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Traffic Planning
Preliminary Communication
Submitted: 27 June 2017
Accepted: 9 Apr. 2018

MODELING TRAVEL MODE CHOICES IN CONNECTION TO METRO STATIONS BY MIXED LOGIT MODELS: A CASE STUDY IN NANJING, CHINA

ABSTRACT

Urban rail transit trips usually involve multiple stages, which can be differentiated in terms of transfers that may involve distinct access and egress modes. Most studies on access and egress mode choices of urban rail transit have separately examined the two mode choices. However, in reality, the two choices are temporally correlated. This study, therefore, has sequentially applied the mixed logit to examine the contributors of access and egress mode choices of urban metro commuters using the data from a recent survey conducted in Nanjing, China. 9 typical multimodal combinations constituted by 5 main access modes (walk, bike, electric bike, bus, and car) and 2 main egress modes (walk and bus) are included in the study. The result proves that the model is reliable and reproductive in analyzing access/egress mode choices of metro commuters. Estimation results prove the existence of time constraint and service satisfaction effect of access trip on commuters' egress mode choice and reveal the importance of transfer infrastructure and environments that serve for biking, walking, bus riding, and car parking in commuter's connection choice. Also, policy implications are segmentally concluded for the transfer needs of commuters in different groups to encourage the use of metro multimodal trips.

KEY WORDS

multimodal rail transit; access and egress; mode choice; mixed logit;

1. INTRODUCTION

The continued urban expansion and increasing job-housing imbalance lead to increased commuting distances in many cities. Undoubtedly, mass transit systems, particularly urban rail transit, have become the optimal transport mode for commuters who wish to avoid long traffic delays during rush hours. Because urban transit systems are not always directly accessible, commuters may have to use more than one transport mode options during travel [1]. In other words, they need to consider the performance of alternative transport modal chains and decide which combination of modes to use. In the case of transit, in addition to physical attributes such as travel time, travel costs, and number of transfers, service components of the entire journey are essential to consider. Only if the service in all stages of the journey is good can rail provide a service comparable to door-to-door travel by car [2]. In that context, Guo and Wilson [3] found that passengers' satisfaction on the entire rail journey usually decreased with the trip time spent on the access and egress stages, and then led to a reduction in the attractiveness of rail transit. Moreover, the access trip is supposed to have effects on the egress trip. For instance, when the time spent on the trip accessing a metro station exceeds individual's expected time range, the passenger may adjust his planned decision on egress mode choice accordingly. Meanwhile, if the trip services provided in the access stage are highly satisfactory, commuters are more likely to use the same mode to egress. These findings underline the importance of considering the access and egress stages in the metro multimodal journey and their interrelations. Surprisingly, such research is scarce. Previous studies have predominantly examined access and egress trips of metro commuters separately.

Therefore, this study was conducted to sequentially examine the entire "access-metro-egress" travel process by considering these correlations between the two stages. Specifically, the objective of this research could be described in three folds: (1) reveal the relative prevalence of combinations of transport modes used by these metro multimodal commuters; (2) investigate the key factors that influence metro commuters' decisions about modal combinations; (3) propose the applicable countermeasures that could improve the travel efficiency of metro commuters' multimodal trips. To this end, we applied mixed logit models to examine combinations of mode choices during the access and egress stages of multimodal commute trips. The estimation was conducted based on a travel survey among urban rail commuters administered in Nanjing, China, where personal socio-demographics, trip diary information, and passengers' satisfaction with the access/egress trips were collected.

This paper has three main contributions. First, the modeling has considered the possible effects of access trip in terms of its time constraint and trip satisfaction regarding the egress mode choice decision, allowing heterogeneity across commuters in different metro combination groups with respect to perceived services. Both are somewhat devoted to policy design for different metro users. Second, this study case in Nanjing supplements the findings of previous studies on this topic and thus adds to the body of knowledge on the choice behavior of commuters. Particularly because most studies have been conducted in developed countries, this study is one of the first that provides findings from China, due to lack of data. Third, findings from other cities do not necessarily apply to China because the changes in land use, extreme congestion in major cities, and the rapid extension of metro lines, jointly with rapid changes in income levels and spending power, have set a different stage for deciding on mode choice.

The remainder of this paper is arranged as follows: Section 2 presents a review of existing studies. Section 3 discusses the data collection and provides a summary of some descriptive statistics. Section 4 describes the model applied in the analysis of the access/egress commuting mode choice. Discussions on estimated results are presented in Section 5. The final section provides conclusions and policy implications.

