A TRAVEL DEMAND PREDICTION MODEL WITH FEEDBACK OF TRANSPORTATION NETWORKS INFLUENCE FOR BEIJING*

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1 Introduction

The four-step travel demand model, due to its rationality and practicability, is still popularly used nowadays. With the time passed, though many a progress has been developed to this classical model, these new approaches require more detailed trip and/or activity data, which is currently quite difficult to collect in developing cities from the perspectives of data quality, budget constraints and human resources related to survey implementation. So, this classical model still has some problems in many aspects, especially for developing cities. One of the major disadvantages is that it cannot represent the urban transportation networks' influence on various aspects of trip making and so on.

What's more, the rapid urban development in developing countries now has always been causing the fabulous changes of the urban transportation networks, thereby, the frequent changes of the travel modes and the destination choices of the citizens, etc, almost everyday. Due to these reasons, the above-mentioned drawbacks of this traditional model become problematic, and consequently, the applications of it to the cities of developing countries appear to be fruitless, despite the originally efficacious applications to the developed cities.

Because of the flaws mentioned above and in order to rationally estimate the impact of transportation networks, consequently, the attributes of different travel modes, etc, this paper developed a new travel demand prediction model by explicitly incorporating the feedback between different prediction steps in the four-step model, with application in Beijing, China, 2000. Mainly the software of *TransCAD* is used to perform this new model. Finally, it is found that the proposed prediction model performs better than the traditional one, and the results by the new model can actually reveal the influence of transportation networks, which is helpful especially for urban transportation planning of mega-cities in developing countries.

2 Overview of Beijing Urban Transportation

Beijing, as the political, cultural and original economic center of China, developed very fast, especially in 1990s. The GDP per capita developed from about U.S. $ 369.13[2] in 1986 to about U.S. $ 2807.50[2] in 2000, with the annual increase ratio about 15.59%. And according to the information from Beijing Municipal Bureau of Statistics, in 2000, the population in Beijing was about 13.82 million.

With the rapid urban development, the amount of auto-vehicle increased fantastically, especially in 1990s. Based on the information published on 5th Aug, 2003, by the Chinese government, the auto-vehicle amount in Beijing developed from about 0.39 million to about 1.58 million from 1990 to 2000, with the annual increase ratio about 15.02%. However, from 1991 to 2002, the urban road area only has the annual increase ratios about 7.02%[2]. According to statistics, the amount of auto-vehicles and bicycles in Beijing increased as 15 times and 7 times fast respectively as the urban road resource increased [1]. In 2002, within the 5th ring road of Beijing, the density of the urban road networks was about 2.8km/sq.km [2]. Much to the worse, urban function concentration to the central part of the city caused 50% of the urban transportation concentrated in this area [2]. Further more, for the large public transportation

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passenger volume, bus took about 73.54% [3]; metro took only 11.51% [3]; taxi took about 14.94% [3], which can show us the inefficient urban railway also contributed to the huge stress to the urban road system. According to the statistic of Beijing government authorities, the average speed of bus decreased from 16.7km/h in 1990 to the 9.2km/h in 1996 [1], with the average travel time of the passengers 22 minutes [1] increased.

3 The Feedback Model and Its Estimation

The urban transportation issues in developing countries, for example, in Beijing mentioned above, due to its rapid urban development with the fabulous changes of the urban transportation networks attributes will absolutely influence various aspects of trip-making behaviors, further more, the OD distribution and trip generations/attractions. To properly evaluate the impact of transportation networks and the effect of transportation planning, especially for the cities in developing countries, it is required to explicitly incorporate the feedback of this influence. This paper attempts to establish such feedback model shown in Figure. 1.

