Transfer Penalty of Public Transport

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Abstract: The public transport accounts for a large proportion in urban traffic, however, generally, travelers are unable to complete the trip with a single form of public transport. With the rapid development of the intelligent transportation and the application of big data, the accuracy of the generalized traffic time is more and more important to the passenger flow forecasting and service level optimization of public transportation system. An improved Logit model based on the theory of principal component analysis is established to calibrate the transfer penalty, which can cover the correlation among the variables. The calibration results show that the improved model is more accurate than the traditional Logit model, the conclusion is more reliable. In this paper, when the total time of the options is similar, if taking the different number of bus line into consideration, the transfer penalty is 12.13 minutes when the number of bus line is one, while it's 9.93 minutes when the number of bus line is two; if taking the same number of bus line into consideration, when there is only one bus line, the transfer penalty is 10.13 minutes, while it's 7.92 minutes when the number of bus line is two.

1. Introduction

With the implement of bus priority policy in China, public transport has been vigorously developed in recent years; public transport plays a more and more important role in urban traffic, but travelers rarely can directly reach destinations, most time the travel is the combination of subway and bus. More and more accurate generalized travel time is necessary because of the rapid development of intelligent transportation, the application of traffic big data, the more accurate passenger flow forecast and the optimization of service level of public transportation system. However, the researches on transfer penalty are not many, so the research on the transfer penalty of public transport is particularly important.

The existing researches on the application of Logit model in traffic mainly focus on the mode choice and the calculation of transfer penalty. The utility theory in economics were introduced into the field of transportation in the 1970s and the mode choice from the perspective of disaggregation is studied[1](Ben-Akiva *et al.*). To analyze the influence of the new subway on the choice of traffic mode, a NL model was established based on the RP/SP survey[2] (Cherchi *et al.*). Considering the individual choice preference, a Mixed Logit model was established to analyze the choice behavior of traffic mode[3] (McFadden *et al.*). To calculate the transfer penalty values on different transfer modes, a Logit model was established based on the New York data[4] (Liu *et al.*). A path preference Logit model was established based on the geographic information system technology and it was

applied to the subway transport system in Boston to improve the estimated accuracy of the transfer penalty[5] (Guo Z *et al.*).

To calculate the transfer penalty value, a Mixed Logit model was established based on the smart card data of Seoul Korea[6] (Yoo G.S). A binary Logit model was established to calculate the transfer penalty values of different transfer modes based on the survey data of different transfer situations in the multi-mode public transport network of the urban rail transit and bus in Shanghai[7] (Wang *et al.*). Bus transfer behaviors and characteristics in Melbourne, Australia were examined based on origin-destination survey data set[8] (Currie *et al.*).

What should be pointed out is that the establishment of MNL model, NL model and Mixed Logit model need to ensure that there is no linear relationship among the variables. However, there is always linear relationship among the variables to some degree, and the linear relationship may influence the reliability of the model. In order to overcome the correlation among variables, an improved Logit model based on the theory of principal component analysis is established. Also, previous studies about transfer penalty of public transport have never taken the bus line number into consideration. Based on the survey data of bus transfer in Xi'an, the bus transfer penalty value with different number of bus line is calculated.

2. Transfer Penalty

Travelers usually can't complete the whole trip only using bus or subway, transfer is always necessary. When choosing transfer mode, walking time, waiting time, on-vehicle time and the number of optional bus line are important factors. The transfer penalty value is an extra psychological burden that travelers realize and generate in the transfer phase, but it does not belong to the travel time. It does not include the walking transfer time, the influence caused by the comfort, security or other objective environment, and it is a specific value.

The definition of transfer penalty will have some differences because of the researches, generally, the transfer penalty is defined as travelers' perception of transfer time (including transfer walking time and transfer waiting time) that is relative to the on-vehicle time. Assuming traveler n's perception of 6 minutes on-vehicle time is equal to the perception of 1 minute transfer time, then for traveler n, the transfer time is 6 minutes on-vehicle time. Therefore, the transfer penalty can be defined as the ratio of the coefficient of transfer time to the coefficient of on-vehicle time in the utility function. The mathematical expression is shown as equation (1):

$$TP = \alpha_1 / \alpha_2 \tag{1}$$

Where TP represents transfer penalty, α_1 represents the coefficient of transfer time in the utility function, α_2 represents the coefficient of on-vehicle time in the utility function.