2. LITERATURE REVIEW

Many studies involving multimodal travel behavior have been conducted in the US or Europe, most of them centered on contributors to individuals' mode choice. Heinen and Bohte [4] showed that bicycle-transit integration is the most commonly used combination in the Netherlands, which is mainly affected by commuter's attitude, access distance, and the presence of bicycle parking facilities. Other studies were mainly centered on factors that are detrimental to the use of multimodal transport chains. Access and egress trips in transit journeys have been most frequently examined, focusing on characteristics such as distance, travel time, transfer and waiting time, and connectivity [5]. As stated by Andersson et al. [6], commuters' willingness to use public transit was mainly positively associated with its accessibility. The availability of transport services provides possible multimodal combinations, and, when making mode choice decisions, individuals usually trade-off the trip time or cost for each modal chain [7]. The proximity of stations to origins or destinations is one of the typical elements that facilitate the accessibility of rail transit. For instance, the time spent in both access and egress stages is found to exert more significant influence on commuters' feeder mode choice than socio-demographics do [8]. The empirical study on metro-bus transfers in Bangkok, Thailand, has proved that, in addition to public security, the distance from metro exits to bus stops is of critical importance to egress satisfaction, the enhancement of which is positively associated with metro usage [9]. Moreover, the conditions at stations, such as the availability of car parking places, path walkability, walking distance, weather, and safety issues surrounding the transit facility significantly affect people's mode choice. Providing car parking or park-and-ride facilities at metro stations influence commuters' decisions on whether to connect with light rail or not [10]. Satisfaction with access and egress trip services to rail station is an important factor affecting rail use [11, 12].

Methodologically, most studies have applied descriptive methods or some modeling approaches [2, 13] for connection mode studies [5, 14-18]. For instance, utilizing trip records from smart cards, Seaborn et al. [13] derived and described that 23% of metro trips involved a bus transfer, while 5% included three or more different types of transport modes. Debrezion et al. [14] specified rail users' choices of both the access mode and the departure station in a nested logit model. Zhao and Li [15], using a multilevel logistic model, successfully studied what factors are detrimental to individual's bicycle use in metro commuting transfer trips. To investigate the access mode choice of multimodal trips in Hanoi, Vietnam, Tran et al. [16] applied a multi-level cross-classified (MCL) model to factors that influence commuters' access mode choice in short trips to the mass transit station. Using a hierarchical nested logit model, Bovy and Hoongendoorn-Lanser [17] estimated commuters' preferences for the access/egress modes considering the underlying similarities between mode choices in access and egress trips. Picturing from multimodal network settings, Arentze and Molin [18] used mixed multinomial logit to examine passengers' preferences between multimodal trips and uni-modal car and public transport trips in long distance travel.

While empirical studies are carried out in China, some pertain to qualitative descriptions and statistical analysis of metro commuters' transfer behavior. Other studies only give insights on the factors that influence the use of specific multimodal integration. Cheng and Liu [19] examined the inconvenience of bicycle-transit travel from users' perspective by the Rasch model and found that the weather conditions, bicycle related facilities, and road traffic situation are the most common contributors. To improve the metro ridership in Nanjing, Chen et al. [20] utilized multiple linear regressions to investigate the determinants of bicycle-metro transfer demand and found that bicycle parking facilities, bicycle rental services, and the land use neighboring the metro station are the primary factors. Using a multiplicative model, Zhao et al. [21] indicated that feeder bus lines and bicycle P&R spaces around metro stations were main factors affecting metro station-to-station ridership for both home-end and activity-end stations. Wen et al. [22] used the latent class NL model to analyze the access mode choice behavior of high-speed rail users in Taiwan and found that travelers' heterogeneity preferences should be considered in strategies for access mode improvement.

In short, most of the above studies on multimodal travel behavior have emphasized the importance of access/egress stages and considered the effect of transfer related characteristics on the metro ridership, but few have comprehensively analyzed the access and egress mode choices for the entire origin-destination trip. Moreover, far rarer studies have incorporated the potential effects of access trip attributes on egress mode choices. Therefore, we will address these drawbacks and include the possible effects in this study.

3. SURVEY AND DATA DESCRIPTION

3.1 Survey design

For this study, a survey among metro commuters was carried out in Nanjing, China. In 2013, only two metro lines were in operation, with an 87 km delivery distance. *Figure 1* shows the layout of the metro system that connects 5 main areas of Nanjing by 57 stations. With the average speed of about 40 km/h and the service frequency of 3 min in rush hours and 5-8 min in non-rush hours, it carried 1,238,000 passengers daily, which took a rather smaller portion of urban transport than the private car did [23]. The ticket fare depends on how many stations passengers pass through, ranging from 2 to 4 yuan (1 yuan = 0.161 US dollar). To lower the rejection rate, the survey was simultaneously conducted in 5 main parks during weekends in

