Research on the Intermodal Scheme of Passengers in Metropolitan Area

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Abstract: In line with the concept of the "one-hour commuting circle," this research focuses on intermodal travel solutions for urban travelers, aiming to enhance passenger service quality and meet their diverse travel needs. The study commences with an investigation into the travel mode preferences of urban residents, establishing the "Railway+" intermodal travel model. Factors influencing travelers' choices of intermodal travel are then analyzed. Targeting the maximization of utility for different traveler groups engaged in intermodal journeys, a dual-layer logit model is employed to construct models for departure time selection and intermodal scheme preferences among urban travelers. The research concludes with an examination of the impact of various attributes on the selection of railway intermodal solutions within the urban context. Furthermore, the study explores the potential for the transition of railway intermodal rides, particularly rail-car-hailing, from holidays to non-holidays and their conversion to other railway intermodal modes.

Keywords: metropolitan area; intermodal travel; demand for a journey; nested Logit model; mode Transforming

1 Introduction

The metropolitan area is an urbanized spatial form within urban clusters, typically centered around megacities or large cities with strong driving functions. It is characterized by a commuting radius of one hour, forming the basic scope of urbanization[1]. Guijin Li[2] believes that multi-modal transportation coordination integrates various modes of transportation during passengers' journeys to achieve convenient and efficient travel. Based on studies, passenger intermodal transport should meet the conditions of single-ticket purchase, direct ticketing, full-service, and seamless connection[3]. Latinopoulos[4] studied passenger travel choice behaviors through a simulated scenario in a questionnaire survey. Qian Chen[5] divided travel scenarios based on distance and analyzed the impact of different attributes on subway multimodal transportation groups' fare schemes using survey data. Min Yang[6] analyzed the demand differences among different passengers in the context of public-rail intermodal scenarios and provided personalized travel plans. Lin Chen[7] modeled the transfer behavior of intermodal passengers between urban hubs through a Multinomial Logit (MNL) model,

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calculated the modal share, and compared it with actual survey results. Kaixuan Zhao[8] analyzed the alleviation of urban traffic congestion by the intermodal use of ride-hailing and rail transit. Xuan Hang[9] conducted a stated preference (SP) questionnaire survey on passenger transfer behavior in Shanghai Hongqiao Airport, constructed an MNL model, and verified the impact of travel mode attributes, time, cost, and individual characteristics on transfer choices. Yujie Wang[10] conducted research on passengers' intermodal travel mode choices in three travel scenarios using the MNL, NL, and MMNL discrete choice models. Bixia Lou[11] offers targeted optimization suggestions for each stage of the integrated air-rail intermodal travel, contributing to the development of personalized travel for intermodal passengers. Vos J D[12] used regression analysis to study residents' satisfaction with leisure travel, and believed that the longer the travel time, the lower the traveler's satisfaction.

Overall, existing research tends to focus on intra-city intermodal transfer behaviors, with limited emphasis on the core of rail travel, the interconnection of intra-city public transportation and road traffic, and the overall process of intermodal travel for urban agglomeration passengers. Additionally, there is insufficient exploration of passengers' intermodal mode selection behaviors and transformation issues during holidays and non-holidays within the urban agglomeration.

This paper starts by examining passengers' intermodal selection behavior. Combining Stated Preference (SP) surveys and simulating intermodal travel scenarios for urban passengers, we establish an intermodal option selection model. The study explores the impact of different influencing factors on the utility of travel time and the selection of intermodal modes. Furthermore, it analyzes the possibility of transitions between different intermodal modes.

2 Data Collection and Analysis

2.1 Questionnaire Design

Passenger intermodal travel refers to a scenario where passengers utilize a single ticket for the entire journey, allowing seamless transitions between different modes of transportation. During transfers between various modes, passengers utilize intermodal channels, eliminating the need for secondary security checks. To incentivize passengers to choose intermodal travel, discounts are applied to intermodal ticket prices.

The travel scenarios for different intermodal models are outlined in Table 1.

Table 1. Intermodal Travel Scenarios

Intercity travel mode	Urban travel mode	Travel time /min	Wait time /min	Travel cost/yuan
Railway	+Bus	40	7	11
	+Bike-sharing	45	2	11
	+Subway	42	3	14
	+Online car-hailing	30	5	17

The influencing factors within each category are outlined in Table 2.

