ISSN : 0974 - 7435 Volume 10 Issue 23

2014

BioTechnology
An Indian Journal

FULL PAPER
BTAIJ, 10(23), 2014 [14509-14514]

Disaggregated and integrated model of residential location, activity space and travel mode choice

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ABSTRACT

The purpose of this paper is to build the disaggregated and integrated model of Residential Location, Activity Space and Travel Mode Choice, to analyze the intrinsic relationships and inherent rules between these three elements, further to provide a basic reference for the resolution of traffic congestion problem which is caused by the unbalance transportation supply and demand. The utility maximization theory, nested logit model and 2013 Beijing travel survey data were used for building the model. The model have two levels, the first one is space choice level, which was used the land use variables, such as residential location and mixed land use; the other is mode choice level, taken the transportation variables, like travel time, travel cost etc. Parameter estimation results shown: (1) the absolute value of t test for each parameter are greater than 1.96. That means each parameters have influence on selection results in 95% confidence level. Model first and second level hit rate are all greater than 81%. Thus it is indicated the model precision is high. (2) The central part of Beijing has a higher degree of mixed land use characteristics. The travel mode choice is closely related with travel space size. It is all concluded that two level nested logit model can reflect the relationship between mode choice and land use very well.

KEYWORDS

Travel mode; Residential location; Activity space; Nested logit model.

INTRODUCTION

The interactive feedback relationship remains between city traffic and land use. All kinds of human activities occur on lands with different natures. The separation of all kinds of lands with different natures lead to the traffic flow spatially; contrarily, various traffic facilities are being built in order meet the people's travel demand, thus producing the different accessibilities in regions. The accessibility is decisive for land development and use form in the next round. Namely, it is a continuous circled development process among the land use, daily activities, traffic demand, accessibility and land reuse. Therefore, it is theoretically significant and realistic for studies on the intrinsic relationship between traffic and land use, revealing of their inherent rules law, addressing of the relation between limited urban land resources and growing traffic demand to fundamentally resolve the urban traffic jams arising from the traffic's unbalanced supply and demand relationship.

The research on the travel mode choice is very important in the process of traffic demand forecast. Many Chinese and foreign scholars have developed a wide range of researches and made significant progress. Most studies used the traditional 4-stage models such as Ortúzar, Miller, Asensio, Liu Bingen, Yin Huanhuan and Guan Hongzhi et al [1-5]. However，the prediction accuracy is inadequate in the traditional 4-stage model as the small traffic district is made as the smallest analytic unit using aggregated data. Foreign scholars began studying the disaggregated model as early as in 60's in twentieth Century. After dozen years of development, McFadden et al have made significant progress by 70's [6]. Based on this, Ben-Akiva and Lerman expounded the basic principles of the disaggregate model by taking the example of travel mode choice model in 1985. Models usually selects out personal and family social economic attribute variables in traveller and policy variables as explanatory variables, and expresses the factors that are unobserved with random variable ε. Meanwhile, every traveller selects his/her own most effective travel mode according to his/her characteristics and choice branch properties. For example, Algers, Vovsha, et al studied the travel mode choice using disaggregated method. The results of the studies showed that gender, age, occupation, income, number of owned cars and other social economical attribute in individuals and families play key effects on travel mode choice. However, as viewed from the present studies, for the travel mode choice, many studies used multinomial Logit model and ignored the impact of land use nature on travel mode choice.

The present paper constructs a disaggregate model of residential location, space activity and travel mode choice using Nested Logit model based on the survey data of residents in Beijing city in 2013 and analyzes the correlation between the different travel modes and land use nature.

TRAVEL MODE AND LAND USE NATURE

As per the spatial-temporal geographical theory by Hagerstrand, the activity space and travel mode are related closely. The more advanced the travel mode is and the fast the speed is, the larger the activity space will be[7]. On contrary, the activity region choice has similarly a huge impact on the travel mode choice. Typically, the travellers will choose the right travel mode be based on the land use nature, spatial scope and their social and economic attributes of itself in activity regions.

