Study on Traffic Access Mode Choice of Urban Railway System in Beijing

Hongzhi Guan [1,*]; Shan Huang [2]; Hai Yan [1]

1. Beijing Key Laboratory of Traffic Engineering, Beijing University of Technology, Beijing 100124, China
2. Capital Engineering & Research Incorporation Limited, Beijing 100176, China

hguan@bjut.edu.cn, hmqin@bjut.edu.cn

Abstract: An effective traffic access system of urban railway will greatly increase the accessibility of transportation system. This paper analyzes the distribution between the access modes choice and the access distance and access time by a revealed preference survey for the ingress and egress of urban railway in Beijing. Then a joined nested mode choice logit model is sets up using the survey data. Three factors of access time, access cost and access distance on the traffic access mode choices of urban railway are analyzed. It is confirmed to be effective based on the combined estimated methodology by the comparison between the joined model and the ML model. The elasticity analysis of the model's variables is conducted to analyze to what extent each variable influences the access mode choice of travelers. The conclusions provide an analytical tool for urban railway planning and construction, also advices on policy application. [Researcher. 2009;1(5):52-57]. (ISSN: 1553-9865)

Key words: railway access mode; nested logit model; joined model

1 Introduction

The convenience of the traffic access mode of the ingress and egress of urban rapid railway system influence the individual's travel mode choice to some extent. To build an effective traffic access system will increase railway's attraction, bring forth the function of urban railway and decrease traffic jams.

Many scholars have done researches on the traffic access mode of urban railway. Korf and Demetsky had classified the subway stations into five types and analyzed the subway station access mode choices (Korf, 1981). Bates had classified traffic access facilities based on the service covered by buses and intercity passenger transport and railways. It had discussed how to improve the present access facilities (Bates, 1978). Dickins had put forward the proposals for the locations, attributes and size of the access facilities based on the survey data of 51 cities in Europe and North America (Dlckins, 1991). There were some studies about the traffic access facilities in China including the analysis on the access time, access distance and system evaluations from a planning view (Wang, 2003; Du, 2005; Wu, 2005). Guan Hongzhi had developed two different logit models based on the survey conducted in Beijing to analyze the mode choice behavior on the arrival and departure railway station respectively (Guan, 2007).

This paper focuses on the analysis of traffic access mode choice behaviors based on a survey conducted in Beijing and analyzes the factors that influence the traffic access mode choices of travelers riding urban railways. A nested logit model is then used to develop a traffic access mode choice model of railway. This model analyzes the access process of the ingress and egress of the railway. Furthermore, the elasticity of each influencing factors was analyzed to illustrate how the variables affect the access mode choice behavior of travelers using urban railway systems. The conclusions are valuable for the traffic policies of the urban railway system.

2 Surveys and analysis

The revealed preference data survey was conducted in Beijing. In order to analyze the traffic access mode choice preference of railway users, the questionnaire include items about the individual gender, age, occupation, income, and car ownership and trip purpose, trip origin, traffic access modes, access time and cost. There are six traffic access modes considered in the survey including buses, walking, taxis, bikes, private cars, and others (Guan, 2007).

The survey uses face-to-face interviews. Six railway stations were selected based on the different land exploitation degree and layouts, geographic locations, and development characteristics around the railway station in Beijing. The number of valid questionnaires is 761, which is suitable for the sample data in the building of the logit model.

2.1 Distribution of the traffic access modes

The traffic access modes of the railway include ingress and egress access modes as shown in Fig. 1. As shown in Fig. 1, the differences between the distribution of ingress and egress access modes choice are small. Walking is the dominant traffic access mode of urban railway and the choice proportion is over 70%. Bus ranks as the secondary traffic access mode of urban railway with a proportion of over 20%. The proportions of the other traffic access modes are relatively small.

