AN ON-LINE TRAFFIC SIMULATION TO PREDICT NEAR FUTURE TRAVEL TIME ON URBAN EXPRESSWAYS

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abstract: This study develops an On-Line traffic simulation system which predicts travel times on urban expressways in the near future. The simulation is validated by comparing the predicted travel time at every 5 minutes to the observed actual AVI (Automated Vehicle Identification) data. Current travel time information based on the summation of travel time on consecutive links are also compared.

1. INTRODUCTION

Recent developments in Intelligent Transport Systems are expected to bring the environment in which dynamic traffic information and dynamic route guidance are frequently supplied to users. On the other hand, there have been negative opinions on the system such as providing traffic information may sometimes make traffic condition worse because everyone would try to use routes recommended by the current information (Arnott *et al.*, 1991).

Several studies have analysed effects of dynamic route guidance on traffic. Moritsu *et al.* (1991) have analysed the impacts of information based on current traffic condition. There are two types of drivers in driver's route choice: guided and unguided drivers. A guided driver chooses a route of the shortest travel time based on the current traffic condition, whereas an unguided driver chooses a fixed route. Moritsu *et al.* (1991) reported that the negative effect appears, when over 70% of drivers are guided and that the positive impact may also be reduced by the communication delay.

Mahmassani *et al.* (1991) have developed a simulation model to investigate effects on the performance of a congested urban traffic under real-time in-vehicle information. The study reports that the optimal condition is achieved when a driver switches his current path only if the improvement in remaining travel time exceeds some threshold level of about 20% of the remaining trip time.

These two studies analyse impacts of traffic information based upon present conditions. On the other hand, Yoshii *et al.* (1995, 1996) have analyzed effects of dynamic route guidance systems providing very accurate present and predicted travel time information, and reported that traffic condition would be improved more by providing the predicted travel time information in most cases, especially when an unexpected accident occurred. Whereas in real field, it is quite difficult to precisely predict future traffic condition. We should, therefore, investigate how accurate we can predict travel time. In this study, we develop a prediction system by dynamic traffic simulation and validate it.

Many traffic simulation model had been developed since 1970's. SATURN (Vliet *et al.*, 1991), CONTRAM (Leonard *et al.*, 1989), DYTAN (Kido *et al.*, 1978), the BOX model (Iida *et al.*, 1991), SOUND (Yoshii *et al.*, 1995) and others which applicable to areawide networks incorporating with drivers' route choices have been developed. A common problem with these model except for SOUND is that traffic density on a link has not been controlled in relation to the traffic flow. This was the reason for using the dynamic traffic simulation model SOUND in this study. More specifically, let's consider highway sections with large and small bottleneck capacities as shown in Figures 1 and 2. When the capacity is large as in Fig.1, the traffic density in the upstream section is normally low compared to that with small capacity as in Fig.2. Thus, depending upon the density, priorities of vehicles change; that is, a vehicle coming from on ramp stands in a queue with different order between these two situations, and one from main line also stands different order. Travel time is strongly affected by priority. In general, on- and off- ramps on an urban expressway locate closely to each other, and hence, the control of traffic density is important to maintain priorities of vehicles especially at merging points. Vehicle's priority is required to reproduce traffic condition accurately.

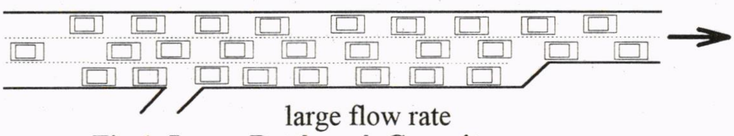

Fig.1 Large Bottleneck Capacity

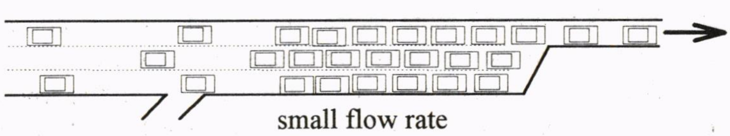

Fig.2 Small Bottleneck Capacity

2. PREDICTION SYSTEM

The accuracy of the predicted travel time has been evaluated by comparing to the observed travel time measured by AVI (Automatic Vehicle Identification) and current travel time calculated by summing up currently prevailing travel time of every links. The system uses the dynamic traffic simulation model, SOUND (a Simulation model On Urban Network with Dynamic route choice), which can reproduce dynamic traffic condition for an oversaturated expressway network in urban areas and the reproducibility has been validated using the expressway data.

