

# Proportional Estimation Method of Urban Rail Passenger Flow Transfer Path Selection Based on IC Card Data

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**Abstract:** Based on the analysis of the influencing factors of urban rail transit passenger flow transfer path selection behavior and the components of travel time, a method of estimating the proportion of urban rail transit passenger flow transfer path selection based on IC card data is proposed. Firstly, the research determines the shortest interchange path algorithm as Dijkstra algorithm and the graph-based depth-first search algorithm as the effective interchange path search algorithm; analyzes the factors influencing the passenger flow interchange path selection behavior as three types of travel time, interchange cost and road network familiarity; constructs the generalized cost function of effective interchange path selection by combining travel time and interchange cost; establishes the passenger flow probability selection model by combining road network familiarity. To eliminate the influence of absolute difference of utility on the probability of path selection in the polynomial logit model, the path probability selection model is improved with the help of minimum travel cost; Bayesian estimation is used to compare the passenger travel time with the theoretical travel time to identify the closest effective interchange path, and the joint distribution probability is used to calibrate the probability selection model in terms of travel time and interchange cost. The coefficient, coefficient of interchange passenger flow, penalty coefficient of interchange number, familiarity of road network and other related parameters are combined with the joint distribution probability to calibrate the probability of selection of different effective interchange paths.

**Keywords:** Urban rail transportation, Route selection ratio, Dijkstra algorithm, IC card data, Parameter estimation.

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## 1. Introduction

The percentage of passenger traffic routes of urban subway (hereinafter referred to as urban rail) is used as the basis for line flow distribution. At present, the number distribution methods of urban rail in China and abroad mostly use the multi-path proportional division technology. The number of routes is generally set using the Logit model based on various forms of impedance functions (mileage, time) [1], and the coefficients in this model are determined by a large number of manual data. Because the measurement cost is relatively expensive, the data reliability is difficult to ensure. Both domestic and foreign urban rail use AFC system to record passenger travel information, The system can accurately obtain the location and time of passengers entering and leaving the station.

Mengtian Leng et al. Jang W [3] established a relevant analysis model based on IC card data, identified the transfer points of each passenger in the travel path, analyzed the possible travel transfer modes between the passenger's departure and destination, and discussed the relationship between relevant data and traffic planning. Tianyou Liu et al. Zheng Yajing and Zhao Ji et al. [5] obtained the effective transfer path of transfer passenger flow through IC card data, thus strengthening the connection between OD combination and transfer passenger flow, and obtaining more accurate transfer passenger flow data. Based on the IC card data, Chen Yanyan et al. [6] used the passenger travel OD to match the IC card data of passenger travel, combined with the relationship between the passenger travel time in peak hours and the passenger travel time in non-peak hours, provided a calculation formula for the waiting time of passengers traveling in peak hours based on the IC card big data, and

studied the characteristics of the waiting time of passengers going out. Zhang Yimu et al. [7] proposed a calculation method of getting on and off station points based on time matching according to the IC card of urban subway, BRT and bus networks, obtained the travel chain of transfer passenger flow, and discussed the impact of matching threshold on the overall matching accuracy. Liu Jianfeng and other [8] people studied the main influencing factors of passenger route selection of urban rail transit, and verified the main influencing factors through actual survey data. Lin Zhan et al. [9] gave a traffic distribution model of urban rail transit network based on the improved Logit model, and studied and proved the model and method. Sun Yan and other [10] people tested the rationality of the model in terms of goodness of fit and expected results according to the characteristics of travelers.

Based on the IC card data and Bayesian estimation, this paper proposes an estimation method of the proportion of urban rail passenger flow transfer route selection based on the IC card data, which provides a new idea for the determination of passenger flow transfer.

## 2. Influencing Factors of Rail Passenger Flow Transfer Route Selection Behavior

The formation of rail transit network structure, when passenger flow chooses an effective transfer path, it is affected by various factors such as travel time, transfer cost, road network familiarity and so on. Therefore, the selection of effective transfer path by passenger flow is often a comprehensive decision result after comprehensively considering the above factors.

