Integrated Multimodal Metropolitan Transportation Model

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Abstract

This paper reveals the disadvantages in the current urban transportation models in China and proposes an integrated region-urban multimodal transportation model based on the traditional four step method. The model introduces a time allocation step, suggests better approaches in steps such as trip distribution and mode choice, and improves the connections among each model. This model framework incorporates the land use and transportation system, and is capable to evaluate the impact of land use and facility construction. Disaggregate travel behavior analysis is applied in the model for various steps to improve the accuracy in forecasting. The framework is suggested as a reference to improve the urban transportation model and integrate the urban planning and transportation planning closely.

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Keywords: transportation planning, integrated-multi-layer model, destination choice model, market segment

1. Introduction

With the continuing urban sprawl, traffic congestion is the critical issue in most metropolitan areas, which influence the performance of social activities and daily lifestyle. This is substantially caused by the spatial incoordination between the traffic demand and the capacity of transportation facilities. Hence, coordinated development of land use and urban transportation system is a basic approach to relieve the traffic congestion. And therefore, an integrated multimodal transportation model is required for urban and metropolitan areas (Waddell, 2002), incorporating land use/economy growth models, transportation planning models and supplemental models, such as emission model. This systematic model can provide the current and predicted traffic situation, examine the effectiveness of improvement scenarios, evaluate the urban development plan, and support the decision and policy making for land use and transportation operation and management.

The first transportation model is the land use and transportation model in United States based on the travel survey in 1944. After 1950s, the model is improved to the traditional four-step model (including trip generation, distribution, mode choice and traffic assignment), which is applied to many regions and metropolitans for urban transportation planning (Black, 1981). The four-step model are further studied with disaggregate destination choice, mode choice models to improve the accuracy of forecasting (Ben-Akiva and Lerman, 1985; Hensher and

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At present, most of the metropolitan transportation models are developed based on the traditional trip based model with various compositions and structures (Horowitz and Farmer, 1999; Mishra et al., 2011). In addition, there are some tour-based, activity-based travel demand models (Bowman and Ben-Akiva, 2001), and integrated large-scale land use and transportation models under development and applied (Wilson, 1998) outside China. These integrated regional planning models are still in progress in China. For example, by the end of third stage of the transportation model for Shanghai, the trip distribution is still gravity model and growth factor model, and divided logarithm method is still used for mode choice (Lu et al., 2008). A multi-level model is designed for Beijing with regional-city-district planning and micro-simulation, but not connected efficiently (Li et al., 2008). Other models for Nanjing, Kunming and Shenzhen are discussed in (Ling et al., 2008) with varieties of limitations and advantages. Overall, there are some insufficiencies in the current model in China: (1) targeting at personal trips only, without considering the regional passenger travel and freight movement; (2) Static analysis of travel demand forecasting without variance over time of day and day of week; (3) aggregated model with few discrete travel behavior studies. Additionally, the properties of roadway segments, such as mixed bus, car and bicycle use are not defined in the network construction; connections between transfers are always ignored in mode choice analysis. There are also no supplemental models for energy use, gas emission and air quality study which is a major concern in many metropolitan areas.

This paper proposes a framework of integrated multi-layer transportation model based on the current transportation models in China and experiences from foreign countries to fill the gap in urban transportation planning model.

2. Framework of integrated transportation model

2.1. Compositions

Firstly, this model is composed by multiple components covering region and urban wide passenger and freight movements. Also, different models should be conducted for weekday/weekend, peak hour/off-peak because travel patterns are different over time period. Disaggregate methods and market segments can be used in destination choice to replace gravity model. This framework divides the traditional four-step model for the overall system to several modules with different four-step models with specialty according to the targets. Besides, the integration of land use and transportation system is considered by connections in economy growth module, land use module and transportation module. (Figure 1) Interactions and feedbacks among the modules are jointly used in the framework instead of the usage of land use factors in trip generation and distribution only.

![Fig. 1. Compositions of the integrated framework](image-url)
2.2. Framework Structure

The proposed framework of integrated land use and transportation model suitable and feasible for urban areas in China is shown in Figure 2.

Fig. 2. Structure of the integrated framework

The interaction and feedback is considered in this framework. Transportation module is the major component, but regional economy growth and land use modules are also closely linked to connect land use factors and feedbacks of trip distribution results for various economy and land use policies and scenarios. This framework also separates the trips in regional and urban areas to capture the impact of regional traffic on the city center, such as external trips and bypass trips. Passenger travel and freight movement are analyzed in both regional and urban level independently and assigned to the network in the end. This framework also contains a time allocation step to integrate the multi-level study area and passenger and freight movements.

3. Model Components and Connections

3.1. Regional Level Model

Regional model is focusing on the trips with either end outside the urban area for passenger and freight separately. This layer is partitioned to regional model zones according to boundaries of urban districts and counties.