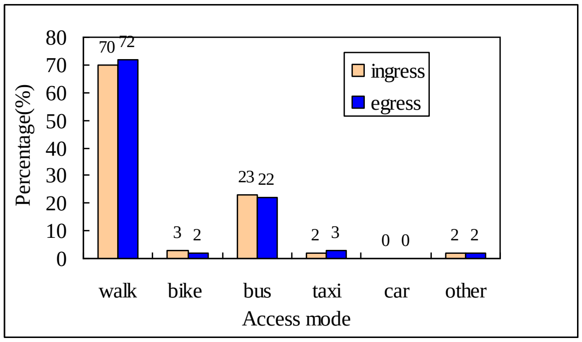

Figure 1. Access mode distribution

2.2 Distribution of access distance

Fig. 2 shows the access distance differs significantly between the access and egress access mode choice. The mean access distance is 1.4 km and the average egress access distance is 2.0 km. This indicates that the egress access distance is higher than that of the access mode.

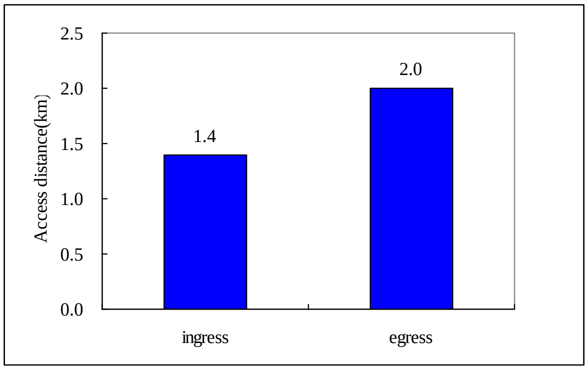

Figure 2. Distribution of access distance

2.3 Distribution of bus access time

Also, Fig. 3 shows that the bus access time varies greatly between ingress and egress access modes choices when railway riders take bus as a traffic access mode. The mean bus access time is 11 minutes, which is largely lower than the mean egress access time of 25 minutes.

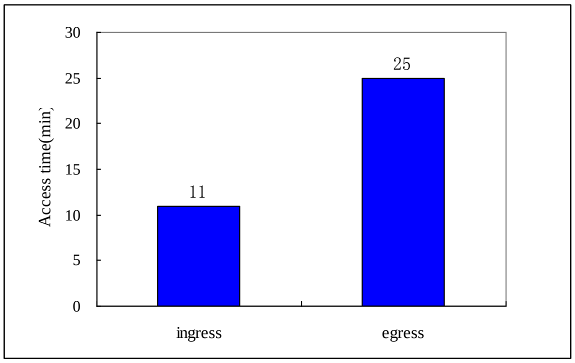

Figure 3. Distribution of bus access time

3. Methodology and models

As the logit model is an effective mathematical tool to study traffic behavior and is required a small sample, this paper adopts the NL (Nested Logit) model to do researches on the behavior of transport mode choices put forwarded here. The normal equation of NL model is as follows (McFadden, 1973):

$$P_n(tm) = P_n(t|m)P_n(m) = \frac{\exp(V_{(t|m)n})}{\sum_{t'=1}^{R_{mn}} \exp(V_{(t'|m)n})} \cdot \frac{\exp[\omega(V_{mn} + I_d)]}{\sum_{m'=1}^{M} \exp[\omega(V_{m'n} + I_d)]} \quad (1)$$

Where:

$P_n(tm)$ —the probability of the nth traveler choosing tm;

$P_n(m)$ —the probability of the nth traveler choosing m;

$P_n(t \mid m)$ —the probability of the nth traveler choosing r under the condition of choosing m first;

$V_{(t \mid m)n}$ —the fixed part of the utility function of t under the condition of choosing m;

V_{mn} —the fixed part of the utility function of m;

I_d —the inclusive value;

ω —the scale parameter.