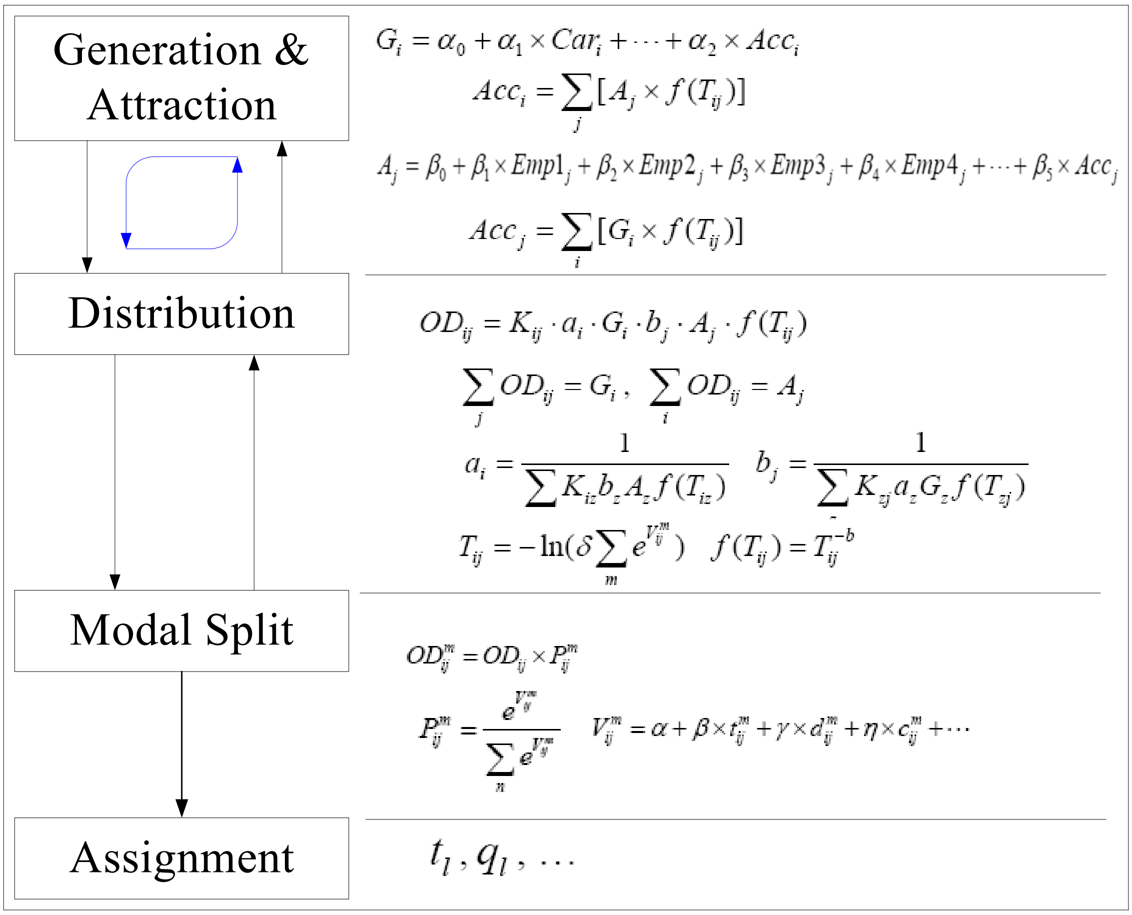

Figure1. The Travel Demand Prediction Model with Feedback for Beijing, China

The new model starts with the estimation of modal split, established based on a multinomial logit (MNL) model, and the inclusive value (i.e., expected maximum utility related to modal choice) calculated from the MNL model is used to represent the total performance of transportation networks An inverse power function of the inclusive value is introduced into the trip distribution model, a double-constrained gravity model, to work as the impedance function for OD trips.

After the estimation of this inverse power function based on the current OD matrix, the trip generation accessibility (Acc_i) and trip attraction accessibility (Acc_j) for each zone are calculated by the impedance function of this double-constrained gravity model and are incorporated into the linear regression models of trip generation (G_i) and attraction (A_j).

The above-mentioned calculation steps also result in a new OD matrix and new generation and attraction volumes of each zone, which further become the basic data for the estimation and application of the gravity model and the regression models in next iteration. By repeating these feedback steps until certain convergence criteria are reached, the final travel demand prediction model is obtained.

It is also possible to incorporate the trip assignment into this repeated process. But in this new model, since the implementation of traffic assignment is very time-consuming, it is done only after the convergence of all the calculation steps with OD matrices of different travel mode in consideration of the operation efficiency of the whole model.

About the convergence criteria, they can be set according to the real situation in the model applications. As for the application to Beijing, the convergence criteria have been set as Figure. 2.

For Trip Generation & Attraction Models

$$Max\left\{\left|\frac{G_i^{k+1}-G_i^k}{G_i^k}\times 100\%\right|,\left|\frac{A_i^{k+1}-A_i^k}{A_i^k}\times 100\%\right|\right\}<0.5\%$$

For Trip Distribution Model

$$Max\left|\frac{OD_{ij}^{k+1}-OD_{ij}^k}{OD_{ij}^k}\times 100\%\right|<0.5\%$$

Small Zone: $i, j=1,2,\cdots m$ Iteration Times: $k=0,1,\cdots$

Figure. 2. Convergence Criteria of the Proposed Model

In the model estimation to Beijing case, with the data from Beijing Transportation Research Center, the urban area is divided into 340 transportation zones. With the convergence criteria reached, the estimated values of the variables parameters in the Multi-Regression models adopted in trip generation/attraction step, shown in Figure.1, become stable. As we can see from Table 1&2, after the last iteration, the t-scores become bigger than 1.0e+006 with the standard errors smaller than 1.0e-006. At the same time, we got the stable value of the index b of the Double Constraint Gravity model for trip distribution, shown in Figure1, which is about 0.277198, and the final mean cost error of the estimation for this Double Constraint Gravity model is smaller than 1.0e-003.