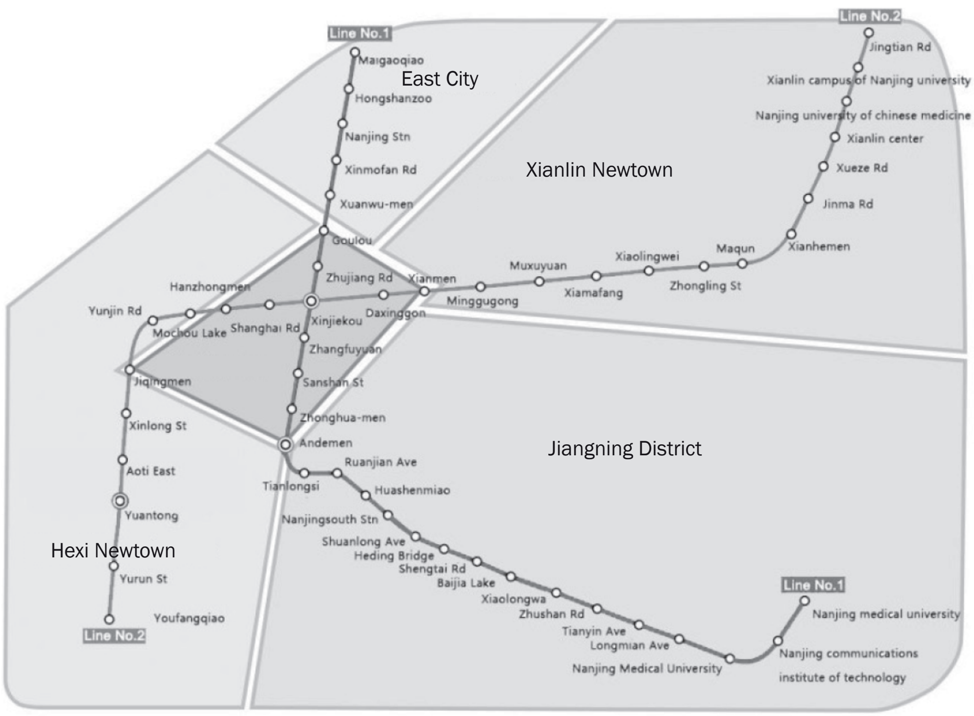

Figure 1 – Metro system layout in Nanjing, China (2013)

April. One park was located in the city center and the other four were respectively located along the four directions of the metro lines. In April, the weather in Nanjing is quite nice and stable, and more families enjoy their weekends in parks so they are more willing to share their time in the survey. To reduce the possible bias caused by the survey, we randomly invited respondents and started with the question if they were metro commuters and willing to participate in our survey. During the interview, all respondents were guided through the questions. A total of 925 completely answered questionnaires involving thirty stations were collected.

The questionnaire was structured into three main sections: socio-demographics, journey details, and commuters' perceptions on access/egress trip services. The first section mainly involves commuters' personal information, such as the gender, age, personal income, and household vehicle ownership. The second section on journey details focuses on attributes that cover both access and egress trips, such as the primary transport mode, travel time, travel distance, and the metro stations that they entered and exited. In addition, the time constraint of access or egress was collected through the question whether the accessing time was greater than their expected time range. The third section mainly involves the access/egress trip services. After the survey, we differentiated 5 possible modes in the access choice set (private car, bus, electric bike, bike, and walk) and 3 primary modes in the egress choice set, where the private car and electric bike were excluded due to low usage. Service items that describe facilities or environments for each access and egress mode were given in the questionnaire, and respondents were required to give judgments for the modal combination that they predominantly used on a 5-point Likert scale, from 1 (strongly disagree) to 5 (strongly agree). The detailed service items for each mode are listed in *Table 3*. In an attempt to investigate the satisfaction effect of access service on commuters' egress mode, respondents were required to answer whether they were satisfied with their access trip (satisfied or not satisfied). As electric bike has a similar service description in terms of facility conditions and environments to the bike, we presented them in the same row.

3.2 Descriptive analysis

After data validation, 825 questionnaires with complete information were obtained. *Table 1* shows the shares of different access and egress modes. 83.71% of respondents walked or rode the bus to the home-end metro station, and only a small share rode the bike, electric bike, or drove private car. In the work-end trip, 99% of respondents were walkers or bus riders, and a negligible share were bicyclists. Very few commuters rode bike in the work-end trip because bikes are not allowed to be boarded on metro, and the overnight parking of bikes at egress stations is not safe due to the risk of theft. Of all possible mode combinations, we chose 9 main combinations derived from 813 observations as our analytic sample: WMW (Walk-Metro-Walk, 43.39%), TMW (Bus-Metro-Walk, 17.44%), TMT (Bus-Metro-Bus, 11.86%), WMT (Walk-Metro-Bus, 10.3%), BMW (Bike-Metro-Walk, 6.26%), CMW (Car-Metro-Walk, 4.24%), EMW (Electric bike-Metro-Walk, 2.18%), BMT (Bike-Metro-Bus, 1.69%), and EMT (Electric bike-Metro-Bus, 1.58%).

Table 1 – Sample shares of access and egress modes (N=825)

Access modes	Egress modes			Total
	Walk	Bike	Bus	
Walk	43.39	0.72	10.30	54.41
Bike	6.26	0.36	1.69	8.31
Electric bike	2.18	-	1.58	3.76
Bus	17.44	-	11.86	29.30
Car	4.24	-	-	4.24
Total	73.51	1.08	25.43	100.00

A statistical description of the analytic sample is presented in Tables 2-3. The female and the male are equally distributed. 63% of the sample is aged between 20 and 29, and about one third is aged between 30 and 39. The majority of the sample is highly educated with a college/technical school degree, which is consistent with the case that Nanjing is one of main educational centers in China gathering several university towns. Nearly 40% receives a monthly income of 4,000–6,000 yuan, about one-third more than 6,000 yuan, and over 25% receives less than 4,000 yuan.