It is convenient to organize ingress and egress mode in one model to show the distinct influence of each variable. According to the preceding statistical analysis, there is little difference between ingress and egress of railway in terms of the proportion for each mode, but the variation of bus access time and access distance is considerable. The structure of the NL model is shown in Fig. 4. It has four branches of access modes: bus, walking, taxi, and bike, as well as two limbs: ingress and egress. What is noticeable is that the relationship between ingress and egress is not mutually exclusive but parataxis, so the estimation methods will be a little different from the normal NL model.

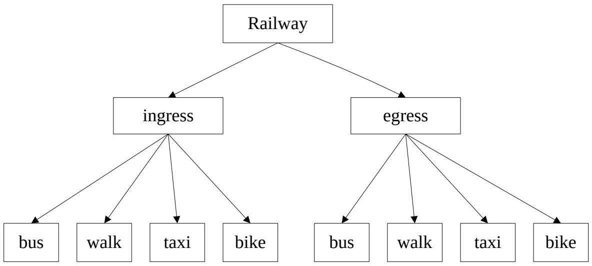

Figure 4. Access model structure

Firstly it is assumed that the fixed part of the utility functions of ingress and egress is the same and the random components' variances of the utility functions have different levels of randomness, which can be expressed by (Guan, 2004; Ben-akiva, 1990):

$$Var[\varepsilon_f] = \frac{1}{\omega^2} Var[\varepsilon_r] \tag{2}$$

Then the scale parameter " μ_r " and " μ_f " of the utility functions of arrival and departure can be expressed by:

$$\mu_r / \mu_f = \omega \tag{3}$$

If assume $\mu_r = 1$, using standardized process, hence the maximum likelihood function of traffic mode choice of railway's arrival and departure can be formulated as

$$L_f(\theta,\omega) = \sum_{n=1}^{N} \sum_f \delta_{fn} \left[\omega V_{fn} - In \sum_f \exp(\omega V_f) \right] \tag{4}$$

$$L_r(\theta,\omega) = \sum_{n=1}^{N} \sum_r \delta_{rn} \left[V_{rn} - In \sum_f \exp(V_f) \right] \tag{5}$$

where δ_{fn} and δ_{rn} are results of traffic mode choice of railway's arrival and departure:

$$\delta_{in} = \begin{cases} 1 & \text{the n}^{\text{th}} \text{ traveler choosing i}^{\text{th}} \text{ mode} \\ 0 & others \end{cases} \quad (i = f, r); \tag{6}$$

where θ is the unknown vector parameter of utility functions V_{fn} and V_{rn}.

Based on these assumptions, the parameter can be estimated by the following sequential estimation method:

Step1:

Define $V_{fn} = \theta_{f0} + \sum_k \theta_k X_{nk}$ (X_{nk} is the influence factor on travelers' transport mode choice of railway access); and then estimate the access model in function 3 from the access data to obtain $\hat{\theta}_{f0}$ and $\widehat{\omega\theta}_k$.

Step2:

Define $V_{rn} = \theta_{r0} + \gamma \sum_k \widehat{\omega\theta}_k X_{nk}$ (X_{nk} is the influence factor on travelers' transport mode choice of railway egress); and then estimate the egress model in function 4 from the egress data to obtain $\hat{\gamma}$ and $\hat{\theta}_{r0}$,

Calculate $\hat{\omega} = {}^{1}\!/_{\hat{\gamma}}$, $\hat{\theta}_k = \hat{\omega}\theta_k / \hat{\omega}$.

Step 3:

Multiply X_{fnk} by $\hat{\omega}$ to obtain a modified access data set, and change the fixed part of access model's utility functions "V_{fn}",

define $V_{fn} = \theta_{f0} + \sum_k \theta_k (\hat{\omega} X_{fnk})$; Pool the egress data and the modified access data; and then estimate the two models jointly to $\hat{\theta}_k$.

In order to find a model which is suitable for both ingress and egress model, according to the access model structure shown in Fig. 4, this paper utilizes scale parameter " ω " to join the ingress data and egress data. In order to explain its validity and superiority, this paper also set up another model was just a simple ML (Multinomial Logit) model with data of ingress and egress.