## 2.1. Travel time

Travel time refers to the total time spent by the passenger flow after selecting an effective transfer path to enter the starting station from the swiping card, and then swiping the card to exit the station after arriving at the destination station. Travel time is usually composed of two parts: the time for the passenger flow to take the bus and the waiting time.

The travel time of transfer passenger flow at the starting and ending points can be expressed as:

$$T_{ij}^i = \begin{cases} t_{ij}^i \\ t_{ij}^i + s_{ij}^i \end{cases} \quad (1)$$

Station  $i$  is the starting point or destination station

Where:

—The travel time of the vehicle at the station between the beginning and the end of the passenger flow;

—The dwell time of the vehicle at the station between the beginning and the end of the passenger flow.

The travel time of passenger flow on an effective transfer path in the set of effective transfer paths can be expressed as:

$$\bar{T}_k^l = \sum T_{ij}^l \quad (i, j) \in K \quad (2)$$

Where:

—A collection of valid transfer paths.

The waiting time refers to the time from the arrival of the passenger flow at the departure platform to the boarding time. The waiting time of transfer passenger flow occurs at the starting station or transfer station. The waiting time is positively correlated with the train operation schedule. According to the field survey, the waiting time of transfer passenger flow is usually 0.5 of the departure interval of the line.

## 2.2. Transfer fee

The main difference in transfer costs during the transfer process is the number of transfer times and the walking time of passenger flow in the transfer channel. Therefore, the transfer costs in different directions in the transfer station can be expressed as the walking time of passenger flow.

Transfer fee:

$$w_i^{l,m} = \phi \sqrt{V_i^{l,m}} \quad (3)$$

Where:

—Transfer station;

—Transfer from line to line;

—Walk time from line transfer to line;

—Transfer passenger flow adjustment coefficient.

The total transfer cost can be obtained by considering the waiting time of the passenger flow during the transfer:

$$E_i^{l,m} = a \left( w_i^{l,m} + 0.5 * f_m \right) \quad (4)$$

Where:

—Change passenger flow coefficient value;

—Departure interval.

When an effective transfer path of passenger flow requires multiple transfers, the impact of transfer times on transfer costs should be considered, and the penalty adjustment coefficient of transfer times of passenger flow should be added. And the more transfer times, the greater the penalty coefficient. At this time, the transfer fee can be expressed as:

$$\bar{E}_i^{l,m} = a * (e_{i,k})^\beta * (w_i^{l,m} + 0.5 * f_m) \quad (5)$$

Where:

—When the passenger flow selects an effective transfer path in the set of effective transfer paths, the cumulative number of transfers at the transfer station;

—Penalty adjustment coefficient for transfer times of passenger flow.

## 2.3. Familiarity with road network

Road network familiarity is an important factor for passenger flow to choose an effective transfer path. Generally, the road network familiarity of passenger flow can be summarized by IC card number or issuing relevant questionnaires. The more familiar the transfer passenger flow is with the road network, the more feasible it is to choose the shortest transfer path. When the passenger flow is not very familiar with the road network, they often choose the route with less transfer times or shorter mileage, but the travel time of this route is not necessarily the least. Therefore, when the change passenger flow has different familiarity with the road network, it will not only affect the choice of the shortest transfer path for the change passenger flow, but also affect the distribution of the change passenger flow on the road network.

## 3. Construction of Effective Transfer Route Selection Model for Rail Passenger Flow

### 3.1. Definition of effective transfer path of passenger flow

With the continuous acceleration of the rail transit network process, passenger flow travel from the starting point to the destination is often not a direct route for passengers, and generally requires transfer to arrive, which is the fastest time and the least cost. There are generally multiple travel paths to choose between the starting point and the ending point of the rail transit network. Therefore, the transfer paths for passenger flow in the rail network are called effective transfer paths. The effective transfer path has the following three characteristics:

1) There are multiple effective transfer paths between the starting point and the ending point. Because the stations covered by each effective transfer path are different, the effective transfer paths formed are also different, which are called different effective transfer paths;

2) The passenger flow will only take the same station on the same route and in the same direction once during the trip;

3) When the passenger flow chooses different effective transfer routes, there will be no significant difference in travel

time.