The initial view on the location distribution of home-end and work-end metro stations indicates the spatial mismatch between job and housing in Nanjing whereby 68% of respondents reside in suburbs and 78.6% work in the city center. *Table 2* presents the time allocations for the 9 combination trips. For all multimodal trips, the average accessing time is 14.1 min, the average egress time is 12.2 min, and the transfer/commute ratio is 0.48, implying that on average commuters have to spend nearly half of the journey time transferring to and from the metro. TMW has the longest access time (21.4 min), and TMT has the longest egress time (19.8 min), both of which have ratios higher than 0.5. This indicates that either in access or egress trip the bus ride took a relatively long time. CMW has the lowest transfer/commute ratio (0.40), although its commute time is rather long (61.8 min), which reflects the combination's high efficiency in commuting. Most

Table 2 – Statistical description of the sample (N=813)

Personal characteristics					
Variable	Gender		Age		
	Female	Male	20–29	30–39	40–49
Proportion	50.7%	49.3%	63%	32.8%	4.2%

Variable	Education			Monthly income (yuan)		
	High school and below	Undergraduate	Master and above	<4,000	4,000–6,000	>6000
Proportion	12.3%	75.2%	12.5%	25.6%	40.2%	34.2%

Journey details				
Variable	Location of home-end metro station		Location of work-end metro station	
	In suburb	In center	In suburb	In center
Proportion	68%	32%	21.40%	78.60%

User group	Average entire trip time	Access time [min]	Egress time	Average transfer/ commuting time ratio
WMW	48.6	11.1	9.8	0.43
WMT	56.2	10.6	16.9	0.49
BMW	53.4	11.9	9.8	0.41
BMT	60.6	11.1	15.4	0.44
EMW	52.8	11.7	11.3	0.44
EMT	57.0	10.6	19.0	0.52
TMW	61.8	21.4	12.9	0.56
TMT	76.2	18.9	19.8	0.51
CMW	61.8	12.7	11.8	0.40
Mean	54.6	14.1	12.2	0.48

Variable	Access distance				Egress distance			
	<1 km	1–3 km	3–5 km	>5 km	<1 km	1–3 km	3–5 km	>5 km
Proportion	39.5	35.3	13.6	11.6	56.9	26.8	10.4	5.9

respondents reported that their home-end access distances and work-end egress distances were within 3 km.

Table 3 shows passengers' ratings on the service description in access/egress trips. Most items averaged between '3 – neutral' and '4 – agree', meaning that most services are positively perceived among commuters. However, some bus-related items in WMT, BMT, EMT, TMW, and TMT have values lower than 2.2, i.e., on-time performance and enough space on bus. Across the groups with the same access or egress mode, the corresponding attributes are perceived differently, and in the group with the same connecting mode the services of the access and egress modes are valued differently.

As it is assumed that both the time spent on access trip and its service satisfaction have effects on the egress mode, we made an initial overview of them. Combinations with these two main egress modes show a significant difference in the time exceeding ratio and a high sensitivity of female commuters to time, given that 13% more female commuters than male thought their access time was excessive. Thus, the combined effect of gender and time exceeding constraint is solved as an explanatory variable in egress mode choice. As expected, higher satisfaction ratios on access trip were reflected among commuters who used the same mode in both stages such as WMW and TMT and both have a satisfaction ratio 5% more than their counterpart.

4. METHODOLOGIES

To investigate the entire journey of metro commuters, we elaborately modeled the commuters' mode choice decisions in access and egress trips in Nanjing. Five main alternatives (i.e., "walk", "bike", "electric bike", "bus", and "car") are included in the mode choice sets for access trips, and two main modes (i.e., "walk" and "bus") are included for egress trips. In this study, we sequentially applied the mixed logit due to its high pliability. First, as a kind of random utility model, the mixed logit model is suitable for the modeling estimation of discrete mode choice. Second, the mixed logit allows for the heterogeneity in the preference patterns of commuters in different combination

Table 3 – Descriptive statistics of mode specific service quality (N=813)

Stage	Mode	Items	Perception of mode specific service quality									
			WMW	WMT	BMW	BMT	EMW	EMT	TMW	TMT	CMW	Mean
Access	Walk	Sufficient walking facilities	4.03	3.99	-	-	-	-	-	-	-	4.02
		Walking environment comfort	3.59	3.59	-	-	-	-	-	-	-	3.59
		Enough walking space	3.61	3.51	-	-	-	-	-	-	-	3.59
	Bike/ Electric bike	Sufficient riding facilities	-	-	3.86	4	3.11	3.84	-	-	-	3.73
		Riding environment comfort	-	-	3.64	3.42	3.33	3.46	-	-	-	3.52
		Enough parking space	-	-	3.04	2.85	3	2.76	-	-	-	2.96
		A safe parking spot	-	-	3.32	2.71	2.61	2.53	-	-	-	2.97
	Bus	Acceptable walking distance 1	-	-	-	-	-	-	3.63	3.93	-	3.75
		Acceptable walking distance 2	-	-	-	-	-	-	3.25	3.8	-	3.47
		Bus on-time performance	-	-	-	-	-	-	2.04	2.09	-	2.06
		Enough space on bus	-	-	-	-	-	-	1.65	2	-	1.79
	Car	Good traffic condition	-	-	-	-	-	-	-	-	3.4	3.4
		Enough parking capacity	-	-	-	-	-	-	-	-	4	4
Egress	Walk	Sufficient walking facilities	3.93	-	3.91	-	3.72	-	4.06	-	3.8	3.95
		Walking environment comfort	3.7	-	3.8	-	3.38	-	3.82	-	3.71	3.73
		Enough walking space	3.57	-	3.68	-	3.33	-	3.65	-	3.43	3.58
	Bus	Acceptable walking distance 1	-	3.86	-	3.7	-	3.3	-	3.56	-	3.67
		Acceptable walking distance 2	-	3.48	-	3.21	-	3.15	-	3.44	-	3.42
		Bus on-time performance	-	1.99	-	2.15	-	2	-	1.96	-	1.99
		Enough space on bus	-	1.85	-	2.15	-	2.2	-	2	-	1.96