Application of the survey data in the logit railway access mode choice model for arriving at and departing from the stations gave the results listed in Table 1. According to the correlation analysis and the research in the transportation mode we select some variables: access time, access fee and access distance to establish the choice model.

Table 1. Parameter estimates of the access model

	model1 (joined model)		model2 (ML)	
	Coefficient	t-statistics	Coefficient	t-statistics
Constant(walk)	3.233	2.7743	8.6656	7.1451
Constant(bike)	-2.4782	-2.4631	1.7322	1.6724
Constant(bus)	1.3092	1.7351	3.3009	3.5798
Access fee	-0.7812	-5.5936	-0.1945	-3.7942
Access time	-0.5335	-5.4789	-0.1298	-1.4398
Access distance	-4.1627	-7.8584	-4.1486	-7.5715
Scale parameter ω	2.1681	5.8500	——	——
$\bar{\rho}^2$	0.8267		0.8032	

Comparing model 1 with model 2, the value of $\bar{\rho}^2$ of model 1 improved from 0.8032 to 0.8267. And the value of t test on access time, which is the most important variable to influence the behavior of people's access mode choice, increased greatly from -1.4398 to -5.4789, which is significant under confidence level of 95%. From this point of view, model 1 is more effective than model 2.

The coefficients for three variables in model 1 (access time, access fee, and access distance) are all negative, which means some access mode's utility will decrease with the increase of any one of these three variables. The finding is in accordance with the widely accepted belief that the more time-consuming, the higher access fee, and the longer distance access to the metro station a trip is, the greater possibility that one will switch to an alternative transport mode.

Furthermore, it is noticeable the value of access time and access fee's coefficients. Normally the value of the coefficient reflects each variable's impact on the utility function. As these two variables are public, the ratio of access fee and access time will reflect travelers' time value to some extent. An interesting result is this ratio is much higher than the actual value of travel time for Beijing. This is because the average income of rail users is higher than the average income for all of Beijing, which is clearly shown in Fig. 5. Compared to all modes users, the proportion of mid income rail users is larger, while the proportion of high income group is equal.

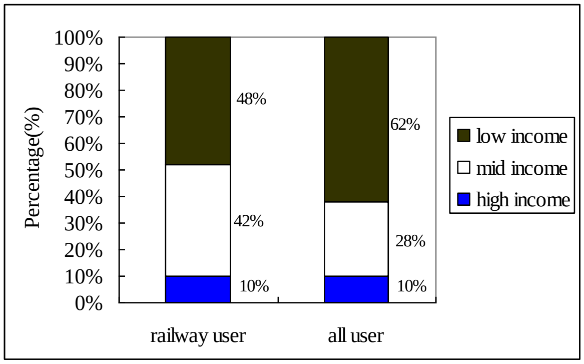

Figure 5. Contrast of the income between rail users and all users

4. Elasticity analysis

To analyze how and to what extent each variable influences choices of policy makers; we conduct the elasticity analysis to find out how the mode choice ratio changes when only the studied variable changes while other variables remain constant. So this paper chooses access distance, bus access time, and bus access fee as the variables to analyze. Here only bus access fee and bus access fee are chosen in sensitiveness analysis, the reason is that the access between rail and bus has attracting more and more attentions.

4.1 Access distance

Based on model 1, Fig. 6 shows an elasticity analysis of access distance variable, therein X axis is the access distance and Y axis is traveler's choice probability on each transport mode under different access distance. The conclusion is that when access distance increases, the proportion of the walking mode decreases sharply, while the proportion of bike and bus modes surge. Since the proportion of taxi is zero until the access distance exceeds 4 km, Fig. 6 excluded the taxi mode. It is interesting to note that when access distance reaches 1.5 km, the proportion of the walking mode is equal to that of the survey. It can be confirmed that the convenient walking access distance is 1.5 km, slightly longer than the common belief of 0.5~1km. The reason may be that the density of railway stations and the railway network in Beijing are not large enough, leading the rail station far away from the origins and destinations. So the conclusion is that the best access distance between two rail stations is less than 1.5 km.