Previous studies on transfer penalty value have different results[9-16](Algers *et al*, Hunt, Liu *et al*, Wardman *et al*, Guo *et al*, Sun, Douglas *et al*, Gong *et al*): one class focused on 2.5 to 4 minutes; another class focused on 8 to 10 minutes; some studies held that transfer penalty value is 1.8 to 3 times of the total transfer time; and a small part of the studies held that the transfer penalty value is larger than 30 minutes. This paper proposes an improved Logit model based on the theory of principal component analysis, further, taking the bus line number into account, the transfer penalty is calculated.

3. Methodology

3.1. Basic Model

Pursuing the maximum utility is a significant principle of disaggregate model, in which travelers

are supposed to know all the information about alternatives and follow the compensation theory[17] (Guan). The utility function U_{in} of traveler n for mode *i* is shown in equation (2):

$$U_{in} = V_{in} + \varepsilon_{in} \tag{2}$$

Where V_{in} represents fixed utility; ε_{in} represents a random term.

Assuming the choice set for traveler n is A_n, and the utility of mode j is U_{jn}, then the condition that traveler n selects mode *i* from A_n is shown in equation (3):

$$U_{in} > U_{jn}, i \neq j, j \in A_n \tag{3}$$

The probability that mode *i* is selected is shown in equation (4):

$$P_{in} = \frac{e^{V_{in}}}{\sum_{j \in A_n} e^{V_{jn}}} = \frac{e^{\alpha_i + \beta_i X_i}}{\sum_{j \in A_n} e^{\alpha_j + \beta_j X_j}}, (i = A_n) \tag{4}$$

Where P_{in} represents the probability that traveler n chooses mode *i*; α_i represents the constant, X_i represents the attribute; β_i represents the coefficient of attribute X_i.

3.2. Principal Component Analysis

Principal component analysis is a data dimension reduction algorithm, and also a feature extraction method[18](Jollife). It improves the anti-jamming capability of the raw data and reorganizes the original indicators with a certain correlation to form a new set of indicators that are irrelevant to each other. These new indicators are linear combination of original indicators.

The main idea of principal component analysis is to express the relationship using the selected linear combination variance. The larger the $Var(F_1)$ is, the more information F_1 contains. So, F_1 that is called the first principal component should have the largest variance. If F_1 cannot represent the original indicators, the second linear combination F_2 should be considered, also, the existing information in the F_1 should be removed in F_2, thus data redundancy can effectively be reduced and original information can be better reflected, namely $Cov(F_1, F_2) = 0$ should be satisfied. F_2 is called the second principal component, and based on this method, more principal components can be constructed until original indicators can be represented. Thus, the resulting principal components are not only irrelevant, but their variance decreases in turn.

Assuming that there are n samples with p variables to be observed in data set X, the mathematical expression of the principal component analysis is shown in equation (5).

$$X = \begin{bmatrix} x_{11} & \vdots & x_{1p} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{np} \end{bmatrix} = \begin{bmatrix} x_1, x_2, \cdots\cdots x_p \end{bmatrix} \tag{5}$$

The principal component analysis is to combine the original p variables $x_1, x_2, \cdots\cdots x_p$, and the formed p new variables are shown in equation (6).

$$\begin{cases} F_1 = w_{11}x_1 + w_{21}x_2 + \cdots + w_{p1}x_p \\ F_2 = w_{12}x_1 + w_{22}x_2 + \cdots + w_{p2}x_p \\ \qquad\qquad \cdots \\ F_p = w_{1p}x_1 + w_{2p}x_2 + \cdots + w_{pp}x_p \end{cases} \tag{6}$$

The coefficient w_{ij} in the above models satisfies the following three conditions: F_i and F_j $(i \neq j; j = 1, 2, \ldots\ldots p)$ are not related; The variance of $F_1, F_2, F_3, \cdots\cdots, F_p$ decreases in turn; $w_{k1}^2 + w_{k2}^2 + \cdots + w_{kp}^2 = 1$, $k = 1, 2, \ldots\ldots, p$.