Note: All service attributes were measured on a 5 point Likert scale with the range from 1 –'strongly disagree' to 5 – 'strongly agree'.

groups, the inclusion of which is proved to be beneficial to the fitness of mode choice model [24]. Finally, the model is able to specify the influence of access on egress stages such as the time constraint of accessing and effect of personal satisfaction with access mode on egress mode.

4.1 Mixed logit model specification

The choice probability of a mixed logit model in the trip t (i.e., access trip t=1, and egress trip t=2) by person n can be expressed as follows [25]:

$$P_{ni}^{t}(\boldsymbol{\beta}) = \int L_{ni}^{t}(\boldsymbol{\beta}) f(\boldsymbol{\beta}) d\boldsymbol{\beta} = \int \frac{e^{V_{ni}^{t}(\boldsymbol{\beta})}}{\sum_{j} e^{V_{nj}^{t}(\boldsymbol{\beta})}} \cdot f(\boldsymbol{\beta}) d\boldsymbol{\beta} \qquad (1)$$

where L_{ni}^{t} is the logit probability of individual n choosing alternative i as the mode choice in trip t, $\boldsymbol{\beta}$ is the parameter vector to be estimated, and $f(\boldsymbol{\beta})$ is a density function of $\boldsymbol{\beta}$, which varies across different commuters and thus allows the preference heterogeneity of commuters. $V_{ni}^{t}(\boldsymbol{\beta})$ is the deterministic utility of alternative i by the metro commuter n in trip t depending on the parameter $\boldsymbol{\beta}$. The typical utility of function of choosing alternative mode i by metro commuter n in either trip t can be specified by:

$$U_{ni}^{t} = V_{ni}^{t}(\boldsymbol{\beta}) + \varepsilon_{ni}^{t} = \boldsymbol{\beta}' \mathbf{X}_{ni}^{t} + \varepsilon_{ni}^{t} \qquad (2)$$

where $\mathbf{X}_{ni}^{t}$ is a vector of explanatory variables in terms of socio-demographics of individual n, journey details of trip t, and service attributes relating to alternative mode I, and ε_{ni}^{t} is the error term (i.i.d. Gumbel-distributed). Notably, to investigate the effect of access trip on egress mode, we additionally included the variables denoting the satisfaction effect and time constraint of access trip in the function of egress mode choice.

4.2 Model estimation and validation

To avoid the possible correlation resulted from the Halton draws [26], we sequentially estimated the parameters for the access and egress mode choices by using 500 random draws in the software BIOGEME [27]. The estimated final log-likelihood values for access and egress mode choices are -205.749 and -41.629, and the adjusted Rho-square values are 0.601 and 0.620. Both suggest that the estimated mixed logit models are appropriate for analysis. To prove the superiority of mixed logit, we respectively developed the multinomial logit and binary logit for the two stages and compared their prediction capabilities in *Table 4*. As expected, the mixed logit predicts better in both stages, and the improved correct prediction somewhat confirms the findings that including the effects of access trip and accounting for the

Table 4 – Comparisons of prediction capacities

Access model	Mixed logit	Multinomial logit
Variables included	27	27
Alternative	Correct prediction [%]	
Walk	95.48	77.43
Bike	89.83	72.88
Electric bike	87.10	67.74
Bus	88.42	74.38
Private car	88.57	68.57
Overall	92.34	75.43
Egress model	Mixed logit	Binary logit
Variables included	23 *	16
Alternative	Correct prediction [%]	
Walk	98.83	78.50
Bus	90.95	69.04
Overall	96.79	76.05

