process of metro travel perception. Through a questionnaire survey of metro passengers in Wuhan, relevant data were collected and analyzed using Structural Equation Modeling (SEM) to explore the impact mechanism of different stages of metro travel on passengers' travel emotions. Additionally, Multi-group Structural Equation Modeling (MSEM) was employed to investigate differences among different groups. The following conclusions were drawn:

(1) The impact mechanism results show that passengers' travel emotions are positively influenced by pre-boarding and post-alighting perceptions, accessibility perception, and in-carriage perception. Among these, accessibility perception has the greatest impact on travel emotions and is a key factor in enhancing passengers' travel emotions.

(2) The group effect results indicate significant differences in travel emotion perception between different genders and travel frequencies. In terms of gender, male passengers' travel emotions are more influenced by accessibility perception, while female passengers' travel emotions are more affected by pre-boarding and post-alighting perceptions. Regarding travel frequency, passengers who frequently use the metro are more influenced by accessibility perception, while occasional users are more affected by

Table 9 | Results of Multi-group Analysis

Path	Gender				Trip Frequency			
	Man		Woman		Frequent Travelers		Occasional Travelers	
	Std	P	Std	P	Std	P	Std	P
pre-boarding/post-alighting perceptions →Emotional perception	0.208	**	0.435	**	0.257	**	0.325	**
Accessibility perception →Emotional perception	0.492	***	0.252	0.229	0.459	***	0.330	**
In-carriage perception →Emotional perception	0.302	***	0.259	**	0.269	**	0.313	***

Note: ***、**、*indicate significance at the 0.01 0.05, and 0.1 levels, respectively.

pre-boarding and post-alighting perceptions and in-carriage perception.

6.2. Limitations and Future Work

This study has provided some insights into the impact of the entire metro travel process on passengers' emotions, but there are still several limitations. The current study has focused on analyzing the differences in gender and travel frequency groups, and future research should incorporate other group differences such as age, income level, travel time, and travel purpose to enhance the explanatory power of the model. Moreover, the geographical location of metro stations may affect passengers' accessibility perception and travel experience. Metro stations located in the city center often have better accessibility than those in peripheral areas. Additionally, different metro stations may bring different perceptions to passengers. These differences may moderate the significance of the relationships among the variables examined in this study. Therefore, future research needs to further explore the impact of these factors to more comprehensively reveal the mechanisms that affect travel emotions and to provide more targeted strategies for improving passenger experience.

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