The new obtained random variables are irrelevant to each other and the variance decreases sequentially when the above three conditions are satisfied. If the former k principal components contain 85% and more of the total variance, it indicates that the former k principal components can retain the original variable information to the utmost.

3.3. Improved Model

First, the original i variables $X_1, X_2, \cdots, X_n$ were analyzed using the principal component analysis, and then the principal components $F_1, F_2, \cdots, F_K$ were filtered when the cumulative contribution rate reaches 85% and more of total variance. The correlation coefficients among the principal components are zero. Finally, the improved Logit model is established with the resulting principal components, and the expression is shown in equation (7).

$$P_{in} = \frac{e^{V_{in}}}{\sum_{j \in A_n} e^{V_{jn}}} = \frac{e^{\alpha_i + \beta_i F_i}}{\sum_{j \in A_n} e^{\alpha_j + \beta_j F_j}}, (i = A_n) \tag{7}$$

4. Data Collection

Personal attributes and mode attributes are selected to design the questionnaire, and personal attributes and levels are shown in Table 1.

Table 1 Personal attributes

Attribute category	Attributes	Attribute levels
Personal attributes	Gender	Male
		Female
	Age	Age of 18—30
		Age of 31—40
		Age of 41—50
		Age above 50
	Education level	Under high school
		University
		Master and above

Mode attributes are: subway travel time, bus travel time, transfer walking time and transfer waiting time. If the bus line number is different, the attribute values will be different, so two different values are used in the level setting.

In this paper, SP survey was adopted to obtain the data, which is an investigation under the condition of hypothetical scenario. Pre-determined influence factors and levels are combined into different scenarios for travelers to compare, order or make discrete choice, and the choice behaviors that respondents prefer to adopt are obtained.

To avoid the impact that the total travel time of different transfer programs have on travelers' choices, the total travel time is set to the similar value. Simultaneously, the balanced design method is introduced to ensure the survey accuracy and avoid the long-term response. The final scenario combinations are shown in Table 2.

Table 2 Scenario combinations

Scenarios	Choice	Bus line number	Subway travel time	Walking time	Waiting time	Bus travel time
Scenario1	A	1	10	6	11	29
	B	2	25	9	4	13
Scenario2	A	1	15	12	5	23
	B	2	20	2	10	18
Scenario 3	A	1	20	3	14	17
	B	2	15	12	1	23
Scenario 4	A	1	25	9	8	11
	B	2	10	6	7	28

When the optional bus line number is same: bus line number is one and two, the transfer penalties are calculated, and the scenario combination designs are shown in Table 3 and Table 4 respectively.

Table 3 Scenario combinations with bus line number is one

Scenarios	Choice	Bus line number	Subway travel time	Walking time	Waiting time	Bus travel time
Scenario 1	A	1	10	6	11	29
	B	1	25	9	8	11
Scenario 2	A	1	15	12	5	23
	B	1	20	2	14	17
Scenario 3	A	1	20	3	14	17
	B	1	15	12	5	23
Scenario 4	A	1	25	9	8	11
	B	1	10	6	11	29

Table 4 Scenario combinations with bus line number is two

Scenarios	Choice	Bus line number	Subway travel time	Walking time	Waiting time	Bus travel time
Scenario 1	A	2	10	6	7	28
	B	2	25	9	4	13
Scenario 2	A	2	15	12	1	23
	B	2	20	2	10	18
Scenario 3	A	2	20	3	10	18
	B	2	15	12	1	23
Scenario 4	A	2	25	9	4	13
	B	2	10	6	7	28

In this survey 350 persons were asked and 80 percent of the data is valid. Because there are three scenario combinations and in each scenario combination there are four scenarios, 1120 valid data was obtained for each scenario combination.

5. Result Analysis

The traditional Logit model and the improved Logit model are established based on the 1120 valid data taking the different number of bus line into consideration. The calibration results of the

traditional Logit model are shown in Table 5.