** the effects of access trip are included*

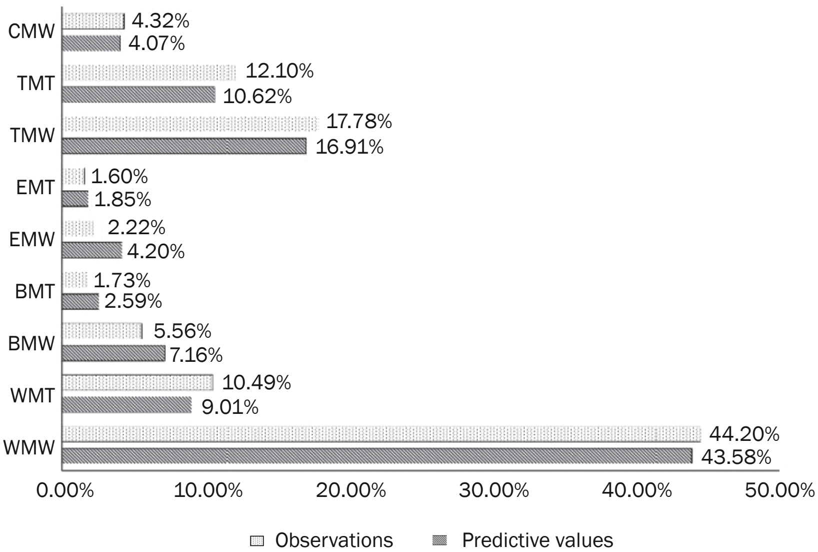

Figure 2 – Predictions on the shares by mixed logit

heterogeneity in service attributes across different commuters can help improve the model performance [27, 28]. Given correct predictions for each alternative in both models, we continued to make predictions on the shares of the 9 typical multiple modal combinations. The validation result in *Figure 2* shows that no significant differences exist between predicted and observed shares. Both validations imply that the estimated results of models are reliable and reproductive.

5. RESULT DISCUSSION

The estimated results of mixed logit models for access/egress mode choice are presented in *Tables 5-6*. The different coefficients of journey details and socio-demographics across different access groups clearly confirm their different impacts on the mode choice, which also proves the preference heterogeneity across the different combination groups to some extent. The variation in coefficients of 'male' on access alternative modes indicates that in the access trip men are more loyal to private car driving, and women are more inclined to electric bike riding. The varying association of access/egress distance with mode choices is not surprising as each mode has its suitable serving distance. For instance, walking is usually preferred in a short trip, while bus and private car are absolutely advantageous in a long distance trip. Based on the estimation, we made the analysis on the mode choice for both stages.

5.1 Behavior analysis for access mode choice

Ownership of a household vehicle such as bike, electric bike, or private car is negatively associated with the 'walk' access mode. Compared to other access modes, the effect of access time is less significant because usually the walking time is so short that commuters are not sensitive to its variation. Access distance shorter than 1 km has the highest coefficient, and it is decided by the metro service accessibility in the neighborhood of commuter's residence, such as the coverage of the metro lines. As expected, all walking service aspects have significant effects, and the coefficient of sufficient walking facilities is much higher (coefficient=1.770). It implies that walkers do not strongly require improvement of walking environments but rather care more about the necessary functions of facilities that could serve their daily walking.

The 'male' gender has a statistically positive association with the 'bike' access mode, which suggests that such mode is preferred by men. The negative coefficients of age and commuting time indicate that with aging and increasing of commute time commuters are less likely to ride the bike to metro. The household ownership of electric bike is negatively associated with this transfer mode. The access distance from 1 km to 3 km is essentially important to bikers (coefficient=2.970) implying that biking is superior to other modes in this distance range. Nearly all service items on biking are positively associated with this access mode. The insignificant effect of enough parking spaces is surprising and suggests that commuters are not very concerned with this item although many think that the current parking space is not adequate (refer to *Table 3*). In particular, if compound services with sufficient riding facilities (coefficient=2.610), comfortable riding environment (coefficient=1.630), and guarded parking space near a metro station (coefficient=2.280) are provided, more commuters may be willing to bike to the station.

Commuters' gender and education level are significantly associated with 'electric bike' access mode choice. Their coefficients indicate that female commuters show a great preference for electric biking, while the highly educated are not keen on this transfer mode. The negative coefficient of accessing time indicates that electric bike riding, as a type of slow transport mode, is not suitable for long time commute. When access distances reach 1–3 km or 3–5 km, more commuters are more likely to use this mode to access. Similarly, improving services in electric bike riding environments can increase its usage in access trips. Better riding infrastructures, such as comprehensive riding facilities, spacious and comfortable riding environments, and stations supported with enough and safe parking spots could encourage more commuters to use this mode.

The coefficients of gender, age, and income suggest that the 'bus' access mode is favored by female and older commuters but not welcomed by high-income commuters. Unlike slow transport modes, bus is more sensitive to the access time and the location of home-end metro station. Increasing access time largely reduces the chances that an individual will take a bus on access trip. Such high sensitivity (-1.150) may be due to often unreliable service provided by bus. The home-end metro station in the city center is negatively related to bus riding because the city center in Nanjing is highly covered by metro services, and many people are able to reach the station on foot. As a motorized mode, bus is more suitable for access distances longer than 5 km, with the coefficient of 8.93. All bus service attributes have a significant positive influence.

In the 'car' access group, the male (coefficient=0.988) are more inclined to car usage. A high coefficient of driving licenses (4.270) indicates them as a prerequisite in car use. The high sensitivity of car commuters to access time (coefficient=-1.490) is not surprising because they value time higher than other groups. Similar to bus riding, the home-end location in the city center goes against car usage in the access stage, as the land use pattern, traffic conditions, and metro services in the city center are not suitable for car driving. From the access distance, we found that