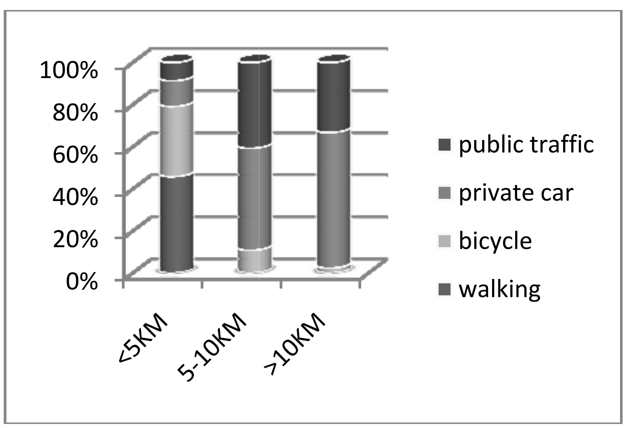

FIGURE 1: Travel mode share rate

In the present paper, the travel space is divided into 3 spatial scopes: <5Km, 5~10Km and >10Km, according to the distance between the departure and destination based on the scale and characteristics of Beijing City. Travel mode is divided into 4 categories: public traffic, private car, bicycle and walking. Figure1 shows the choice between travel space and modes in the survey data of Beijing city in 2013. It is seen from Figure1 that the dominant traffic mode is walking and bicycling in less than 5Km travel distance in Beijing City, respectively accounted for 45.82% and 33.33%, and the rates of car and public traffic are respectively accounted for 12.21% and 8.64%. In 5~10Km travel distance, almost nobody selects walking mode, and the ratio of bicycling mode declined significantly from 33.33% within 5km to 10.83%, however, the ratio of car and public traffic modes greatly improved, accounted for 48.49% and 40.68% respectively. when the travel distance is greater than 10Km, the ratio of bicycling mode is very low, only accounts for 2.38%, the ratio of car mode is significantly increased, upwards of 64.37%, the ratio of public traffic mode decreased remarkably, but it is still at a dominant position.

It is known from the above analysis that the travel space and travel mode are closely related. Therefore, it is theoretically significant and realistic to build an integrated choice model through comprehensive consideration of travel mode, land use nature and travel space.

MODEL CONSTRUCTION

Theoretical basis

The disaggregated model is constructed as per the utility maximization theory, i.e. assuming that the traveller usually chooses to the option that reaches their own utility maximization[8]. The random utility theory is applied as below[9]:

(1) The utility function consists of fixed item of non random variation and probability item of random variation, both of them show a linear relationship.

(2) To determine the fixed item of non random variation.

(3) To determine the probability item of random variation. Based on the above description, the utility function of disaggregated model is as below:

$$U_{in} = V_{in} + \varepsilon_{in}, \quad (1)$$

Where, U_{in} is a utility function representing the utility of the i-th option by the n-th traveller ; V_{in} is a fixed item of U_{in} ; ε_{in} is a probability item.

When the attributes of various options have many similarities, Nested Logit model is typically considered in order to avoid due to bias caused by IIA characteristics at following application conditions [10]:

(1) The variance in option error is the same in each layer.

(2) In layer with larger variance, the options have larger similarity.

The basic Nested Logit model is as below:

$$P_n(rm) = P_n(r|m)P_n(m), \quad (2)$$

Where, $P_n(rm)$ represents the probability of the n-th traveller selecting option; $P_n(r|m)$ represents the probability of option r choice when travel n has selected option ; $P_n(m)$ represents the probability of traveller n selecting option m ; $r = 1, 2, \cdots, R_{mn}$; $m = 1, 2, \cdots, M_n$; M_n

represents the total options in second layer of traveller n ; R_{mn} represents the total options in first layer of traveller n in node m. It is worth noting that layering principle of Nested Logit model is usually to put the option with larger similarity in the same layer. According to what is derived from reference[11,12], the probability of traveller n selecting option r based on option m :

$$P_n(r|m) = \frac{e^{\lambda_1 V_n(r|m)}}{\sum_{r=1}^{R_{mn}} e^{\lambda_1 V_n(r|m)}}, \quad (3)$$

IV of option m in the upper layer is as below:

$$V_{mn}^* = \frac{1}{\lambda_1} \ln \sum_{r=1}^{R_{mn}} \exp(\lambda_1 V_n(r|m)), \quad (4)$$