2.1. Outline of Prediction System

The outline of prediction system is shown in Fig. 3. Road network which consists of nodes and links is set up under the condition; each link includes one or more detectors. Traffic data, speed, density and flow, can be collected through traffic detector. Using these data, we can get traffic condition on each link at current time. In addition to this data, simulation requires traffic data in advance, number of generating vehicle at each origin and divergent ratio at each diverging section. The system should prepare these data in some method referring to past historical traffic data. After the system prepared these data, traffic simulation can be executed. Then the system outputs predicted travel time. The simulation is executed at 5 minute's intervals and estimates traffic condition for one hour.

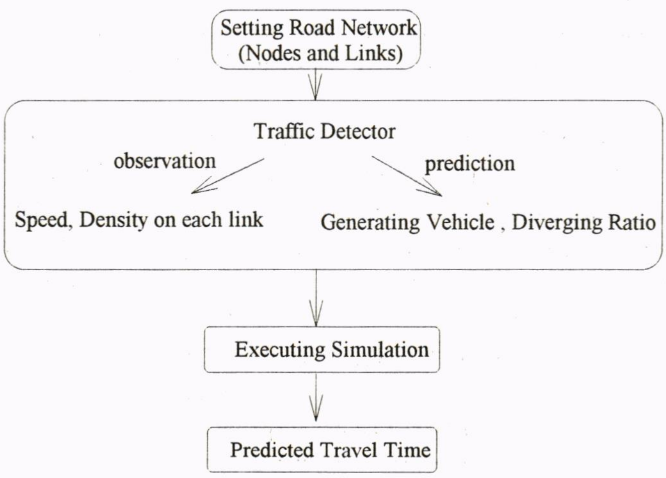

Fig. 3 Outline of Prediction System

2.2 Input Data

(1) Vehicle Density on each Link

The system requires initial vehicle densities on each link at the start of simulation. They can get from dealing with detector data. Detectors can observe time mean speed (V) and flow rate (Q). Though there are several ways of evaluating traffic density on each link, this system uses the following method on first stage:

Traffic density (K) on each link is determined by equation (1).

$$K=Q/V \qquad \text{......................................(1)}$$

Q: Traffic flow rate observed at detectors located on a link
V: Time mean speed observed at detectors located on a link
(Time mean speed substitutes for space mean speed because the difference between both values are very small.)

(2) Generating Flow Rate and Divergent Ratio

Future flow rate at each origin and divergent ratio at diverging section within the simulation time should be prepared in advance. In cases where these future flow rate and divergent ratio are not known, they should be predicted with some prediction method. In this paper, the main focus is on the simulation performance of reproduction, the system has been input the exact data observed after simulation time about generated vehicle and divergent ratio.

2.3 Simulation

SOUND, a dynamic traffic simulation model, has been applied to a road network in this study. This chapter explains the structure of the simulation model.