Table 5 – Estimation results for access mode choice

Choosing order: t=1	Access mode choice				
Variables	Walk	Bike	Electric bike	Bus	car
	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
Socio-demographics					
Male	--	0.377*	-0.695*	-0.582*	0.988*
Age	--	-0.447*	--	0.483*	--
Education (edu)	--	--	-0.653*	--	--
Individual monthly income (income)	--	--	--	-0.208*	0.621*
Ownership of bike (ob)	-0.264*	--	--	--	--
Ownership of electric bike (oeb)	-1.390**	-2.370**	--	-1.150**	--
Ownership of private cars (oc)	-0.696*	--	--	--	--
Ownership of driving license (lic)	--	--	--	--	4.270**
Journey details in access stage					
Access time (hmt)	-0.320**	-0.871**	-0.872**	-1.150**	-1.490**
Location of home-end metro station is in city center (os)	--	--	--	-0.664*	-0.457*
Access distance <1km (hmd1)	6.58**	--	--	--	--
1km<Access distance<3km (hmd2)	--	2.970**	1.140*	0.121*	--
3km<Access distance <5km (hmd3)	--	--	2.130*	7.130**	6.410**
5km< Access distance (hmd4)	--	--	--	8.930**	10.100**
Mode specific service quality for access stage					
Sufficient walking facilities (WF)	1.770**	NA	NA	NA	NA
Walking environment comfort (WE)	0.184*	NA	NA	NA	NA
Enough walking space (WS)	0.316*	NA	NA	NA	NA
Sufficient riding facilities (BF)	NA	2.610**	1.680**	NA	NA
Riding environment comfort (BE)	NA	1.630**	1.080*	NA	NA
Enough parking space near metro station (PS)	NA	--	2.150**	NA	NA
Safe parking spot near metro station (SF)	NA	2.280**	2.090**	NA	NA
Acceptable walking distance between home and bus stop (HBS)	NA	NA	NA	2.250**	NA
Acceptable walking distance between bus stop and metro station (BSM)	NA	NA	NA	1.640**	NA
On-time bus performance (BusF)	NA	NA	NA	0.940*	NA
Enough space on bus (BusS)	NA	NA	NA	0.771**	NA
Good traffic condition (TC)	NA	NA	NA	NA	1.890**
Enough car parking capacity near the metro station (ParkC)	NA	NA	NA	NA	1.160*
Final log-likelihood=-205.749	Adjusted Rho-square=0.601				

***Parameter is significant at the 95% level; * Parameter is significant at the 90% level; NA: not available*

private car has the advantage in long access distances, especially in the 3–5 km range (coefficient=6.410) and more than 5 km (coefficient=10.100). For car commuters, good road traffic conditions and sufficient parking capacities near the metro station are of interest, and both improvements would promote the park-and-ride mode.

5.2 Behavior analysis of egress mode choice

In the group of 'walk' egress commuters, satisfaction with access trips is positively associated with their subsequent decision on the egress mode, and commuters are more probable to continue to walk after exiting the metro. To some extent, it implies that preference of a specific mode could be retained for the mode choice decision in the egress stage. Significant effects of access time, greater than expected for both men and women, have been found in terms of promotion of walking in the egress stage. This could be explained by the fact that usually walking is the preferred transport mode for short trips, and the time spent is shorter than in other modes. Commuters are likely to have the possibility to adjust according to the required time. In the egress trip, walking is particularly suitable for

Table 6 – Estimation results for egress mode choice

Choosing order: t=2	Egress mode choice	
Variables	Walk	Bus
	Coeff.	Coeff.
Constraints of access time and mode specific service quality for access stage		
Satisfaction with access stage by walk (awalks)	0.128**	--
Satisfaction with access stage by bike (abikes)	--	--
Satisfaction with access stage by electric bike (aebikes)	--	--
Satisfaction with access stage by bus (abuss)	--	1.430**
Satisfaction with access stage by car (acars)	--	--
Male * access time more than expected (hmttmale)	0.421*	--
Female * access time more than expected (hmttfemale)	0.120*	--
Socio-demographics		
Age	--	0.06*
Education (edu)	--	--
Individual monthly income (income)	--	--
Journey details in egress stage		
Egress time (mwt)	-0.666**	-1.210**
Location of work-end metro station is in city center (ofs)	--	-0.881*
Egress distance <1km (mwd1)	11.500**	--
1km< Egress distance <3km (mwd2)	0.810*	--
3km< Egress distance <5km (mwd3)	--	5.150**
5km< Egress distance (mwd4)	--	10.700**
Mode specific service quality for egress stage		
Sufficient walking facilities (WF)	1.560**	NA
Walking environment comfort (WE)	0.771**	NA
Enough walking space (WS)	1.060*	NA
Acceptable walking distance between work-end metro station and bus stop (MBS)	NA	0.197**
Acceptable walking distance between bus stop and workplace (BSW)	NA	3.200**
On-time bus performance (BusF)	NA	0.475*
Enough space on bus (BusS)	NA	0.070**
Final log-likelihood=-41.629	Adjusted Rho-square=0.620	

***Parameter is significant at the 95% level; * Parameter is significant at the 90% level; NA: not available*

egress distances within 1 km (coefficient=11.5) and somewhat suitable for distances from 1 km to 3 km (coefficient=0.810). With respect to walking facilities, similar influence has been found in this mode.