Table 5 Calibration results of traditional Logit model

Attributes	Calibration coefficient (t test)
Constant	-1.5223(-3.5106)
Age of 31-40	0.1123(3.0126)
On-vehicle time	-0.1303(-2.0359)
Waiting time	-0.1626(-3.1327)
Walking time	-0.1808(-5.2936)
Bus line number	0.5726(2.6537)
ρ^2	0.2031

The calibration results show that the significant factors are age of 31-40, on-vehicle time, walking time, waiting time and the number of optional bus line number.

The principal component analysis of one transfer bus number is carried out except for the attribute of bus number. The results and the principal component tables are shown in Table 6, Table 7 respectively.

Table 6 Results of the principal component analysis

Component	Initial eigenvalue			Extraction factor		
	Sum	Variance %	Contribution rate%	Sum	Variance %	Contribution rate%
1	2.001	16.677	16.677	2.001	16.677	16.677
2	2.000	16.668	33.345	2.000	16.668	33.345
3	1.893	15.774	49.119	1.893	15.774	49.119
4	1.446	12.047	61.166	1.446	12.047	61.166
5	1.421	11.838	73.004	1.421	11.838	73.004
6	1.184	9.871	82.874	1.184	9.871	82.874
7	1.015	8.462	91.336	1.015	8.462	91.336
8	0.913	7.612	98.948			
9	0.126	1.052	100.000			

Table 7 Principal component table with bus number is one

Attributes	Principal component						
	1	2	3	4	5	6	7
Gender	0.009	-0.001	-0.055	0.079	0.228	0.070	0.629
Age of 18—30	-0.005	-0.015	-0.133	-0.531	-0.286	0.067	-0.134
Age of 31—40	-0.002	0.004	-0.003	0.079	0.651	-0.103	-0.278
Age of 41—50	0.004	0.003	0.112	0.346	-0.315	-0.520	0.298
Age above 50	0.005	0.008	0.002	0.213	-0.083	0.716	0.272
Under high school	0.010	0.038	0.400	0.194	-0.114	0.163	-0.367
University	-0.016	-0.055	-0.510	0.144	-0.027	-0.058	-0.024
Master and above	0.010	0.034	0.261	-0.417	0.164	-0.102	0.444
Subway travel time	-0.362	-0.032	-0.023	-0.002	-0.007	-0.008	-0.012
Waiting time	-0.344	-0.162	-0.013	-0.003	-0.004	-0.004	-0.003
Walking time	-0.324	-0.172	-0.014	-0.004	-0.005	-0.004	-0.003
Bus travel time	-0.362	-0.032	-0.023	-0.002	-0.007	-0.008	-0.012

The principal component analysis of two transfer bus number is carried out except for the attribute of bus number. The results and the principal component tables are shown in Table 8, Table 9 respectively.

Table 8 Results of the principal component analysis

Component	Initial eigenvalue			Extraction factor		
	Sum	Variance %	Contribution rate%	Sum	Variance %	Contribution rate%
1	2.030	16.913	16.913	2.030	16.913	16.913
2	1.970	16.415	33.328	1.970	16.415	33.328
3	1.893	15.772	49.100	1.893	15.772	49.100
4	1.446	12.047	61.147	1.446	12.047	61.147
5	1.421	11.838	72.985	1.421	11.838	72.985
6	1.184	9.871	82.855	1.184	9.871	82.855
7	1.015	8.462	91.317	1.015	8.462	91.317
8	0.913	7.612	98.929			
9	0.126	1.052	99.981			
10	0.002	0.019	100.000			

Table 9 Principal component table with bus number is two

Attributes	Principal component						
	1	2	3	4	5	6	7
Gender	0.005	0.007	-0.055	0.079	0.228	0.070	0.629
Age of 18—30	-0.013	0	-0.133	-0.531	-0.286	0.067	-0.134
Age of 31—40	0.002	-0.003	-0.003	0.079	0.651	-0.103	-0.278
Age of 41—50	0.003	0.004	0.112	0.346	-0.315	-0.520	0.298
Age above 50	0.009	0	0.003	0.213	-0.083	0.716	0.272
Under high school	0.029	-0.002	0.401	0.194	-0.114	0.163	-0.367
University	-0.044	0.004	-0.512	0.144	-0.027	-0.058	-0.024
Master and above	0.028	-0.003	0.262	-0.417	0.164	0.102	0.444
Subway travel time	-0.481	-0.106	-0.016	-0.002	-0.006	-0.008	-0.012
Waiting time	-0.127	-0.125	-0.014	-0.003	-0.004	-0.004	-0.003
Walking time	-0.137	-0.136	-0.014	-0.002	-0.005	-0.004	-0.002
Bus travel time	-0.481	-0.106	-0.016	-0.002	-0.006	-0.008	-0.012