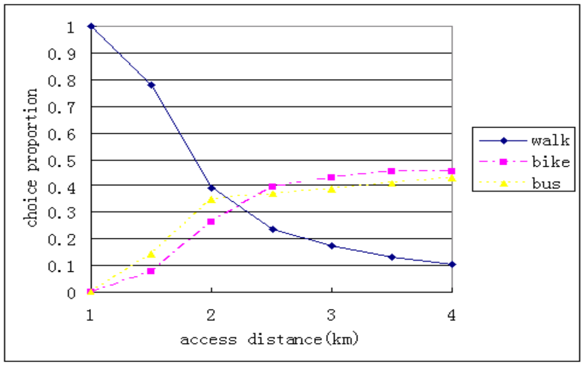

Figure 6. Analysis of sensitiveness on distance

4.2 Bus access time

Based on model 1, Fig. 7 shows the sensitive analysis of bus access time variable. Due to the negligible influence of bus access time on walking mode proportion, Fig. 7 has not shown the walking mode. In Fig. 7, the conclusion is that with the increase of bus access time, the proportion of bus mode decreases while those of the other three modes increase. When the bus access time is 10 minutes, the proportion reaches 25%, nearly the same as the actual proportion revealed in the survey. So it can be concluded that when the bus access time is less than 7 minutes, the proportions of the other modes will be transferred to the bus mode; when the bus access time is between 10 minutes and 20 minutes, the bus mode proportion will shift to the walking mode; when the bus access time increases from 30 minutes to 50 minutes, the bus mode proportion will mainly move to the bike mode, and when the bus access time is more than 50 minutes it will mainly transfer to the taxi mode. So the convenient access time is less than 20 minutes for the bus mode.

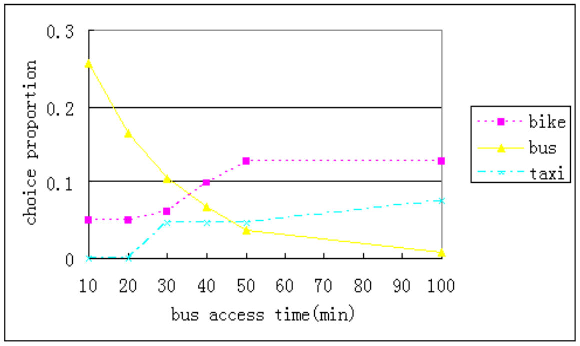

Figure 7. Analysis of sensitiveness on bus time

4.3 Bus access fee

Based on model 1, Fig. 8 shows the sensitive analysis of bus access fee variable. For the same reason with Fig. 7, the walking mode proportion is excluded in Fig. 8. The choice proportion of bus mode decreases with the increase of bus fee, especially when the bus fee is over 2RMB, the choice probability of bus dropped sharply. In the whole, the decreasing speed of bus passenger flow is higher than that of other mode's increasing speed. So the conclusion that bus access mode is more sensitive to the bus access fee is drawn, especially when the latter exceeds a certain value.

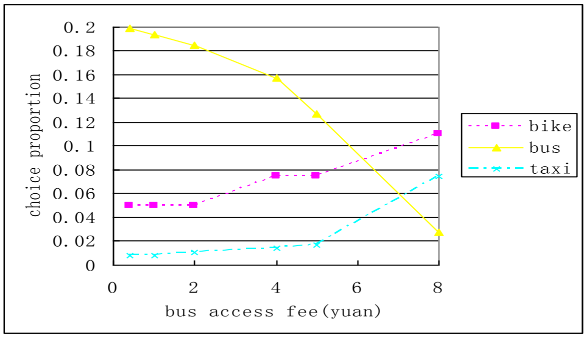

Figure 8. Analysis of sensitiveness on bus fare

5. Conclusions

By analyzing the railway lines in Beijing, this paper, in order to improve the integration of railway lines design and construction into the overall transportation system, evaluates the connections between railways and regular public transportation systems, sets up a joined nested mode choice logit model using the survey data. Conclusions from the parameters' analysis in model and sensitive analysis are as follows:

