A DYNAMIC MULTI-MODAL TRANSPORT SIMULATION MODEL

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1. Introduction

This paper discusses the development of a dynamic multi-modal transport simulation model. Conventionally, multi-modal transportation system analysis is only carried out in a static framework and dynamic framework is limited to the single mode i.e. road traffic. The decision making process of an individual regarding use of transport system involves mainly three types of decisions namely, departure time choice, mode choice and route choice. This research models these three choice processes in a dynamic framework. Departure time choice along with mode choice provides the time dependent demand for each of the mode. This fact should also be appreciated that the transport supply also changes with time for example the supply of the public transport changes with change in frequency during different times of day and the road traffic which is a non-stationary phenomenon especially during the congested time periods due to evolution and dissipation of queue is also a dynamic process which changes over time. Static analysis ignores these time-dependent variations which prohibits the application of such models to analyze the policies which are time-dependent such as time-varying road pricing. This research extends the dynamic modeling from a uni-modal (i.e. road traffic) case to a multimodal case in addition to the departure time choice modeling.

The paper is organized as following: Section 2 provides the background and literature review of the existing research in this area. Section 3 provides the framework of the overall proposed model and a brief introduction to different components of the model. Section 4 provides details about the case study using the proposed methodology in addition to the data requirements and data sources. Section 5 provides the conclusion and future research direction.

2. Background and literature review

In the past, attempts have been made to model the dynamic nature of the transportation systems. Most of these models are trying to model the dynamic aspect of the supply side i.e. these are dynamic traffic assignment models. Peeta and Ziliaskopoulos[1] provide an extensive overview of these types of models. These models consider the time-dependent variations in supply side but ignore one of the important aspects of the demand side which is departure time choice. In recent years, few attempts have been made to incorporate the departure time choice for the dynamic network analysis[2)-6)] but these models only consider one mode i.e. road traffic. One of the important aspects which are ignored in this study are the mode choice models. Public transport modes such as rail and bus are competing with the road traffic and any policy affecting the road traffic is also going to affect the public transport and vice versa. Mode choice which is a behavioral aspect and affects the demand model is dependent on the dynamic changes in the public transport supply model such as different frequencies during different times of day and different congestion levels inside public transport which affects the comfort of the users.

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3. Framework of proposed model

The limitations of the existing dynamic transportation models described in the previous section highlight three important issues which are dealt in this study:

1) Departure Time Choice
2) Mode Choice
3) Multi-modal network

Figure 1 illustrates the flow chart of the proposed framework. The important components and working of the proposed model is explained in the following sub-sections.

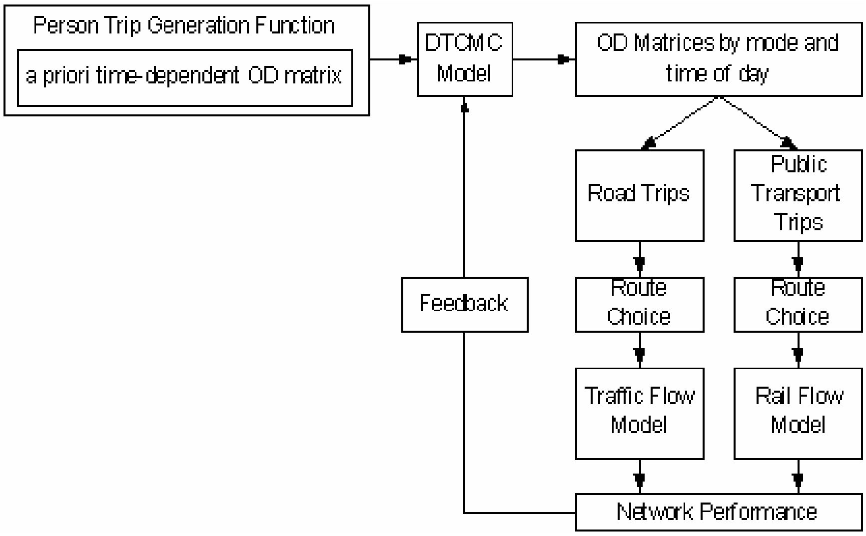

Figure 1: Proposed Model Framework

(1) Person Trip Generation Function

The model uses a time-dependent Origin-Destination matrix which is estimated a priori. This OD matrix acts as an exogenous input to the model. The departure time choice model adjusts this a priori OD matrix to minimize the disutility under the assumption of rational behavior.