As presented in Fig. 4, SOUND consists of two parts: vehicle simulation module and route choice module. In the vehicle simulation module, travel time in each link is evaluated by moving vehicles forward along routes determined by the route choice module, whereas the route choice module evaluates every driver's route at a regular intervals based on travel times estimated by the vehicle simulation module. These two modules are repeatedly

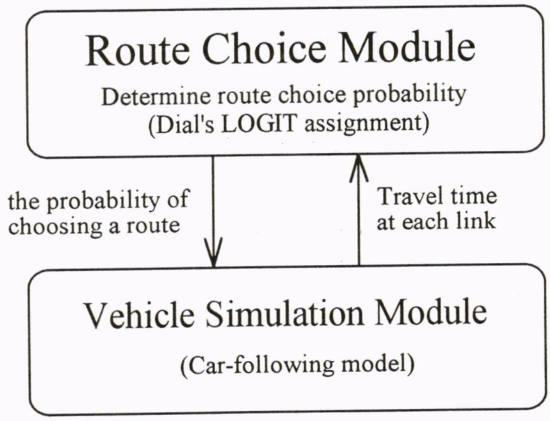

Fig. 4 SOUND Model

implemented to reproduce dynamic evolution of traffic flow on a network. Therefore, SOUND does not reproduce an exact user equilibrium flow but approximately describes the equilibrium flow dynamically.

(1) Car-following Model

In the vehicle simulation module, at every scanning intervals ($\triangle t$), each vehicle (or each group of several vehicles) on the network moves discretely in the order from downstream of each link based on the pre-specified flow-density relationship (q-k curve). Suppose two vehicles A and B run on a link at time t as shown in the upper diagram of Fig. 5. At time $t+\triangle t$, the front vehicle A first moves by some distance as in the lower diagram of Fig.5. In this situation, if vehicle B moves by L, the spacing between A and B becomes s at time $t+\triangle t$. Since each vehicle stores its current position which means that the distance s+L can be determined in the module, moving distance of vehicle B during scanning interval $\triangle t$ is calculated so that relationship between spacing s and velocity $L/\triangle t$ agree with spacing-velocity relationship transformed from pre-specified flow-density one.

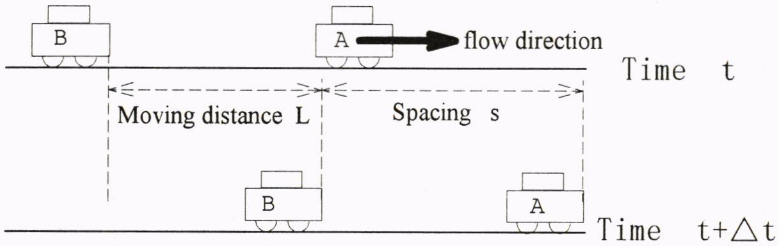

Fig. 5 The Car-Following Method

(2) Route Choice Module

Firstly drivers are divided into two groups: Route Choice Group who selects routes based upon time varying travel times on a network, and Fixed Route Group who does not change routes regardless of travel times.

For Route Choice Group, the route choice probabilities are updated at every ΔT ($\geq \Delta t$) interval by the Dial's Logit assignment with parameter θ shown below based on link travel times obtained from the vehicle simulation module. On the other hand, for Fixed Route Group, the fixed probabilities are calculated similarly by the Dial assignment with another parameter value of θ based on the free flow link travel times at speed of 60 km/h.

$$\mathrm{Prob}(r) = \frac{\exp(-\theta \cdot T_r)}{\sum_i \exp(-\theta \cdot T_i)} \qquad \text{.......(2)}$$

where Prob(r) = route choice probability of route r,
T_r = travel time of route r,
θ = non-negative parameter

Then, based on the determined route choice probabilities, the divergent ratio at every diverging node by destinations is re-evaluated. Hence, in the vehicle simulation module, a vehicle chooses the next link to go based on the above divergent ratio. Consequently, a vehicle in Route Choice Group on the network may change the route at every ΔT.

3. APPLICATION TO TOKYO METROPOLITAN EXPRESSWAY

3.1 Application Network

Figure 6 shows the application network in this study. It is 12km length expressway section from Yoga to Tanimachi, a part of Tokyo Metropolitan Expressway. The network consists of 5 origins and 4 destinations, and about 50 ultra-sonic detectors (side fire type) and 2 AVI (Automated Vehicle Identification) readers are located in this network. During daytime, heavy traffic congestion occurred in this section. Therefore, travel time from Yoga to Tanimachi changed depending on the traffic condition. When there is no congestion, the section can be traversed in about 10 minutes. On the other hand, when the traffic is heavy, the travel time could be more than 1 hour. Predicted travel time is evaluated at every 5 minutes from 6 a.m. to 9 a.m.