Table 2. Analysis of Influencing Factors

Type	Variable	Variable definition
Personal Attributes	Age X_1	1. [18，25）, 2. [25，35）, 3. [35，45）, 4. [45，50）, 5. [50，60）, 6. else
	Gender X_2	1. man, 2. woman
	Income X_3	1. Below 2000 yuan, 2. [2000，4000）, 3. [4000，7000）, 4. [7000，10000）, 5. [10000，15000）, 6. Above 15000 yuan
Travel Characteristics	Travel frequency X_4	1. Less than 1 time per month, 2. 2-3 times per month, 3. 1-2 times per week, 4. 3-4 times per week, 5. more than 5 times per week
	Travel cost X_5	1. [10，15）, 2. [15，20）, 3. [20，25） 4. [25，30）
	Travel time X_6	1. [40，45）, 2. [45，50）, 3. [50，55）
Intermodal Mode Attributes	Transfer waiting time X_7	1. [0，5）, 2. [5，10）, 3. [10，15）
	Comfort X_8	1. Prioritizing Ticket Price , 2. Emphasis on Waiting Time, 3. else

2.2 Analysis of Questionnaire Results

A total of 402 online questionnaires were collected in the survey, and after excluding incomplete or improperly filled questionnaires based on response time, a total of 366 valid responses were obtained, resulting in an effective response rate of 91%, the results of the influencing factors analysis are presented in Figure 1.

Analysis of the questionnaire data reveals that the majority of passengers fall within the age range of 18-50 years, constituting 86.25% of the sample. The gender distribution is relatively balanced, with males accounting for 53.28%. The income distribution among passengers is fairly even, ensuring a more objective representation of results. The highest proportion of passengers, at 26.5%, indicates a travel frequency of 1-2 times per week, reflecting a notable demand for railway travel among the surveyed individuals. During festive periods, the proportion of travelers is 70.2%, whereas non- festive periods travel constitutes 29.8%. Among the four intermodal modes, the "Railway + Bus" intermodal mode emerges as the primary choice for passengers, constituting 34.7%. Following closely is the "Railway + Shared Bicycle" intermodal mode, accounting for 27.3%. The "Railway + Ride-Hailing" intermodal mode is less favored, making up 14.8%, with passengers expressing a preference for reduced waiting times. In holiday travel, the majority of people prefer the "Railway + Bus" intermodal travel mode.

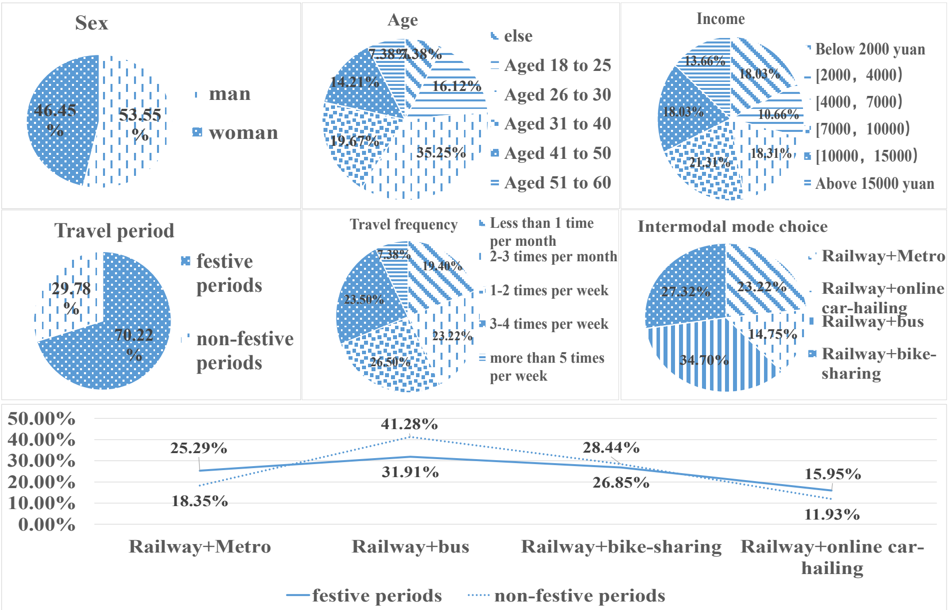

Figure 1. Analysis of Influencing Factors

3. Construction of Intermodal Travel Scheme Selection Model

3.1 Model Establishment

In Figure 2,the first hierarchy determines whether the passenger travels during holidays (T), serving as the upper-level choice set in the model. The second hierarchy corresponds to different intermodal modes (M), constituting the lower-level choice set in the model. Within the NL structure, the probability of passenger n choosing the virtual choice set for travel time t is expressed as:

$$P_n(t) = \frac{\exp(V_{nt} + V_{nt}^*)}{\sum_{t=1}^{T} \exp(V_{nT} + V_{nT}^*)} \tag{1}$$