(2) Departure Time Choice and Mode Choice Model(DTCMC Model)

Users of the transport system need to make two choices before using the system; these are departure time and mode choice. These choices can be made simultaneously or in a hierarchal order such as first deciding the mode and then departure time or first deciding the departure time and then deciding mode.

The basic assumption in this model is that each individual has a preferred arrival time to reach his destination and the departure time decision is made keeping in mind that preferred arrival time. Following Small[7], utility for a trip departing at time *t* can be formulated as given below:

$$U(t,m) = \alpha . TT(t,m) + \beta . C(t,m) + \gamma . EAP + \lambda . LAP + \beta' . L$$

where, *t* represents departure time and *m* represents the mode. *TT(t,m)* and *C(t,m)* represent the travel time and cost of using mode *m* at departure time *t*. The travel time may be constant but perceived cost may be varying for the different departure times using public transport due to different congestion levels as cost depends on congestion also. For road traffic, travel time may differ during different times of day depending on the congestion and cost may also differ depending on the time-varying tolls. Also,

$$EAP = \max(PAT - t - TT, 0) \quad and$$
$$LAP = \max(t + TT - PAT, 0)$$

where, *PAT* is Preferred Arrival Time, *EAP* represents the Early Arrival Penalty and *LAP* represents the Late Arrival Penalty. *L* is a binary variable representing whether the arrival is later than *PAT* or not.

$$L = \begin{cases} 1 & if\ LAP > 0 \\ 0 & otherwise \end{cases}$$

Estimation of the parameters $\alpha, \beta, \gamma, \lambda, \beta'$ is a part of this research.

This model provides the time-dependent origin and destination matrix which serves as an input to the simulation of each mode. In present case, we are only concentrating on two modes i.e. car and rail. Hence the output of this model provides the input for the traffic and rail simulation.

(3) Rail Route Choice and Flow Model

After getting the time dependent OD matrix for rail users, the next step is the route choice between each OD pair. The route choice model in this case is based on the logit choice model. The assignment methodology used is Stochastic Users Equilibrium. Dial[8] proposed an algorithm for solving the stochastic user equilibrium using logit model. We utilize the same methodology in this study. The generalized cost of each path consists of the congestion cost and transfer cost in addition to the travel time and fare. The congestion cost represents the discomfort of boarding a congested train while the transfer cost represents the discomfort of changing the train.

(4) Traffic Flow Model

For the traffic flow model an existing dynamic traffic simulation model named SOUND[9] will be used. This traffic simulation represents the traffic flow mesoscopically. Traffic assignment procedure used in this model is Dynamic User Optimal (DUO) which implies that each user tries to minimize the cost based on current information. This model also uses Dial's algorithm[8] for stochastic user equilibrium based assignment.

(5) Feedback

As the proposed model is a multi-modal dynamic transport simulation model including departure time choice, hence at equilibrium a user cannot switch either departure time choice, mode and/or route in order to reduce his disutility. This condition is quite difficult to achieve in one run of the proposed simulation model. For this reason, it may be necessary to include a feedback loop which will update the network performance in a day-to-day learning fashion in order to achieve the equilibrium.

4. Case Study and Data

The above described multi-modal transport simulation model is planned for application on Tokyo Metropolitan Area network. This network consists of the following sub-networks:

a. Zone configurations

This study uses the data from Person Trip Survey 1998, the keikaku zones which are medium-level zones are used as origin and destination zones. The Daily trips between each OD pair are estimated from the PT survey in addition to distribution of trips during different times of the day. Yellow polygons in figure 2 show these OD zones. The size of the zones varies with populations and is small inside the city area where population densities are higher and large in suburbs where population densities are lower.