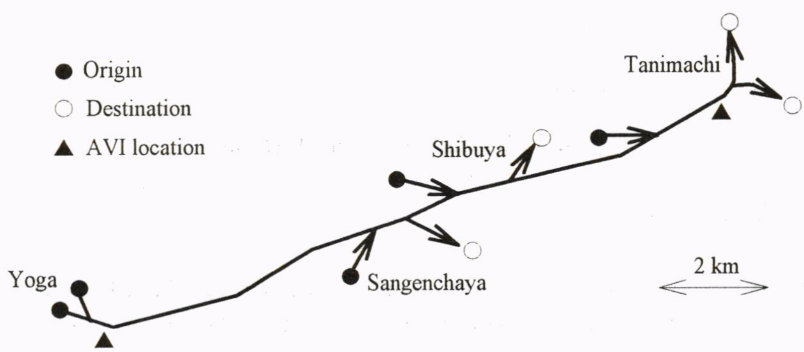

Fig. 6 Application Network

3.2 Data Set

(1) Vehicle Density on each Link

Time mean speed and flow rate are observed every 5 minutes from 6 a.m. to 9 a.m from field detectors. Using these data, number of vehicles (density) on each link at the start are calculated from equation (1).

(2) Generating Flow Rate and Divergent Ratio

Number of vehicles generated at each origin and divergent ratio at each diverging section are also prepared every 5 minutes from 6 a.m. to 9 a.m. in advance. Exact amounts are prepared in this study though they should have to be predicted.

(3)Flow-Density Relationship on each Link

Traffic simulation requires Flow-Density relationship at each link to determine vehicle movement (see Section 2.3). The flow-density relationship are expressed as quadratic function with maximum speed limit of 60km/h (see Fig.7). Because SOUND does not distinguish vehicle type, such as truck or passenger car, traffic capacity are changed depending on the proportion of heavy vehicle (Akahane *et al.*, 1987). Figure 8 shows the number of generated vehicles and the proportion of trucks at each hour in the morning period (Center for Tokyo Metropolitan expressway Technology, 1993). From this figure, we remark that Morning peak period is from 7 a.m. to 9 a.m., the share has been variable changed and the share at morning peak period is smaller than the share at off-peak. Then function parameters have been set by each link and by each one hour.