Then, the probability of traveller n selecting option m is as below:

$$P_n(m) = \frac{e^{\lambda_2 (V_{mn} + V_{mn}^*)}}{\sum_{m=1}^{M_n} e^{\lambda_2 (V_{mn} + V_{mn}^*)}}, \quad (5)$$

The utility of traveller n selecting option rm is as below:

$$U_n(rm) = V_n(r|m) + V_{mn} + \varepsilon_n(r|m) + \varepsilon_{mn}, \quad (6)$$

Where, $V_n(r|m)$ is the fixed item of traveller n selecting option rm ; V_{mn} is a fixed item irrespective of r, but only changed with m ; $\varepsilon_n(r|m)$ is the probability item of traveller n selecting option rm ; ε_{mn} is the probability item of traveller n selecting option m.

Data analysis

4680 out of 5000 random samples from survey data of residents in Beijing city in 2013 times were screened. 3 choice branches in choice layer of activity space include respectively <5Km, 5 ~ 10Km and >10Km. The travel mode and space in samples were showed as in Table 1.

TABLE 1: Observed results of different travel mode and space

Travel model	**Travel distance**					
	<5KM		5-10KM		>10KM	
	Sample size	Percentage	Sample size	Percentage	Sample size	Percentage
Walking	1002	45.82	-	-	-	-
Bicycling	729	33.33	111	10.83	35	2.38
Car	267	12.21	497	48.49	945	64.37
Public traffic	189	8.64	417	40.68	488	33.24
Total	2187	100	1025	100	1468	100

Variables selection

The final choice of traveler is subject to the social economic characteristics in traveler and families[9]. The residence location includes the central area and the urban area. The choice set of travel modes includes walking, bicycling, car and public traffic (bus and subway).

CALIBRATION RESULTS OF PARAMETERS

As per definitions and classification of explanatory variable shown in Table 2, give the NL data structure of disaggregated and integrated model in Table 3.

TABLE 2: NL model variables and descriptions

Variables	**Description**
Travel time	Real value, numerical variable
Travel cost	Real value, numerical variable
Gender	Male 0, female 1k, classification variable
Age	3 age stages: 15-29/ 30-45/ 45or above
Job	Institutions or state-owned / private enterprise or foreign company / other
Monthly income	3 categories: < 5000/5000-10000/>10000
Car possession	No 0, Yes 1
Travel O&D	Traveller's departure and destination: H-W/H-S/H-O/W-O/0-0
Residential area	Central area 0, urban area 1

Note: the central area includes Dongcheng District and Xicheng District, the urban area includes Haidian District, Chaoyang District, Shijingshan District and Fengtai District. H-W indicates travels between the residence and work locations. S indicates schools, O indicates hospital, entertainment, shopping and other locations

TABLE 3: NL integrated model data structure

Option	Level 2				
	Result	Inherent dummy argument		Travel O&D	Residential area
Level 2		X_{m1}	X_{m2}	X_{m3}	X_{m4}
<5Km	I_{1n}	1	0	X_{1n3}	X_{1n4}
5～10Km	I_{2n}	0	1	X_{2n3}	X_{2n4}
>10Km	I_{3n}	0	0	X_{3n3}	X_{3n4}
Parameters	λ_2	θ_1	θ_2	θ_3	θ_4

Option		Level 1							
		Result	Inherent dummy argument			Time	Cost	Gender	…
Level 2	Level 1		$X_{(r\|m)1}$	$X_{(r\|m)2}$	$X_{(r\|m)3}$	$X_{(r\|m)4}$	$X_{(r\|m)5}$	$X_{(r\|m)6}$	…
<5Km	Walking	$I_{(1\|1)n}$	1	0	0	$X_{(1\|1)n4}$	$X_{(1\|1)n5}$	$X_{(1\|1)n6}$	…
	Bicycling	$I_{(2\|1)n}$	0	1	0	$X_{(2\|1)n4}$	$X_{(2\|1)n5}$	$X_{(2\|1)n6}$	…
	Car	$I_{(3\|1)n}$	0	0	1	$X_{(3\|1)n4}$	$X_{(3\|1)n5}$	$X_{(3\|1)n6}$	…
	Public tra	$I_{(4\|1)n}$	0	0	0	$X_{(4\|1)n4}$	$X_{(4\|1)n5}$	$X_{(4\|1)n6}$	…
Parameter			β_1	β_2	β_3	β_4	β_5	β_6	…

