Application of Micro-Simulation on Truck Route Choice Model

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Abstract: The journey speed along an arterial road depends not only on the arterial road geometry but also on the traffic flow characteristics and traffic signal coordination. The reliability of travel time is one of the most important issues in the planning of logistical operations. The estimation of travel time information is a hard task. Most logistical models consider travel time as input data (vehicle routing problem, and some facility location problem) assuming an average travel time value based on probe vehicles, VICS, or volume-delay estimations such as BPR functions. In this paper, micro-simulation is used to incorporate the detailed dynamics of travel times into the route choice of freight vehicles as an alternative to improve the stochasticity of the travel times used by the logistical models.

Key Words: Micro-simulation, Freight vehicle Route Choice, Cognitive Cost

1. INTRODUCTION

Travel time information is an important issue in transportation planning and logistics. It has been applied in various Intelligent Transport Systems, such as in-vehicle route guidance and advanced traffic management systems. However travel time is affected by a range of different traffic factors such as efficiency of signal controls and traffic volume, making the accurate prediction of travel time a difficult and data consuming task. Understanding those traffic factors affecting travel time is essential for improving prediction accuracy in related travel time studies.

Free flow travel speed is one of the factors that affect travel time. However, the journey speed along an arterial road depends not only on the arterial road geometry but also on the traffic flow characteristics and traffic signal coordination (Lum et al., 1998). Other main factors related to travel time prediction that have also been cited in previous studies include holiday and special incidents (Karl et al., 1999), signal delay (Wu, 2001), weather conditions (Chien and Kuchipudi, 2003), traffic operation (disturbed level) and congestion level (traffic flow) (Richardson 2004; 1978). The greater the length of the forecasting period, the higher the prediction error (Kisgyorgy and Rilett, 2002). The adoption of specific variables for prediction will determine the efficiency and accuracy of the travel-time prediction model.

Simulation is a valuable decision support tool for evaluating transportation policies or systems (Paul and Kevin, 1994). The application of simulation in transportation field is wide extending from as small applications such as traffic signal optimization at an individual intersection to wide scale applications such as evaluating national transportation strategies. Simulation provides a path for the evaluation of transportation designs or strategies without any breakdown test. Many tests that are difficult to be examined before can be analyzed easily.
now (Marcelo, 2002).

Through the assistance of better computer power and modeling techniques, the process of modeling becomes far faster and easier than before. Therefore, transport professionals start trying to predict real-time traffic conditions for gaining more understandings from dynamic modeling. Several software have been developed specifically for transportation and traffic engineering purposes. In this paper, VISSIM is used as a travel time evaluation tool to the freight vehicle route planning, feeding simulated travel times to a route choice model. VISSIM is a microscopic traffic simulator developed by PTV AG (Germany) using the Wiedeman car-following model.

Simulation can capture statistics on the variability of traffic characteristics (Paul and Kevin 1994). Anderson and Bell (1998) used traffic data generated from a traffic simulator to develop further research. Also simulation has the ability to trace entities through a system of multiple processes and operations. In the applications of simulation in traffic engineering, transport professionals use both microscopic and macroscopic concepts to produce forecasted data for safety improvement, driver behaviors analyses, traffic-signal optimization, network planning, and others.

The results of simulation, specially micro-simulation can be applied to construction feasibility studies, signal design, fuel consumption, traffic study, railroad capacity studies, train operation studies, ITS, etc. This paper intends to further develop the application of micro-simulation in logistical studies, where the development of vehicle routing algorithms consider and require travel times variability during the time of the day and hypothetical travel times in case of special scenarios, such as disruption of the normal traffic due to natural disasters.

2. MICROSCOPIC TRAFFIC SIMULATION FOR LOGISTICAL PLANNING

The reliability of travel time is one of the most important issues in the planning of logistical operations. The estimation of travel time information is a hard task. Most logistical models consider travel time as input data (vehicle routing problem, and some facility location problem) assuming an average travel time value based on probe vehicles, VICS, or volume-delay estimations such as BPR functions.

Micro-simulation can be used to incorporate the detailed dynamics of travel times into the route choice of freight vehicles as an alternative to improve the quality of the travel times used by the logistical models. The applications of micro-simulation in logistics planning also include evaluation of tours, route choice behavior, fleet management, internal vehicle operations of distribution centers and loading/unloading areas, among others.