In order to determine the effective transfer path of passenger flow, [7] determine the effective transfer path of passenger flow according to the travel cost, threshold correction parameters, and the transfer times of passenger flow under different effective transfer paths. The judgment formula is as follows (Formula 6-7):

$$b_k \leq 0.466 \cdot \ln(b_{\min} + 1) + b_{\min} \quad (6)$$

$$N_k \leq N_{\max} \quad (7)$$

Where:

—The travel cost of the first effective transfer path in the set of effective transfer paths formed by the passenger flow at the start and end points;

—The minimum travel cost of the shortest effective transfer path in the set of effective transfer paths formed by the passenger flow at the start and end points;

—The number of transfers required for the first effective transfer path in the set of effective transfer paths formed by the passenger flow at the start and end points;

—The maximum transfer times of all effective transfer paths in the set of effective transfer paths formed by the passenger flow at the starting point and the ending point, usually

Generalized cost model for efficient transfer path selection

For an OD pair in the passenger flow, the total cost of the passenger flow on an effective transfer path in the set of effective transfer paths can be expressed as:

$$D_k = C_k + \varepsilon_k \quad (k \in K) \quad (8)$$

Where:

—Defined expenses;

—Random error term;

—A collection of valid transfer paths.

In combination with travel time and transfer cost, the cost function of the shortest transfer path of passenger flow is expressed as:

$$\begin{aligned} D_k &= C_k + \varepsilon_k = \gamma \sum_l \bar{T}_k^l + \sum_i \bar{E}_i^{l,m} + \varepsilon_k \\ &= \gamma \sum_l \sum_{ij} T_{ij}^l \cdot \delta_{ij,k} + \end{aligned} \quad (9)$$

$$\begin{aligned} &\sum_i a * (e_{i,k})^\beta * (w_i^{l,m} + 0.5 * f_m) \cdot \varphi_{i,k} \cdot \eta_{l,k} \cdot \eta_{m,k} + \varepsilon_k \\ &\delta_{ij,k}, \varphi_{i,k}, \eta_{l,k}, \eta_{m,k} \end{aligned} \quad (10)$$

Where:

—Ride time coefficient;

—The relationship between the starting and ending points and the shortest transfer path;

—The relationship between the transfer station and the shortest transfer path;

, - the relationship between the line and the shortest transfer path.

### 3.2. Probability selection model of effective transfer route of passenger flow

The probability that the transfer passenger flow selects an effective transfer route in the set of effective transfer routes during a trip is the lowest probability that the total cost of the effective transfer route in the set of effective transfer routes. Different effective transfer paths correspond to different selection probabilities. At present, when calculating the probability of effective transfer path selection, the most commonly used is the polynomial logit model (MNL model). Assuming that the random error term in the cost function is independently and identically distributed and follows the Gumbel distribution with a mean of 0, according to the distribution function and density function of the Gumbel distribution, the probability of passenger flow selecting the effective transfer path in the set of effective transfer paths can be expressed as:

$$p_k = \frac{\exp(-\theta C_k)}{\sum_{p \in K} \exp(-\theta C_p)} \quad k \in K \dots \quad (11)$$

Where:

—Constant, whose value represents the loyalty of passenger flow to an effective transfer path. The greater the value, the greater the probability of passenger flow choosing the effective transfer path. Usually, this value represents the familiarity of passenger flow with the traffic network.