Passenger travels are estimated by regional or intercity travel survey and the historical daily traffic volume by car, bus, air, train and water. They are studied by three types of Origin-Destination (OD): (1) External-Internal
(EI) trips made by households or persons entering urban area from the outside; (2) Internal-External (IE) trips generated within urban area and distributed to other regional area; and (3) Bypass trips with stops in the urban area. Freight movements are estimated by the commodity flow by truck air, train and water, and also three types of OD as passenger movements.

Freight travels are estimate according to the commodity flow survey and the historical daily freight activities by all kinds of modes. The commodity flows and related freight transportation activity need specific to county level.

The output from the regional model counts few in the urban traffic volume, and the disaggregate model for the regional level requests more tasks in travel survey. Therefore, aggregated analysis is preferred initially based on the traffic volume and the commodity flow. And the disaggregate approach can be further developed continuously.

The IE and bypass trips obtained in the regional model are used as input to time allocation directly and assigned to urban network. The EI trips (outcome from visitor model) are inputted to urban trip generation model and distributed with other urban level trips.

3.2. Urban Level Model

3.2.1. Urban Passenger Model

3.2.1.1 Trip generation model

Regression model and category analysis model are commonly used for trip generation. The factors in regression models reflect the correlation between base year trip production and the independent variables. These factors are not appropriate to describe future year when the land use changes dramatically. Category analysis model consider the household type only, while in reality, the trip generation varies by trip purpose even from the same type of households in the same zone. In this paper, a multilayer category analysis model is proposed for the integrated transportation model. The first layer is the location (central area, other downtown area, inner suburban areas, and outer suburbs); the second layer is the cross-classification of family type by number of persons (1,2,3,4,5 or more) by number of workers (1,2,3 or more) and by average monthly income per person (such as < ¥2000, ¥2000 to ¥4000, ¥4000 to ¥6000, ¥6000 to ¥10000, ¥10000 or more), the third layer is the trip type divided into home-based work trips (HBW), home-based shopping trips (HBS), home-based other trips (HBO), non-home-based work trips (NHBW), non-home-based other trips (NHBO). The formula is given as follow:

\[
P_{ki}^{m} = \sum_{s} a_{s}^{m} \times N_{s ki}^{m}
\]

Where, \( m \) is the trip type (HBW or HBS or HBO or NHBW or NHBO); \( k \) is the location type (central area, other downtown area, inner suburban areas, and outer suburbs); \( i \) is traffic analysis zone (TAZ) number; \( P_{ki}^{m} \) is the \( m \) trip production of TAZ \( i \) which is belong to location \( k \); \( s^{m} \) is the family type \( s \) with trip purpose \( m \); \( a_{s}^{m} \) is the \( m \) trip rate of family \( s \) belong to location \( k \); \( N_{s ki}^{m} \) is the number of family \( s \) with trip purpose \( m \) in TAZ \( i \) belong to location \( k \).

Similarly, trip attraction model are segmented by location, trip purpose and employment type instead of simply classification of job or land use. The production and attraction rate are achieved from travel survey and regression analysis. The advantages of the above market segment model are capturing the location factors, and increasing the accuracy of predictions for home-based trips and flexibility with changes in land use scenarios. This model is less complex than disaggregate models and suitable for travel demand forecasting, statistical analysis and comparison among planning scenarios.
3.1.2.2 Trip Distribution model

The growth factor model and gravity model used for trip distribution has limitation in explaining individual travel behavior and estimating impact of individual characteristics and their preferences as well as policy changes. Here, a discrete choice model for destination choice is suggested incorporating location, household type, destination zone employment density and travel cost. The utility of choosing a trip destination \( j \) for a trip \( n \) produced in zone \( i \) is given by (Mishra, S. et al., 2013):

\[
U_{ijn} = S_j + \alpha \times L_{ij} + \sum \beta^m \times D^m_{ij} + \sum \beta^m \times N^m_{ij} + \sum \beta^m \times Z^m_j + C_{jn} 
\]

(2)

Where, \( S_j \) is the size variable for destination zone \( j \); \( L_{ij} \) is the mode choice logsum between zone pair \( ij \); \( D^m_{ij} \) represents the various distance terms (linear, log, squared, cubed and square root); \( N^m_{ij} \) represent person, household or production zone characteristics for trip \( n \) and is used for creating interaction variables with distance terms; \( Z^m_j \) represents attraction zone characteristics (other than the size term); and \( C_{jn} \) is a correction term to compensate for the sampling error in the model estimation (i.e., it represents the difference between the sampling probability and final estimated probability for each alternative); \( \alpha \) and \( \beta^m \) is parameters.

This model provides accurate trip distribution prediction and is sensitive to various planning situations with flexible combinations of household type, destination zone employment and cost. The model can also be applied to different trip purposes (work, shopping, and other) with different coefficients.