Several barriers exist for the application of special shortest path search algorithms in micro-simulation assignment procedures. Current traffic simulators can hardly apply specific assignment methods for each vehicle type simultaneously, or implement a shortest path search based on a impedance measure calculated considering network attributes.

Integration between microscopic simulation and macroscopic demand analyses could potentially be used to provide an intermediate improvement to the route choice search, however, the implementation of a tour representing the solution for a vehicle routing problem would yet be a technical barrier.
The study presented in this paper proposes the integrated use of micro-simulation with external programming on macroscopic demand analyses level to permit the construction of hybrid models to the evaluation of logistics systems. The objective of this study is the development of a model planned in two stages:

a) Development of a model to the construction of truck routes in the micro-simulation using shortest path search models specially developed for freight vehicles;

b) Development of a model to the evaluation of vehicle routing problem solutions using micro-simulation.

This paper describes the first stage of the study.

3. ROUTE CHOICE FOR FREIGHT VEHICLES

Schreiner et al. (2007) have shown the influence that diverse parameters referring to the network have over the route choice of freight vehicles. The basic idea is that the driver will choose the best perceived route, even that the chosen one is not the shortest or the cheapest in absolute terms. The hypothesis is that each network attribute influences the perception of the length or cost of the link so that it is cognitively the best route for that driver.

In the same study, the influence of a set of network attributes was estimated using the Maximum Route Overlapping methodology, generating cognitive coefficients for each attribute. A sample of truck routes was divided into types of trucks: container-trailers and non-container-trailers. The coefficients obtained for non-container-trailers are presented in Table 1.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Parameter</th>
<th>Duplicate rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOT</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Tolled</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>CBD</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>RingRoad7</td>
<td>0.9</td>
<td>0.803336</td>
</tr>
<tr>
<td>4 Lanes</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>0.7</td>
<td></td>
</tr>
</tbody>
</table>

Note: Value of Time (VOT) in JPY/min
Source: Schreiner et al. (2007)

The influence of such coefficients in assignment methods were addressed by Schreiner and Hyodo (2007), showing a considerable divergence between the results of usual equilibrium method and the results of a modified assignment method that considers the network influence. According to Schreiner et al. (2007), the representation of observed truck routes doubled from around 40%, when considering plain travel cost, to over than 80%, when considering the cognitive cost.

3.1 Evaluation of shortest path consistency using micro-simulation

The model presented here is composed by a micro-simulation model interfaced to the static network model (SNM) proposed by Schreiner et al. (2007). The SNM was specifically developed for the evaluation of the "best path" considering the influence of network
An iterative process transfers the result of the shortest path search in SNM to the micro-simulation, where it is simulated along with the background traffic (other vehicles). The travel time for the shortest path, denominated route while in the simulation, is updated in the SNM database, which performs the shortest path search now considering the new travel times.

Fig. 1 shows a flowchart of the model. The iterative process initializes by setting the route choice parameters, which are the cognitive coefficients.

In the SNM the shortest path is searched considering the generalized cost that represents the cognitive travel cost for the driver. A set of links $L = \{l_1, \ldots, l_{\text{NOL}}\}$ and nodes $N = \{n_1, \ldots, n_{\text{NON}}\}$ define the network. Each link $l$ is represented by a vector of attributes such as length, number of lanes, lane width, type of link (tolled or non-tolled), toll price, etc.

A trip is defined by the vector $r = \{O_r, D_r, VOT_r\}$. The vector includes the origin node, destination node, and individual value of time. The path used by the truck routes is defined as the set of links leading to the destination $D_r$, from the origin $O_r$, which incurs in the minimum generalized cost for the trip $r$, considering the cost for each link $l$ as

$$GC_i = (Fuel \times Eff \times Length_i + VOT_i \times TT_i + Toll_i) \times \prod \beta_i^{j_o}$$  (1)
where:
GCl: generalized cost of link \( l \);
Fuel: fuel cost [JPY/liter];
Eff: engine efficiency [liters/km];
Length: length of link \( l \) [km];
VOT: value of time for the trip \( r \) [JPY/min];
TT: travel time on link \( l \) (which is updated by the simulated value);
Toll: Toll price on link \( l \).