The positive coefficient (1.430) of satisfaction with bus service in the access stage suggests that commuters who are satisfied with bus service provided in the access stage are more willing to adopt the same mode to egress. Age has a slight positive effect on the use of bus to travel from metro to workplace. The significant negative effects of egress time and distance dominate the egress mode choice. Similarly, a work-end metro location in the city center is not suitable for bus egressing. In addition, bus is the dominant mode in the egress distances of 3–5 km and over 5 km with the coefficients of 5.150 and 10.700, respectively. When egressing, metro commuters care more about the walking distance from metro to bus stop and bus on-time performance, while slight effects are found in other service aspects as well.

6. CONCLUSION AND POLICY IMPLICATION

This paper investigated the entire journey of metro commuters accounting for the effects of commuters' satisfaction with the access trip and the time constraint of access on egress stage. Using the data collected in Nanjing, China, we sequentially developed the mixed logit models for access and egress mode choices of metro commuters. The result proved that the estimated model is reliable and reasonable for analysis and performs well in prediction. To attract more metro users, emphasis should be placed on the optimization of transfer experience at access/egress stages, and our analysis on access/egress mode choice optimization enables designing policies in accordance with such objective.

Several conclusions can be drawn according to the above analysis. First, nine typical multimodal combinations constituted by five main access modes (walk, bike, electric bike, bus, and private car) and two main egress modes (walk and bus) account for 99% of the survey sample: 'Walk-Metro-Walk', 'Bus-Metro-Walk', 'Bus-Metro-Bus', 'Walk-Metro-Bus', 'Bike-Metro-Walk', 'Car-Metro-Walk', 'Electric bike- Metro-Walk', 'Bike-Metro-Bus', and 'Electric bike-Metro-Bus'. Second, it was confirmed that passengers' satisfaction with the access trip and time spent in access stage do have effects on their egress mode choice and the incorporation of these effects has partly improved the egress model's performance. Third, the preference heterogeneity, particularly regarding time and distance, has been presented across commuters in different combination groups.

The estimates of mixed logit models have jointly revealed the different roles played by the variables in different categories, such as socio-demographics, access/egress trip characteristic, the specific service provided in trips to metro stations, and constraints posed by access trip in commuters' transfer mode choice decisions. The findings also indicate the importance of transfer service quality that could increase ridership by improving connecting services provided in access and egress trips. For metro commuters with specific transfer modes, we have established applicable countermeasures in three groups. First, a safe and comfortable walking environment in the home-end or work-end trips should be guaranteed by providing sufficient space designed with appropriate pedestrian crossings and sidewalks. Second, for bus riders who transfer to the stations, strengthening the connections between public transport stops and metro stations is highly important. Bus priority measures should be conditionally taken based on the location of metro stations that buses connect. If the station is located in city center where road space is very limited, flexible measures, such as setting bus priority signals or bus-only lanes during peak hours, could be appropriately considered. On the other hand, when the metro station is beyond the center, other efforts could also be made by providing high-frequency shuttle buses between major residences/workplaces and metro stations. Notably, the operation and schedule of the bus service should be at their best to cooperate with the metro service. Third, to encourage more commuters to use bikes/electric bikes to access or egress from the stations, countermeasures such as improving riding environments, setting bike lanes, adding parking spaces around the metro station, equipping security monitors in parking lots, and providing more bike-sharing services could accordingly be implemented if conditions allow.

Although this study has analyzed connection mode choices of commuters in different combination groups and made specific implications from the estimated results, there are still three aspects remaining to be considered for future research. First, due to the small share of the public bike mode in Nanjing, we did not include this mode in our study. However, with the gradual popularity of bike-sharing and the introduction of relevant supportive policies from the local agency, the public bike should be included in future studies as a critical connection mode. Second, further study could look into the modal shifts from private car to the park-and-ride mode, a topic which is understudied due to its rare usage in China. Last, future research could expand its focus to trips on different purposes and gain a better understanding of urban metro transit trips in Chinese cities.

ACKNOWLEDGEMENTS

This research is funded by the Natural Science Foundation of China (71771049, 51338003 and 51378120), the Six Talent Peaks Project in Jiangsu Province (2016-JY-003), and the Science-Technology Program from Transportation Department in Jiangsu Province (2017Y11).

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基于混合***LOGIT***模型的城市轨道交通接驳方式选择行为研究——以中国南京为例

摘要

城市轨道交通多方式组合出行主要包括“接入–轨道交通–接出”三阶段，出行换乘涉及接入和接出方式选择。以往研究多聚焦于城市轨道单个的接入或接出方式选择分析，极少考虑考虑轨道接入与接出方式间的时空关联性。本文以南京轨道出行调查数据为基础，利用混合*Logit*有序模拟分析影响轨道个体通勤者接驳方式选择的重要因素。实测数据中，南京共有*9*种典型多方式轨道组合出行，接入以步行、自行车、电动车、公共汽车和小汽车*5*为主，接出以步行和公共汽车为主。模型有效、可靠性且适用，分析结果证实接入出行的满意度和时间约束对接出方式的选择有显著作用，同时步行、骑行、公交行车和私家车停车的换乘设施和环境都对通勤者的接驳方式选择有重要作用。最后，本文应不同组合轨道通勤人群的换乘需求，分类总结提升轨道通勤效率的政策，鼓励轨道交通多方式组合出行。

关键词

多模式轨道交通；接入接出；方式选择；混合*Logit;*

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