3.2.1.3 Mode choice model

Multinomial logit model is commonly used to estimate the share of each mode. The probability of mode \( j \) chosen is as follow (Liu, 2001):

\[
P_j = \frac{\exp(bV_j)}{\sum_{i \neq j} \exp(bV_i)} = \frac{1}{1 + \sum_{i \neq j} \exp[b(V_j - V_i)]} 
\]

(3)

Where \( b \) is parameter, and \( V_j \) is the utility of mode \( j \). \( V_j \) is usually obtained by linear regression. But the utility function of different mode should be different with different variables.

In addition, the nested logit model is widely used because the choice alternatives are not independent from each other. There are various types of nest structures for mode choice model. Two limitations in the current mode choice model are: (1) the variables are simply combinations of cost/income, travel time, walking time, and not include the traffic character and individual attributes; (2) the model structure is simple with several traffic modes (e.g. car, bus, and subway) and without considering the joint mode. Here we take the advantage of both multinomial logit model in utility function and nested logit model in nested structure. And also for overcoming the limitations, more comprehensive variables are included, such as travel characters (cost, duration, transfers), individual and household attributes (value of time, vehicle ownership, and so on), regional attributes (e.g. parking), and trip properties (purpose, time period). In addition, alternatives for mode choice should be more detail, such as nested structure with transfer or connection types (see Figure 3).
3.2.2. Urban Freight Model

Aggregate models are suggested for freight demand model because it is less complex and diverse than passenger travel. The vehicle types are categorized as small, medium and large trucks. Trip production and attraction rate for each region, employment type, and vehicle types are estimated from regression analysis. Then gravity model is used for trip distribution (Mishra, S. et al., 2013).

\[
T_{ij} = \frac{P_i \cdot A_j \cdot F_{ij}}{\sum_i (A_i \cdot F_{ij})}
\]  

(4)

Where, \(T_{ij}\) is trip number between production zone ‘i’ and attraction zone ‘j’; \(P_i\) is trip production in zone ‘i’; \(A_j\) is trip attraction in zone ‘j’; \(F_{ij}\) is friction factor between zone ‘i’ and ‘j’.

Friction factor is a function of composite impedance and cost components. The function of friction factors takes the following form (5):

\[
F_{ij} = \alpha \cdot (CT_{ij})^2 \cdot \exp (\gamma \cdot CT_{ij})
\]  

(5)

Where, \(CT_{ij}\) is composite travel time from i to j; \(\alpha, \beta, \gamma\) is parameters. And the composite travel time can be the combination of HT (actual travel time) and VT (toll divided by value of time).

3.2.3. Traffic assignment model

At first, the generated flow in OD matrix for the whole day is allocated to morning peak, noon, evening peak and night. For example, 7:00-9:00 for morning peak, and 16:00-18:00 for evening peak for Shanghai (SHUCM, 2010). Then the traffic assignments are conducted for each time period. Feedbacks are responded to the network for several iterations to fill the gap in static assignment.

To pay attention, the network should also be constructed according to the time period, such as the restricted left turn, or constrained lanes at peak hours.

3.3. Interactions among the models

The input and output of each model are connected in this multi-layer framework. Figure 4 shows the connection of transportation module. For example, the outputs from land use and economy growth model are
used as the input to trip generation model, such as the household characteristics. Regional EI model results are
collected in urban passenger trip generation model. The outcome of all the regional and urban passenger
and freight models are the input to the time allocation model. Traffic flows achieved from the traffic assignment
model are used as feedback to the network, and then trip distribution is updated iteratively to reach stable traffic
assignment. And the final results of traffic module are the input of other models, such as emission model.

[Diagram: Input and output between models]

Fig. 4. Input and output between models
3.4. Supplemental models

This framework is compatible with other supplemental models to calculate energy consumption, gas emission, and air quality, etc. For example, the output of the traffic flow by time and roadway segment can be used to calculate the emission because a large percent of emission contribution arises from transportation modes are primarily from auto and truck travel. From the transportation module, the road function and the volume of each type of vehicle are obtained, so we can use the travel miles and the emission unite of each type of vehicle to get the total emission (Mishra and Welth, 2012). The accessibility and connectivity of the land use can be obtained from the model as a measurement to evaluate different land use scenarios, and also feed back to land use model as a parameter for residents and employees location choice.

4. Conclusions

This paper reveals the disadvantages in the current urban transportation models in China and proposes an integrated region-urban multimodal transportation model based on the traditional four step method. The model introduces a time allocation step, suggests better approaches in steps such as trip distribution and mode choice, and improves the connections among each model. This model framework incorporates the land use and transportation system, and is capable to evaluate interactions between land use and transportation planning. Other supplemental models are compatible to calculate measurements of further interests, such as air quality, land use accessibility and connectivity. Disaggregate travel behavior analysis and market segment are applied in the model in various steps to improve the accuracy in forecasting.

The development and application of the model can be supported in Cube, with Cube script and Java. Parameters can be estimated based on urban and region wide travel survey. The framework is suggested as a reference to improve the urban transportation model and integrate the urban planning and transportation planning closely.

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