\( z_k \) is the \( k \)-th attribute (e.g. road width) for the \( l \)-th link of the \( r \)-th trip;
\( \beta_k \) is an estimated parameter for the \( k \)-th attribute.

In the micro-simulation, two vehicle types are used: cars and trucks. The trucks are divided in two classes: the test truck and others. The traffic of cars and other trucks is obtained by the dynamic stochastic assignment of a OD matrix, while the traffic of the test truck is obtained by static routes created by the SNM.

The micro-simulation modeling permits the evaluation of detailed travel time, taking in consideration even the position of the parking area (including which side of the street and which lane, in case of on-street parking), that would be otherwise ignored by the SNM. An example of such detail is shown in Fig. 2.

The integration between the two models is achieved using the same link identification. The output of the shortest path result in the SNM is adjusted to match the format of the route definition in the micro-simulation. Moreover, one special function is added to the SNM to import the travel time results from the micro-simulation.

The iterative process consists of running the micro-simulation from the same initial time when the test truck begins its trip (an offset between the beginning of the simulation and the departure of the test truck is used to load the network with traffic). In each iteration the new route (calculated in the SNM with the travel times updated in the previous iteration) is created in the micro-simulation and the test truck is sent on its trip. Once the route is simulated, the obtained travel time is sent to the SNM which updates the travel time information on each link travelled by the test truck. Since the simulated travel time is aggregated to the entire route, in the SNM, the travel time is distributed to the links proportionally to the previous travel time values.

\[
NewTravelTime_i = \frac{OldTravelTime_i}{\sum_i OldTravelTime_i} \times \sum_i NewTravelTime_i
\]  \hspace{1cm} (2)

where:

\( i \) represents the links included in the selected path;

\( NewTravelTime_i \) is the simulated travel time for link \( i \);

\( OldTravelTime_i \) is the travel time used by the SNM to the shortest path search.
The iterative process is finalized upon the convergence of the travel time between the two models, defined as

\[
\frac{|\text{TravelTime}_{\text{simulation}} - \text{TravelTime}_{\text{SNM}}|}{\text{TravelTime}_{\text{SNM}}} \leq \text{Criteria}
\]  

(3)

Figure 2  Detail of a truck route leading to a on-street parking area in the micro-simulation

4. CASE STUDY

The use of micro-simulation invariably implies in the necessity for the detailed reproduction of the network geometry and traffic control. Although the required information can possibly be obtained from transportation management authorities, this paper uses a network with hypothetical traffic control to the evaluation of the methodology. Naturally, in a real application the data survey would be an important aspect for modeling and evaluation by micro-simulation.

Ensuring the accuracy of the model can guarantee the authenticity and reliability of the simulation results for alternative scenarios, and the comparative analysis of the impacts of the management methods at the most congested intersection can be carried out effectively.

4.1 Network and demand

The network used in this case study is presented in Fig. 5, 6, and 7. This network is a part of the original network of Tokyo Metropolitan Area used by Schreiner et al. (2007); Schreiner and Hyodo (2007). As the focus remains in addressing the behavior of the truck route as it is influenced by the update of the travel times, one single truck route was selected to this case study.
4.2 Traffic control

Signal controls were applied to the intersections of the main links, while priority relations prevailed in the intersections to access roads. Since the real signal plan data for the network was not available, it was assumed that signal controls in the real world are frequently adjusted according to methodologies based on volume proportions. The signal timings were arbitrated directly proportional to the volume distribution in the approximations of each signalized intersection, in an attempt to reduce the delay time in the intersections to realistic values.

Actuated pedestrian crossings and actuated signal plans were not considered in the case study, however, a few pedestrian crossings were modeled in the proximities of the parking areas to generate a more stochastic variation of the travel time.

4.3 Traffic volume

One important element for the evaluation of the travel time of the studied trucks is the traffic of other vehicles in the network. This traffic, here denominated as background traffic, is obtained through the assignment of a multi-modal origin-destination (OD) matrix, as presented by Schreiner and Hyodo (2007). The OD matrix used in the micro-simulation model was the result of a sub-network generation. The sub-network generation is a procedure used in the travel demand analyses software VISUM, where a part of the original network, along with the associated partial matrices can be generated from the overall network in such a way that, generally speaking, comparable assignment results are obtained for the sub-network (PTV, 2009). The initial travel time used in the SNM is based on the traffic volume taken from the assignment of the original network for the time period of 1pm to 3pm, also presented by Schreiner and Hyodo (2007).