(1) Access distance had significant impacts on the walking mode: As access distance increased, the proportion of the walking mode decreased sharply, and the appropriate access distance should be less than 2 km;

(2) Appropriate access time for the bus mode was around 20 min, if it exceeded 20 minutes, the choice would shift to the bike and taxi modes;

(3) The bus access mode was more sensitive to the bus access fee: In effect, given the low cost of bus fee in Beijing at the present time, the government needs to concentrate on the improvement of bus

services and comfort to maintain the increase of constant patronage.

In order to do a more in-depth and more accurate study on railway access mode choice behavior, the deeper improvement of this paper is to analyze the influence of the access mode on all the travel modes, then to explore what extent of every factor influencing on choice behaviors, which will provide more advice for policy applications and analysis of traveler’s traffic mode choice characteristic.

Acknowledgement:

Foundation item: The Educational Council of Beijing (No. KM200610005005) and the National Natural Science Foundation of China (No. 50678004)

Correspondence to:
Hongzhi Guan
Beijing Key Laboratory of Traffic Engineering,
Beijing University of Technology,
Beijing 100124, China
Telephone: 01186-10-6739-1980
Cellular phone: 01186-137-0114-2716
Emails: hguan@bjut.edu.cn

References

[1] Korf J L, M.J.Demetskv. Analysis of rapid transit access mode choice [R]. Transportation research record No.817. Washington DC: Transportation Research Board, 1981.

[2] Bates Jr E G. A study of passenger transfer facilities [R]. Transportation research record No.662. Washington DC: Transportation Research Board 1978.

[3] Dlckins I S J. Park and ride facilities on light rail transit systems [J]. Transportation. 1991; 18(1):23~36

[4] 王秋平,李峰. 城市其他客运交通换乘轨道交通协调探讨[J]. 西安建筑科技大学学报:自然科学版. 2003; 35(2): 136-139

Wang Qiuping, Li Feng. On the coordination of switching non-rail transport modes to rail transport modes inurban passenger traffic system [J]. Journal of Xi'an University of Architecture &Technology: Natural Science. 2003; 35(2): 136-139（in Chinese）

[5] 杜彩军, 蒋玉琨. 城市轨道交通与其他交通方式衔接规律的探讨[J]. 城市快轨交通. 2005; 18(3):45-49

Du Caijun, Jiang Yukun. Connection of urban rail transit with other public transportations[J]. Urban Rapid Rail Transit. 2005; 18(3): 45-49（in Chinese）

[6] 吴友梅, 张秀媛. 城市轨道交通的公交换乘问题与对策分析[J]. 城市轨道交通. 2005; 27(8):19-21

Wu Youmei, Zhang Xiuyuan. The transfer with bus system and counter measurements of urban mass transit [J]. Railway Transport and Economy. 2005; 27(8): 19-21（in Chinese）

[7] Guan Hongzhi, Yin Yuanfei. Urban railway accessibility[J]. TsingHua Science and Technology. 2007; 12(2):192-197

[8] McFadden D.L. Conditional logit analysis of qualitative choice behaviour [R]. Frontiers in Econometrics, Academic Press. New York. 1973: 105-142

[9] 关宏志. 非集计模型---交通行为分析的工具[M]. 北京：人民交通出版社, 2004

Guan Hongzhi. Disaggregate model---A tool of traffic behavior analysis [M]. Beijing: People transportation publishing company. 2004

[10] Ben-akiva M, Morikawa T. Estimation of travel demand models from multiple data sources [J]. Transportation and Traffic theory, 1990(b), 461-476.

5/9/2009