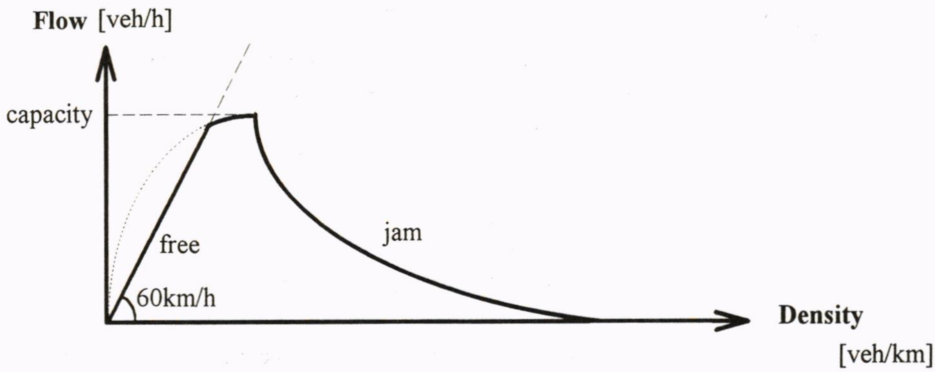

Fig. 7 Flow-Density Relationship

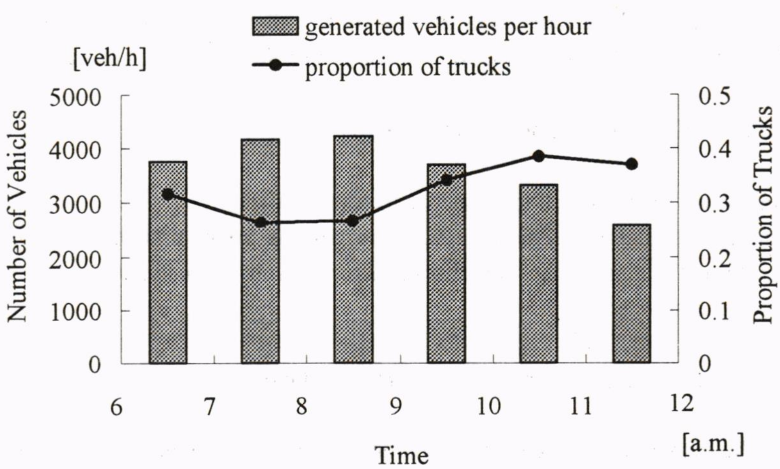

Fig. 8 Generated Vehicles and Proportion of Trucks

(4) Divergent Ratio

Basically we must determine Dial's Logit assignment parameter θ in Route Choice Module in simulation. However, route choice is not applicable in this study network, therefore, instead of parameter θ, divergent ratio at each diverging section was required.

3.3 Application Result

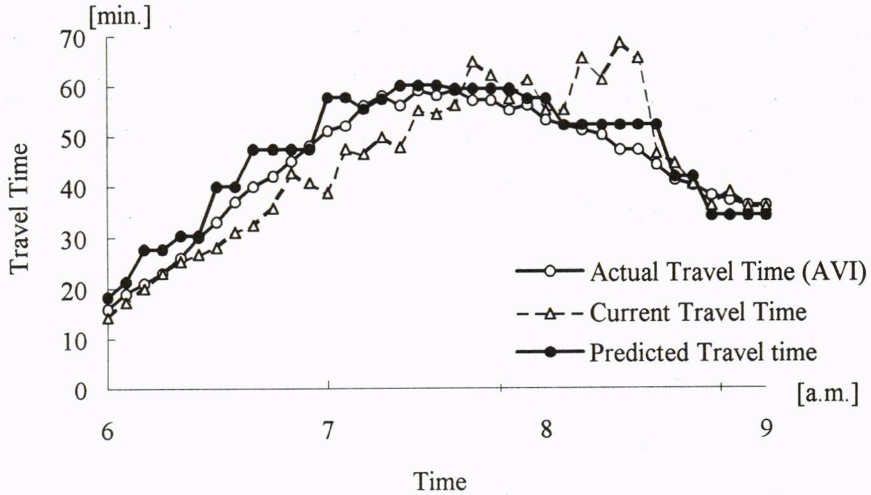

Fig. 9 Travel Time from Yoga to Tanimachi

Figure 9 shows the predicted travel time from Yoga to Tanimachi at each departing time, and compares to current travel time and AVI data. Current travel time means the current instantaneous travel times evaluated from detector data. AVI data means the actual travel time which a vehicle departing Yoga at each time will have been experienced to reach Tanimachi. It can be obtained from number plate matching between Yoga and Tanimachi.

From this figure, the following points are observed :

a) Predicted travel time fits well to actual travel time (AVI).
b) Compared to actual travel time (AVI), the current travel time has the tendency to underestimate at the time when congestion increases and overestimate at the time when congestion decreases.