Based on the principal component table, the principal component data $F_{11}, F_{12}, F_{13}, F_{14}, F_{15}, F_{16}, F_{17}$ of one optional bus line and the principal component data $F_{21}, F_{22}, F_{23}, F_{24}, F_{25}, F_{26}, F_{27}$ of two optional bus line can be obtained by the corresponding deformed survey data. The improved Logit model is established based on the obtained data, and the calibration results of the model are shown in Table 10.

Table 10 Calibration results of the improved Logit model

Attributes	Calibration coefficient (t test)
Constant	-1.8309（2.7532）
Bus line number	0.9219（3.0125）
F_{12}	0.9126（3.3152）
F_{22}	0.9621（2.8532）
F_{13}	6.3127（3.1562）
F_{23}	6.9815（2.9631）
F_{16}	-0.6283（-3.2109）
F_{26}	-0.8523（-2.8732）
ρ^2	0.2952

The comparing results of the significant influencing factor coefficients obtained by the traditional Logit model and the improved Logit model are shown in Table 11.

Table 11 Results comparison

Attributes	Traditional Logit model	Improved Logit model （bus line number is 1）	Improved Logit model （bus line number is 2）
Constant	-1.5223	-2.0548	
Age of 31—40	0.1123	0.0618	0.1231
On-vehicle time	-0.1303	-0.1694	-0.2069
Waiting time	-0.1626	-0.2274	-0.2146
Walking time	-0.1808	-0.2428	-0.2252
Bus line number	0.5726	0.9219	
ρ^2	0.2031	0.2952	

It can be seen that the improved Logit model is more accurate than the traditional Logit model (ρ^2 is larger), and the coefficient of the bus line number in the improved model is higher than the traditional Logit model. It can be concluded that the improved model is more reliable and closer to the actual situation. The results of the two models are standardized on the basis of on-vehicle time, and the results are shown in Table 12.

Table 12 Standardization results comparison

Model	Attributes	Calibration coefficient	Standardization (minute)
Traditional Logit model	On-vehicle time	-0.1303	1.00
	Waiting time	-0.1626	1.25
	Walking time	-0.1808	1.39
	Constant	-1.5223	11.68
Improved Logit model （bus line number is 1）	On-vehicle time	-0.1694	1.00
	Waiting time	-0.2274	1.34
	Walking time	-0.2428	1.43
	Constant	-2.0548	12.13
Improved Logit model （bus line number is 2）	On-vehicle time	-0.2069	1.00
	Waiting time	-0.2146	1.04
	Walking time	-0.2252	1.09
	Constant	-2.0548	9.93

As can be seen from the standardized results, in the traditional Logit model the transfer penalty, transfer penalty of walking time, transfer penalty of waiting time are 11.68 minutes, 1.39 minutes, 1.25 minutes respectively when the number of optional bus line is considered; in the improved Logit model when the bus line number is one, transfer penalty, transfer penalty of walking time, transfer penalty of waiting time are 12.13 minutes, 1.43 minutes, 1.34 minutes respectively; while they are 9.93 minutes, 1.09 minutes, 1.04 minutes respectively when the bus line number is two; moreover, models that consider the different number of optional bus line, the penalty values of them are between values of models that the bus line number is one and two. Also with the increase of bus number, the penalty values reduce.

Similarly, based on the survey data with the bus line number is one and two, the traditional Logit models and improved models are established, the comparing results are shown in Table 13, Table 14 and Table 15,Table 16 respectively.