4.4 Variation of travel time

The travel time results are presented in Figure 3. The travel time for the studied route converged within 12 iterations. Each iteration represents a single run of the micro-simulation.

![Figure 3 Partial results of travel times](image)
It is important to note that the background traffic was assigned using the dynamic stochastic assignment function available in VISSIM. This type of assignment iteratively checks the travel time and travel cost for all OD pairs, eventually requiring several iterations to achieve convergence. In order to avoid interference in the results, the background traffic was assigned previously to the introduction of the truck route in the micro-simulation, so that the travel times due to the background traffic were stable.

In case a fleet of trucks is introduced in the micro-simulation rather than a simple truck, it can be expected that the trucks would influence the travel time of the background traffic. Such interaction would require a larger number of iterations to achieve convergence.

### 4.5 Cognitive cost and travel cost

The results of the cognitive cost for the truck driver as well as the real travel cost are shown in Fig. 4. As the cognitive cost concept is based on a cognitive reduction of the travel cost according to the coefficients related to the network attributes, it is presented as a much lower value as the real travel cost.

As expected, there is no direct relation between the two results. This is explained by the random distribution of attributes in the network, causing the shortest path to change to links with a completely different set of parameters at each iteration.

![Figure 4  Partial results of cognitive cost and travel cost](image)

### 4.6 Alternative routes

In Fig. 5, the initial shortest path is calculated based on the existing travel time estimative (Iteration 1), avoiding the central area of the network, where the highest travel times were set. The pattern of the initial shortest path is maintained in Iteration 2.

In Fig. 6, it is possible to observe the modification of the shortest path pattern as the simulated travel time is updated into the SNM. Besides the more detailed evaluation of the travel time on the links, the other reason for such behavior is the delay in the intersections that is added to the SNM as a proportional increment of link delay. As the travel time is updated (usually to a
value higher than the initial estimation), the shortest path tends to avoid the updated area, as shows Fig. 7 on iteration 11.

One of the elements influencing the shortest path search is the position of the parking area in relation to the link. In the SNM, the links are undirected, which means they do not possess any attributes referring to the direction of the flow. In the micro-simulation, the link geometry is considerably more detailed, specifying the position within the link and even the lane where the parking area is located. This level of detail is likely to be responsible by the modification of the shortest path, initially eastbound (Fig. 5 - Iteration 2) and finally southbound (Figure 7 - Iteration 12).
The convergence takes place when the travel time using the links with the initial estimation is finally higher than using the links with updated travel times (Figure 7 - Iteration 12).

![Figure 7  Convergence process](image)

6. CONCLUSIONS

This study has presented an alternative methodology to the estimation of travel times for freight vehicles. The results obtained from the case study showed that a relative small number of iterations are necessary for the convergence of the model for one route.

Moreover, the use of micro-simulation permitted to include the influence of network details such as position of the parking area with relation to the link, as well as the influence of the stochastic delay caused in intersections due to the traffic control interference.

In terms of travel cost, the use of the cognitive coefficients show that the shortest path chosen by the driver is likely not to be the cheapest option in terms of real travel cost, implying a possible divergence between the travel cost used for planning reasons (based on minimum travel cost) and the path effectively used by the driver (chosen considering the influence of the network attributes).

5. FUTURE RESEARCH

This initial application of micro-simulation for the evaluation of the travel time of freight vehicles shows the possibility of taking advantage of the stochastic results of micro-simulation for route choice and, possibly, vehicle routing problem.

Three other aspects of the application of micro-simulation will be considered in further studies:

a. The detailed independent feedback of the measured travel times in the links and within the nodes (intersections) to the SNM;
b. The implementation of the truck route choice model within the micro-simulation model itself;
The implementation of the route choice based on the cognitive coefficients is still a rather difficult objective since available micro-simulation software have restrictions on the customization of routing and assignment procedures. The development of a routing function based on scripting technology is considered.

The precise modeling of the parking area in the micro-simulation permits the addition of ITS features in the route planning, such as parking area reservation or destination choice based on parking availability.

REFERENCES