The choice probability of passenger flow for each effective transfer path calculated by the polynomial model is based on the utility absolute difference between passenger flow and the travel cost of each effective transfer path, which has an impact on the determination of subsequent transfer passenger flow. Therefore, the minimum travel cost is used to improve formula (11). The probability of the first effective transfer path selected in the improved polynomial model effective transfer path set can be expressed as:

$$p_k = \frac{\exp(-\theta C_k / C_{\min})}{\sum_{p \in K} \exp(-\theta C_p / C_{\min})} \quad k \in K \quad (12)$$

Where:

—The minimum travel cost in the set of effective transfer paths.

## 4. Estimation of Effective Transfer Path Selection Proportion

### 4.1. Data source

The IC card data of the networked operation rail station generally comes from the urban rail transit operation company with a certain level of networking. The information recorded by the IC card data of each city is almost the same. Take the IC card data of Chongqing rail transit for example, the IC card data contents are: card number (ticket\_id), card

type (ticket\_type), entry station number (ent\_station\_id), entry time (ent\_txn\_date\_time), exit station number (exit\_station\_id) Outbound time (exit\_txn\_date\_time). Where ticket\_Type refers to the type of transaction card. The main types are: 0 Livable ordinary card, 05 Livable monthly ticket card, 15 Livable employee card, 14 Livable senior citizen card, 03 Livable student card, 77 Livable senior citizen time card, 20 Love discount card, 98 rail one-way ticket.

## 4.2. Parameter calibration of effective transfer path probability selection model based on Bayesian estimation

Bayesian estimation method is based on the IC card data, which contains the information of the inbound and outbound stations of the passenger flow, the travel time, and so on. It compares the travel time with the theoretical travel time of the effective transfer path calculated by the model, identifies the closest effective transfer path, and determines the effective transfer path of the passenger flow. The cost of this method is small and convenient. Therefore, this study uses Bayesian estimation method to calibrate the relevant parameters in the effective transfer path probability selection model.

The set of effective transfer routes includes the information of inbound and outbound stops and travel time of transfer passenger flow; The relevant parameter set of the effective transfer path probability selection model includes the theoretical travel time of different effective transfer paths, the relevant parameters of the generalized cost model of effective transfer path selection, the interval operation data set of the rail transit network (train interval operation time, train arrival and stop time, train departure interval and passenger flow walking time in the transfer channel, etc.), the time allowable deviation coefficient, and the travel time coefficient, Coefficient value of transfer passenger flow and penalty adjustment coefficient of transfer times of transfer passenger flow.

Because the above parameters have the original distribution before sampling, the edge probability of the joint distribution is usually expressed in the form of normal distribution; Is the conditional probability in the effective transfer path set given the values of the relevant parameter set of the effective transfer path probability selection model; Is the conditional distribution of each parameter, and the above probability is expressed as:

$$\pi(C, \sigma, \gamma, \alpha, \beta | \Gamma) \propto p(\Gamma | C, \sigma, \gamma, \alpha, \beta) \pi(C, \sigma, \gamma, \alpha, \beta) \quad (13)$$

Assuming that the parameters in formula (13) are independent of each other, the joint edge distribution can be converted into:

$$\pi(C, \sigma, \gamma, \alpha, \beta) = \pi(C) \pi(\sigma) \pi(\gamma) \pi(\alpha) \pi(\beta) \quad (14)$$

Given each parameter value, the probability of occurrence of an effective transfer path is equal to the likelihood function of all unknown parameter values when the effective transfer path is known, namely:

$$p(\Gamma | C, \sigma, \gamma, \alpha, \beta) = L(C, \sigma, \gamma, \alpha, \beta | \Gamma) \quad (15)$$

The passenger flow under different effective transfer routes is calculated according to the selection probability of effective transfer routes, and the likelihood function can be rewritten as follows:

$$L(C, \sigma, \gamma, \alpha, \beta | \Gamma) = \prod_{w \in W} p(\Gamma_w | C, \sigma, \gamma, \alpha, \beta) \quad (16)$$

Where:

—— All pairs;

—— A pair;

—— The probability that an effective transfer path is selected when each parameter value is given

—— The likelihood function of all unknown parameter values when the effective transfer path is known.