As per Table 3, the utility function is as below:

$$V_{in} = \theta_i + \sum_{j=3}^{4} \theta_j X_{inj}, i = 1,2;\ V_{3n} = \sum_{j=3}^{4} \theta_j X_{3nj}$$

$$V_{(r|m)n} = \beta_r + \sum_{j=4}^{10} \beta_j X_{(r|m)nj}, r = 1,2,3; m = 1,2,3;$$

With the parameters calibration of surveyed travel sample data of residents of Beijing city in 2013, the results are shown in Table 3. In Table 3, the absolute value of every parameter by *t* test is greater than 1.96, suggesting that the parameter has impacts on the choice results at a confidence level of 95%. By detailed analysis of each parameter, it is concluded as below:

(1) The residents living in central area concentrate in activity scope more and are more willing to travel within less than 5Km distance. The residents living in urban area disperse more in activity scope. This suggests adequately that the mixed land use has a higher extent in central area in Beijing City. The higher the land use extent is, the smaller the traveller's travel scope will be.

(2) When the travel distance is less than 5Km, people are more willing to walk and ride a bike. With increasing travel distance, people are more willing to use public traffic and private cars when at 5~10Km and larger than 10Km. This is fully agreed with surveyed statistic data.

(3) Similarly, the family's month income is also a key effect on the choice of travel space and mode. Families with lower income are more likely to choose walking, bicycling and public traffic modes. Such travelers are still willing to select bicycling even if the travel distance becomes larger.

(4) The age has a significant effect on travel mode choice. The calibration results showed that travellers aged 15-29 have a positive effect on public traffic mode, travellers aged 30-45 have a positive effect on private car mode. Travellers aged more than 45 have a negative effect on bicycling.

(5) The number of family-owned cars also has a significant influence on travel mode choice.

(6) The hit rate measurement model, one of model evaluation indexes, is defined as below:

$$HitR = \sum_{n=1}^{N} \sum_{i \in A_n} S_{in} / \sum_{n=1}^{N} J_n$$

$$HitR_i = \sum_{n=1}^{N} S_{in} / N_i$$

Where, $HitR$ and $HitR_i$ represent the overall hit rate in model and hit rate of each choice branch i; P_{in} is the probability of all options and derived by substituting the estimated parameters and explanatory variables in Equation (2)~(5); $\hat{\pi}_{in}$ is the choice results of model prediction. S_{in} is 1, or otherwise 0, when the actual choice results are consistent with the prediction results in model.

$$\hat{\pi}_{in} = \begin{cases} 1, \hat{P}_{in}, \text{whichever is the largest among } i \\ 0, other \end{cases}$$

$$S_{in} = \begin{cases} 1, \pi_{in} = \hat{\pi}_{in} \\ 0, \pi_{in} \neq \hat{\pi}_{in} \end{cases}$$

As per above definition, all estimated values are substituted into the formula to give the hit rate of choice branch above 81% in each layer. The model has a high precision.

CONCLUSIONS

The present paper constructs the disaggregated and integrated model of urban residential location, activity space travel mode choice with 2-layered nested Logit method. The travel survey data of residents in Beijing City in 2013 was selected for calibration of model parameters. The calibration results showed that all parameters have influences on choice results within 95% confidence level. The hit rate of choice branch in each layer of model is above 81%. The model has a high precision. The mixed land use has a higher extent in central area in Beijing City. The travel model choice is closely relate to the capacity of travel space. The abovementioned results show that the 2-layered nested Logit method can better reflect the factors of influence on travel space and mode choices. However, further improvements remain in the present research, such as itemizing travel spaces and considering hitchhiking cars and other travel modes.

ACKNOWLEDGEMENT

This paper is under the support of "cloud-based data services for SMEs innovation platform" project funded by the Research base construction Project (Project No. 11103994703).

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