In accordance with the utility calculation principles of random utility theory, the probability of selecting the intermodal mode m in the lower level of the Nested Logit (NL) model can be expressed as:

$$P_n(m \mid t) = \frac{\exp(\mu_t V_{n(m|t)})}{\sum_{m=1}^{M} \exp(\mu_t V_{n(M|t)})} \tag{2}$$

Therefore, the final probability of passenger n choosing intermodal scheme is:

$$P_n(tm) = P_n(m \mid t) \times P_n(t) \tag{3}$$

In which:

$$V_{nt}^{*}=\frac{1}{\varepsilon_t}\ln[\exp(\varepsilon_t V_{n(m|t)})] \tag{4}$$

$$V_{n(m|t)}=\sum_{K}\beta_k X_{n(m|t)\ k} \tag{5}$$

In the formula, β_k represents the parameters to be estimated; V_{nt} represents the part of the utility for passenger n that varies with the change in t when choosing the scheme tm; $V_{n(m|t)}$ represents the part of the utility for passenger n that varies with the combination of t and m when choosing the scheme tm; ε_t represents the scale parameter of the virtual choice branch m.

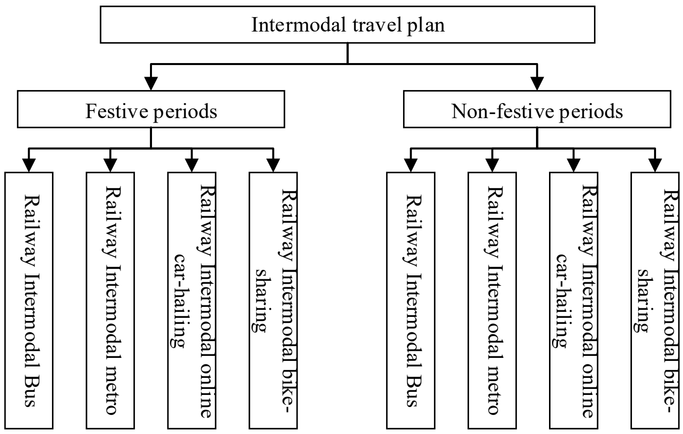

Figure 2. Intermodal Travel Scheme Selection Model

3.2 Model Calibration

The model calibration in this paper is conducted using Stata software. The initial step involves estimating the parameters of the lower-level model. Based on the estimation results, inclusive coefficients are derived. These inclusive coefficients are then employed as influencing factors for parameter estimation in the upper-level model. Inclusive coefficients α_t are:

$$\alpha_t = Ln[\sum_{l=1}^{L}\sum_{m=1}^{M}(\beta_0+\beta_{lm}x_{lm})] \tag{6}$$

In the formula, M represents Number of intermodal modes; L represents Number of lower-level influencing factors; β represents Estimated parameters for lower-level influencing factors.

In non-aggregate models where the dependent variable is not continuous, the choice probabilities should be expressed as log-odds. The log-odds for the nested logit model are expressed as:

$$odd=\frac{P(m_M,t_T)}{P(m_1,t_1)}=\frac{P(m_M)}{P(m_1)}\times\frac{P(t_T)}{P(t_1)}, M=1,2,3, T=2 \tag{7}$$

4. Model Calibration and Results Analysis

The influencing factors of the lower-level through-mode selection model were selected. Variables were introduced into the model, using the "Railway + Ride-hailing" through-mode as the reference object, and the parameter estimation results were obtained through regression analysis, as shown in Table 3.

Table 3. Results of Lower-Level Model Calibration

Intermodal mode	Subway			Bus			Bike-sharing		
Variable name	Coefficient	Standard error	Test	Coefficient	Standard error	Test	Coefficient	Standard error	Test
Constant coefficient	35.01***	-1.518	0	100.2***	-1.757	0	116.2***	-1.7	0
Sender X_1	0.644	-0.514	0.21	-13.84***	-0.931	0	-13.76***	-0.942	0
Income X_3	-0.056	-0.142	0.694	0.476*	-0.281	0.09	0.559*	-0.294	0.058
Travel frequency X_4	-0.315*	-0.184	0.086	0.275	-0.305	0.366	0.276	-0.326	0.397
Travel cost X_5	-16.42***	-0.582	0	-52.45***	-1.247	0	-69.02***	-1.442	0