Different effective transfer paths correspond to different travel costs of passenger flow, and only one effective transfer path can be selected for one trip of passenger flow. Therefore, the sample probability generated when the passenger flow chooses an effective transfer path is the sum of the probabilities of each effective transfer path between the start and end points, which can be expressed by the total probability formula:

$$p_w(\Gamma | C, \sigma, \gamma, \alpha, \beta) = \sum_{r \in R_{ij}} h(\Gamma | C, \sigma, \gamma, \alpha, \beta) f_w(r | C, \sigma, \gamma, \alpha, \beta) \quad (17)$$

Where:

—— The sum of the probabilities of the corresponding pairs when an effective transfer path is selected;

—— The corresponding probability of selecting effective transfer paths in the set of effective transfer paths;

—— The probability of passenger flow generating corresponding travel time samples on the effective transfer path.

The relevant data of passenger flow in the transfer channel, such as walking time, inbound and outbound time, travel time, etc., are obtained through field survey. The above survey data are basically subject to normal distribution, and the sum of the data should also conform to normal distribution. The theoretical travel time distribution of the effective transfer path is obtained by integrating the mean and variance of each survey time:

$$t | r, C, \sigma, \gamma, \alpha, \beta \sim N(\sum \bar{E} + \sum c + \sum O_r + \sum D_r, \sum \sigma + \sigma_o^2 + \sigma_d^2) \quad (18)$$

Match the travel time of passenger flow with the theoretical travel time:

$$h(t | C, \sigma, \gamma, \alpha, \beta) = \frac{1}{\sqrt{2\pi \sum \sigma + \sigma_o^2 + \sigma_d^2}} \exp\left\{-\frac{(t - (\sum \bar{E} + \sum c + \sum O_r + \sum D_r))^2}{2(\sum \sigma + \sigma_o^2 + \sigma_d^2)}\right\} \quad (19)$$

Use Logit model to calculate the probability of effective transfer path being selected:

$$f_w(r | C, \sigma, \gamma, \alpha, \beta) = p_k = \frac{\exp(-\theta C_k / C_{\min})}{\sum_{p \in K} \exp(-\theta C_k / C_{\min})} \quad (20)$$

The cumulative probability of the pair is:

$$p_w(\Gamma|C, \sigma, \gamma, \alpha, \beta) = \prod_{\Gamma \in T_w} p_w(\Gamma|C, \sigma, \gamma, \alpha, \beta) \quad (21)$$

Namely:

$$p(\Gamma_w|C, \sigma, \gamma, \alpha, \beta) = \prod_{\Gamma \in T_w} \left( \sum_{r \in R_w} h(\Gamma|C, \sigma, \gamma, \alpha, \beta) f_w(r|C, \sigma, \gamma, \alpha, \beta) \right) \quad (22)$$

Expand to all pairs in the whole network:

$$p(\Gamma|C, \sigma, \gamma, \alpha, \beta) = \prod_{w \in W} \left( \prod_{\Gamma \in T_w} \left( \sum_{r \in R_w} h(\Gamma|C, \sigma, \gamma, \alpha, \beta) f_w(r|C, \sigma, \gamma, \alpha, \beta) \right) \right) \quad (23)$$

The conditional probability of each parameter is obtained according to the parameter proportion relationship:

$$\pi(C, \sigma, \gamma, \alpha, \beta|\Gamma) \propto \prod_{w \in W} \left( \prod_{\Gamma \in T_w} \left( \sum_{r \in R_w} h(\Gamma|C, \sigma, \gamma, \alpha, \beta) f_w(r|C, \sigma, \gamma, \alpha, \beta) \right) \right) \times \pi(C) \pi(\sigma) \pi(\gamma) \pi(\alpha) \pi(\beta) \quad (24)$$