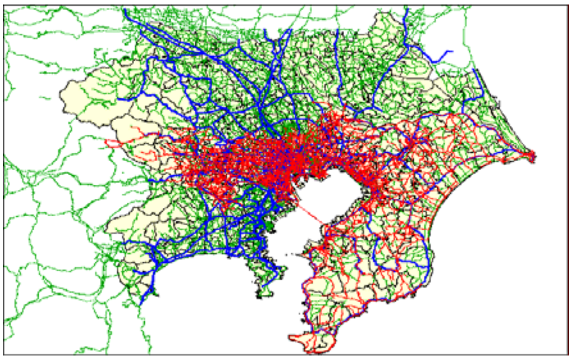

Figure 2: Tokyo Metropolitan Area Multi-modal Network

b. Road network

Road network data is extracted from the Digital Road Map (DRM), which is prepared by Japan Digital Road Map Association. A dense network of roads inside the target area while a sparse network in surrounding area is used. This database includes information such as type of road, number of lanes and speed limit etc.

c. Railway network

This includes the network of all the railway lines inside the target area. All the links are represented as one-way links. In addition to routes, few extra links are added such as access links to connect the stations to the zonal centroids as well as dummy links to represent the transfer between two railway lines. The stations are represented as nodes; there are 1671 stations. This data includes the length of each link as well as average speed estimated from train timetables. Frequency of trains is also included during the morning peak, daytime and evening peak periods.

(1) Stated Preference Survey

A stated preference survey is in progress in Tokyo Metropolitan Area in order to collect data to estimate the parameters of the departure time choice and mode choice models. The target group in the survey is the morning commuters. Two types of scenarios are presented to each user, ones with a fixed preferred arrival time and others with a flexible arrival time window of 2 hours. A fractional factorial design strategy[10] is used to design the stated choice experiments. This survey also elicit the preferred arrival times of the users in order to build a distribution of the preferred arrival times for the whole population to use in simulation.

The design of questionnaire is based on joint departure time and mode choice scenarios. Attributes used are cost, travel time, early arrival time or late arrival time. Twenty five hundred questionnaires are distributed in 50 "chochomoku"s, 10 each in Saitama, Chiba, Kanagawa, Tokyo 23 wards and Tokyo Tama areas. The selection criteria were areas having access to

Figure 3: Selected "chochomoku"s for questionnaire distribution

both rail and expressway and within 70 minutes commute from downtown Tokyo.

(2) Railway Simulation

Railway simulation model is developed to evaluate the network performance for the multi-modal transport system. As a preliminary study, we developed the model using an hourly OD matrix for the whole day. The details of the model are already mentioned in section 3-(3). As the model also considers the congestion cost inside the railway as part of the utility function, hence it renders it as an iterative model which updates the congestion cost in each run until the change in congestion cost becomes negligible. The simulated daily link volumes (aggregated for the whole day from hourly link volumes) are compared against the observed daily link volumes of each link as shown in figure 4. The results show a good correlation when volumes are low but in some high volume links, simulated volumes are underestimated. A closer examination of these links reveals that these links are located inside the city area where many of the links overlap each other and are not much different from each other in selection. One probable reason for this poor performance may be the Independence of Irrelevant Alternatives (IIA) property of logit model which is used for this study. We need to test some alternative route choice model structures such as c-logit in order to overcome the IIA problem.

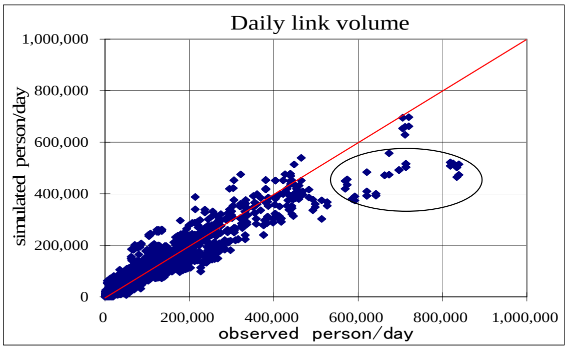

Figure 4: Comparison of simulated vs. observed link volumes of railway

5. Conclusions and Future Research

This paper introduces the framework of a multi-modal dynamic transport simulation system and provides a detailed outline of the different components. This work is still in progress and authors are in the process of developing behavioral models of departure time choice and mode choice as well as preparing the data for the supply models of the transport simulation ie. traffic and railway simulation. Few preliminary results from the railway simulation are presented. Authors hope to complete and improve these models in near future.

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