Table 1. Estimation of the Trip Generation Multiple-Regression Model

Variable	Estimate	Std. Error	T-Statistic
α_0	1410.46		
Car_i	0.984003	1.21157e-007	8.12172e+006
Acc_i	0.000953001	1.63613e-009	582472
R^2	0.3804	No. of Sample	340

Table 2. Estimation of the Trip Attraction Multiple-Regression Model

Variable	Estimate	Std. Error	T-Statistic
β_0	45.8703		
$Emp1_j$	0.197426	4.30261e-008	4.58851e+006
$Emp2_j$	0.103034	3.07892e-008	3.34643e+006
$Emp3_j$	0.368740	9.63037e-008	3.82893e+006
$Emp4_j$	0.0698550	3.50129e-008	1.99512e+006
Acc_j	0.00137100	1.87436e-009	731450
R^2	0.7244	No. of Sample	340

As for these two regression models with the estimation results shown in Table 1&2, Car_i means the car number of zone i. $Emp1_j$, $Emp2_j$, $Emp3_j$ and $Emp4_j$ in turn stand for the numbers of 4 different kinds of employment of zone j.

Moreover, as for the correlations between the estimated and observed trips, the accuracy (R^2) of the proposed feedback model is generally improved, contrasted with the estimation results of the traditional four-step model without feedback. For the accuracies of the Multi-Regression models, shown in Figure.1, for trip generation and attraction, the R^2 s, shown in Table 1&2, have the improvements about 0.01, though, the R^2 of the trip generation model is not satisfying, mainly due to the restrict of the basic zonal data quality. For trip distribution, the accuracy of the Double-Constraint Gravity model, shown in Figure.1, is improved about 0.04, with the R^2 about 0.84. In the step of modal split, we have created the inter- and intral-zonal MNL models respectively, which are explained by Table 3&4.

Mark "+" in these two tables means the attribute factor has been chosen. We can also find, in Table 5&6, that the estimation results of these two MNL models are also satisfying. As for the model accuracy, the R^2 s of bicycle, bus, car and railway are from about 0.36 to about 0.72, with only the taxi's about 0.20. Compared with the results of the traditional four-step model, there have been about 0.001 to 0.003 improvements for the R^2 s of the bus, car, taxi and bicycle of the same MNL models.

Table 3. Inter-Zonal MNL Model

Alternatives	Const	Distance	Time	Time Cost
Railway	+			+
Bus				+
Car	+	+	+	
Taxi	+	+	+	
Bicycle	+	+	+	

Table 4. Intral-Zonal MNL Model

Alternatives	Const	Cost	Time Cost
Railway	+		+
Bus	+		+
Car	+	+	
Taxi		+	
Bicycle	+	+	

Table 5. Estimation of Inter-Zonal MNL Model

Parameter	Estimate	Std. Err.	T-Test
Const	-0.788657	0.011733	-67.214362
Distance	-0.565954	0.003311	-170.944745
Time	-0.003822	0.000314	-12.164232
Time Cost	-0.035203	0.000209	-168.091594
ρ^2 :0.516763; $\bar{\rho}^2$:0.516740; Sample No.:112654			

Table 6. Estimation of Intra-Zonal MNL Model

Parameter	Estimate	Std. Err.	T-Test
Const	-2.456117	0.955945	-2.569309
Cost	-0.067177	0.013760	-4.882186
Time Cost	-0.067177	0.004395	-2.642217
ρ^2 :0.159883; $\bar{\rho}^2$:0.153404; Sample No.: 334			

While, it is a pity that along with the unimproved accuracy of the railway choice of the MNL models, the accuracy of the Stochastic User Equilibrium (SUE) assignment method also shows no improvement, with the R^2 still about 0.59 as the R^2 of the SUE method in the step of trip assignment of the traditional four-step model, due to not only the error diffusion process between each iteration step, but also the incapability to consider the inter-influence of different travel flows on different networks, with only the bus passenger flow, railway passenger flow and road traffic flow individually assigned to the bus network, rail network and road network, restricted by basic network data.

4 Conclusions and Future Research

This paper established a new travel demand prediction model with feedback for Beijing, China. Such model with feedback provides a more practical way to reflect the impact of transportation networks attributes changes on various aspects of trip-making behaviors, further more, the OD distribution and trip generations/attractions as well as fast urban land use development, etc, in developing cities. The goodness-of-fit indices for estimation steps are also satisfactory.

Though the new model performs better than the traditional one, the trip estimate accuracy of this new model still depends on the quality and quantity of the basic data, for example the low R^2 of the multi-linear regression model for trip generation shown in Table 1, due to the zonal data restriction. So by the comparison with the traditional four-step model without feedback, due to lacking of enough convictive basic data, also because of the error transitions, etc, though the proposed model can wholly enhance the model accuracies, the improvement is not very apparent. Besides, the inclusion of the trip assignment step into the feedback iteration calculations and the improvement of model operation efficiency after the inclusion of trip assignment step are the key points in the future research.

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