The following section explains each points in more detailed.

a) There is the tendency that predicted travel time is larger than actual travel time at the time when congestion increases. Though most vehicles in real-life drive far faster than 60km/h, the simulation free flow speed is set at 60km/h. This is one reason why the travel time evaluated in the simulation is usually larger than actual travel time. In addition to this tendency, one of most affective error factor is the phenomenon that traffic density has not been uniform in a link. Especially for the case of increasing congestion, it usually happens that there is large difference in traffic density between two places in a link. Shockwave propagation would cause this condition and its degree of discontinuity is higher than other cases. Observed speed has, therefore, various changed and number of vehicle on this network could not be evaluated accurately.

b) When congestion increases, future traffic congestion which a vehicle departing at origin would experience is heavier than current one. On the other hand, when congestion decreases, current one is heavier than future one. Therefore, it has the tendency that underestimation at the time congestion increases and overestimation at the time congestion decreases.

At present, current travel time information is usually displayed to drivers. However, it includes the above mentioned difference. In order to provide more accurate information, other logic evaluating actual travel time such as our On-Line simulation should be considered.

4. FUTURE SCOPE

This study develops an On-Line simulation which predicts travel times, and validates its accuracy. Some of future research topic would be :

a) determine how to predict vehicle generation rate and divergent ratio within prediction time in near future.
b) Application to a network with route choice.
c) Development of automatic method that determines flow-density relationship using detector data.

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REFERENCES

Akahane, H., and Koshi, M. (1987). Updating of Volume-Density Relationships for an Urban Expressway Control System. **Proceedings of the 10th International Symposium on Transportation and Traffic Theory**, 339-355, Massachusetts Institute of Technology, Cambridge, Massachusetts, U.S.A., July 1987.

Arnott, R., De Palma, A. and Lindsey, R. (1991). Does Providing Information to Driver Reduce Traffic Congestion ? **Transportation Research 25A(5)**, 309-318.

Center for Tokyo Metropolitan Expressway Technology (1993). **The Report of Basic Research about Traffic Engineering and Traffic Economy in Tokyo Metropolitan Expressway.** The Metropolitan Expressway, Public Corporation, Tokyo (In Japanese).

Iida, Uchida, Fujii and Washio (1991). A Dynamic Traffic Simulation Model Considering a Phenomenon of Traffic Jam Lengthening. **Proceedings of Infrastructure Planning 14(1)**, 301-308 (In Japanese).

Kido, Ikenoue and Saito (1978). Searching routes in a network, Traffic assignment model (DYTAN-I). **Institute of Japanese Police Science Report 19-1** (In Japanese).

Leonard, D.R., Gower, P. and Taylor, N.B. (1989). CONTRAM : Structure of the Model. **TRRL Research Report RR178.**

Mahmassani, H. S. and Jayakrishnan, R. (1991). System Performance and User Response Under Real-time Information in a Congested Traffic Corridor. **Transportation Research 25A(5)**, 293-307.

Moritsu, H., Ohara, T., Tada, Y and Inoue, T.(1991). Analysis of Traffic Network Flow by Adapting Route Guidance. **Proceedings of Infrastructure Planning 9**, 37-44, Tottori, Japan, November 1991 (In Japanese).

Vliet, D.V. and Hall, M.D. (1991). **SATURN 8.3-A User's Manual-Universal Version.** Institute for Transport Studies, University of Leeds.

Yoshii, T. and Kuwahara, M. (1995). Development of Traffic Network Simulation Model for Oversaturated Traffic Flow on Urban Expressways. **Traffic Engineering 30-1**, 33-41 (In Japanese).

Yoshii, T., Akahane , H., and Kuwahara, M. (1995). Impacts of the Accuracy of Traffic Information in Dynamic Route Guidance Systems. **Proceedings of the Second Annual World Congress on Intelligent Transport Systems '95**, 1995-2000, Pacifico Yokohama, Japan, October 1995.

Yoshii, T., Akahane , H., and Kuwahara, M. (1996). Impacts of the Accuracy of Traffic Information in Dynamic Route Guidance Systems. **CD-ROM of the Third Annual World Congress on Intelligent Transport Systems '96**, Orlando Convention Center, Florida U.S.A., October 1996.