The multiple parameters in the effective transfer path selection model can be updated and iterated in turn during estimation, including the operation time of each section. Assume that there are a total of parameters and time allowable deviation coefficient, travel time coefficient, coefficient value of transfer passenger flow, penalty adjustment coefficient of transfer times of transfer passenger flow, and road network familiarity parameter, which are converted into multi-dimensional vector and expressed as:

$$X = (C, \sigma, \gamma, \alpha, \beta) = (x_1, x_2, x_3, A, x_{m+5}) \quad (25)$$

The parameter value for the second time is:

$$X^{(t)} = (x_1^{(t)}, x_2^{(t)}, x_3^{(t)}, A, x_{m+5}^{(t)}) \quad (26)$$

Multiple parameters are updated successively in the iteration. When updated, all variables before the second variable are updated. The joint distribution probability can be expressed as:

$$\begin{aligned} \pi'(x_i^*) &= \pi(x_1^{(t+1)}, x_2^{(t+1)}, x_3^{(t+1)}, A, x_i^*, x_{m+5}^{(t)} | T) \\ \pi'(x_i^*) &= \frac{P(T | x_1^{(t+1)}, x_2^{(t+1)}, x_3^{(t+1)}, A, x_i^{(t)}, x_{m+5}^{(t)}) \pi(x_1^{(t+1)}) \pi(x_i^{(t)}) \pi(x_{m+5}^{(t)})}{P(T)} \end{aligned} \quad (27)$$

The joint distribution probability of parameters before updating can be expressed as:

$$\begin{aligned} \pi'(x_i^{(t)}) &= \frac{P(T | x_1^{(t+1)}, x_2^{(t+1)}, x_3^{(t+1)}, A, x_i^{(t)}, x_{m+5}^{(t)}) \pi(x_1^{(t+1)}) \pi(x_i^{(t)}) \pi(x_{m+5}^{(t)})}{P(T)} \end{aligned} \quad (28)$$

The acceptance probability of dividing formula (27) and formula (28) is:

$$\frac{\pi'(x_i^*)}{\pi'(x_i^{(t)})} = \frac{P(T | x_1^{(t+1)}, x_2^{(t+1)}, x_3^{(t+1)}, A, x_i^*, x_{m+5}^{(t)}) \pi(x_i^*)}{P(T | x_1^{(t+1)}, x_2^{(t+1)}, x_3^{(t+1)}, A, x_i^{(t)}, x_{m+5}^{(t)}) \pi(x_i^{(t)})} \quad (29)$$

## 5. Example Verification

Figure 2 shows the simplified road network structure, in which the six nodes represent the rail transit stations in the simplified road network structure, the four nodes represent the rail transit transfer stations, and the common rail stations. The numbers on the connecting stations represent the time required between the two stations. It is assumed that the departure and destination of passenger flow are the same, and the transfer time is the same throughout the transfer process, and the maximum number of transfers allowed is 2. Dijkstra algorithm is used to search the shortest transfer path between the two, and the graph-based depth-first search algorithm is used to search the effective transfer path between the two. There are 3 valid paths between the ODs.

The sample parameter calibration refers to Bayesian estimation method, and is solved by MCMC method. The effective path selection results are shown in Table 1, and the sample parameter assignment is shown in Table 2:

It can be seen from Table 3 that when the passenger flow reaches the balance and the train runs according to the diagram

When driving, the proportion deviation of the effective transfer route of passenger flow estimated by the method in this paper is relatively low, which can meet the passenger demand.

## 6. Conclusion

Based on the IC card data, this paper uses Bayesian estimation to compare the travel time of passenger flow with the theoretical travel time to identify the closest effective transfer path, and uses the joint distribution probability to calibrate the relevant parameters in the path probability selection model, such as the travel time coefficient, the value of the transfer passenger flow coefficient, the penalty coefficient of the transfer times, and the familiarity of the road network; The MCMC algorithm is used to solve the theoretical solution of unknown parameters to determine the probability of different effective transfer paths being selected. The results show that the deviation of parameter estimation results of this method is less than 1%.

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