Based on the parameter estimation results, the probability odds ratios for choosing railway intermodal metro, railway intermodal bus, and railway intermodal shared bicycle relative to railway intermodal ride-hailing can be determined as follows:

$$\frac{P_n(m_1)}{P_n(m_4)} = \exp(35.01 + 0.644x_1 - 0.056x_3 - 0.737x_4 - 16.42x_5) \tag{8}$$

$$\frac{P_n(m_2)}{P_n(m_4)} = \exp(100.2 - 13.84x_1 + 0.476x_3 + 0.275x_4 - 52.45x_5) \tag{9}$$

$$\frac{P_n(m_3)}{P_n(m_4)} = \exp(116.2 - 13.76x_1 + 0.559x_3 + 0.276x_4 - 69.02x_5) \tag{10}$$

Table 4. Upper-Level Model Calibration Results

Variable name	Coefficient	Standard error	Test
Constant coefficient	9.633*[a]	5.524	0.081
Inclusive coefficients α_t	-1.354	1.182	0.252
Age X_2	-0.284**	0.12	0.018
Income X_5	-0.374***	0.110	0.001
Travel time X_6	0.408	0.495	0.41
Transfer waiting time X_7	-0.064	0.21	0.76
Confort X_8	-0.569	0.366	0.12

[a] "*" indicates the significance level of the influencing factors.

Based on the table above, the inclusion coefficient α_t can be calculated and utilized as an influencing factor in the upper-layer model. Additionally, taking into account factors such as age and income. The calibration results are presented in Table 4.

the odds ratio for travelers choosing to travel during holidays relative to non-holidays is:

$$\frac{P_n(t_2)}{P_n(t_1)} = \exp(9.633 - 1.354 - 0.284x_2 - 0.374x_3 + 0.408x_6 \\ -0.064x_7 - 0.569x_8) \tag{11}$$

Therefore, combining the probability ratio formulas for both layers of choices, we can obtain the probability ratio of traveler n simultaneously making choices for departure time and intermodal transportation mode within the metropolitan area. Taking the "Railway + Subway" intermodal mode as an example, the analysis results are as follows:

(1)The parameters for choosing the "Railway + Subway" intermodal mode are as follows: frequency of travel and ticket price, with coefficients of -0.315 and -16.42, respectively. It is evident that as the frequency of travel and subway ticket prices increase, the number of passengers choosing intermodal travel with railway and subway, relative to railway intermodal ridesharing, will decrease.

(2)Assuming a traveler's attribute are , $X_1 = 2,\ X_2 = 1,\ X_3 = 3,\ X_4 = 1,\ X_5 = 2,\ X_6 = 2,\ X_7 = 3,\ X_8 = 1,$ according to the formula, the odds ratio of choosing to travel during holidays and using the "Railway + Subway" intermodal mode is $e^{9.745}$.

From the results, it can be seen that for the passengers with moderate income who occasionally travel and expect the total waiting time to be within 10 to 15 minutes, the probability of traveling on holidays and choosing the "Railway + Subway" intermodal mode is higher than that of choosing the "Railway + Online car-hailing" intermodal mode.

When reducing the combined ticket price (i.e., $X_5 = 1$), the odds ratio of the same traveler choosing the same time and intermodal mode is $e^{26.185}$.

When implementing a combined channel to reduce transfer waiting time (i.e., $X_7 = 2$), the odds ratio of the same traveler choosing the same time and intermodal mode is $e^{9.829}$.

Through comparison, it can be observed that improving either the ticket price or the transfer waiting time in the combined travel process can increase the probability of choosing the "Railway + Subway" intermodal mode.

5. Conclusion

This paper, based on utility maximization theory, establishes a nested Logit model. Through parameter calibration, it identifies the sensitive factors for passengers choosing different modes and analyzes the possibility of intermodal transitions by changing the magnitude of these sensitive factors. The specific conclusions are as follows: (1) According to the calibrated model results, passengers traveling within the metropolitan area are highly sensitive to intermodal fares, while those traveling during holidays are more concerned about the total travel time. (2) Based on the results of probability ratio, optimizing the security check frequency in the "railway+" through-operation process, reducing the total transfer waiting time, and providing discounts on through fares can effectively guide passengers to switch through-operation modes. This has significant implications for improving service quality and optimizing the overall transportation structure.

Building upon this study, passengers can be categorized based on travel preferences into economic, leisure-oriented, efficiency-focused travelers, etc. This allows for an analysis of the distinct characteristics of urban transit mode selection behaviors among different passenger types. However, a limitation of this study is the lack of consideration for the departure and arrival cities in the analysis of passengers' choice of travel mode.

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