Table 13 Comparing results with bus line number is one

Attributes	Traditional Logit model (t test)	Improved Logit model (t test)
Constant	-1.7862 (-2.3685)	-1.7026 (-3.0521)
Age of 31-40	0.1059 (2.1863)	0.0853 (1.9702)
On-vehicle time	-0.1528 (-2.8635)	-0.1681 (-3.2813)
Waiting time	-0.1762 (-2.3715)	-0.1853 (-2.9613)
Walking time	-0.1951 (-2.8519)	-0.2016 (-3.0216)
ρ^2	0.2102	0.2869

Table 14 Comparing results of the standardization dada

Models	Attributes	Calibration coefficient	Standardization
Traditional Logit model	On-vehicle time	-0.1528	1.00
	Waiting time	-0.1762	1.15
	Walking time	-0.1951	1.28
	Constant	-1.7862	11.69
The improved model	On-vehicle time	-0.1681	1.00
	Waiting time	-0.1853	1.10
	Walking time	-0.2026	1.21
	Constant	-1.7026	10.13

Table 15 Comparing results with bus line number is two

Attributes	Traditional Logit model (t test)	Improved Logit model (t test)
Constant	-1.6491 (-2.4128)	-1.4122 (-2.1823)
Age of 31—40	0.1231 (2.1536)	0.0968 (1.9803)
On-vehicle time	-0.1635 (-2.6105)	-0.1783 (-2.7519)
Waiting time	-0.1703 (-2.1285)	-0.1890 (-2.3681)
Walking time	-0.1839 (-2.3912)	-0.2050 (-2.2912)
ρ^2	0.2042	0.3052

Table 16 Comparing results of the standardization dada

Models	Attributes	Calibration coefficient	Standardization
Traditional Logit model	On-vehicle time	-0.1635	1.00
	Waiting time	-0.1703	1.04
	Walking time	-0.1839	1.12
	Constant	-1.6491	10.09
The improved model	On-vehicle time	-0.1783	1.00
	Waiting time	-0.1890	1.06
	Walking time	-0.2050	1.15
	Constant	-1.4122	7.92

The calculation results show that the improved model is more accurate than the traditional Logit model, so the results are more reliable. Also, the transfer penalty, the transfer penalty of walking time and the transfer penalty of waiting time are 10.13 minutes, 1.21 minutes and 1.10 minutes respectively, when the bus line number is one; while they are 7.92 minutes, 1.15 minutes and 1.06 minutes when the bus line number is two. The transfer penalty of walking time is bigger than the transfer penalty of waiting time, which indicates travelers are more sensitive to the walking time. With the increase of the bus line number, all the penalty values will decrease and the larger the degree of decline is, the bigger the impact is.

6. Conclusions and Future Research

To better serve the optimization of the bus system, more accurate generalized travel time is necessary. This paper takes the different number of bus line into consideration, which makes the bus transfer penalty more accurate. Previous studies have never taken the effect of the linear relationship among variables into consideration, to overcome the linear relationship, an improved Logit model based on the principal component theory is established. Based on the survey data in Xi'an, the traditional Logit model and the improved model are established respectively. The results show that the improved Logit model is more accurate than the traditional Logit model, so the transfer penalty is more reliable and closer to reality. In this paper, the total time of the options is similar, if taking the different number of bus line into consideration, when the number of bus line is one, the transfer penalty, the transfer penalty of walking time and the transfer penalty of waiting time are 12.13 minutes, 1.43 minutes and 1.34 minutes respectively; while they are 9.93 minutes, 1.09 minutes and 1.04 minutes when the number of bus line is two. If taking the same number of

bus line into consideration, when there is only one bus line, the transfer penalty, the transfer penalty of walking time and the transfer penalty of waiting time are 10.13 minutes, 1.21 minutes and 1.10 minutes respectively; while they are 7.92 minutes, 1.15 minutes and 1.06 minutes when the number of bus line is two. Also, travelers are more sensitive to the walking time. With the increase of the bus line number all the penalty values will decrease.

In this paper, the bus punctuality rate and the traffic condition are not taken into consideration, how to quantify the factors that affect the reliability of the bus system when calculating the transfer penalty should be studied.

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