Third Annual World Congress on Intelligent Transport Systems, Oct. 1996, Orlando, Florida

A NETWORK SIMULATION MODEL FOR IMPACT STUDIES OF TRAFFIC MANAGEMENT 'AVENUE Ver.2'

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ABSTRACT

This paper describes the development of the road network simulation model for impact studies of traffic management, which we call AVENUE (an Advanced & Visual Evaluator for road Networks in Urban arEas). Since traffic congestion has caused serious social problems in urban areas, traffic assessment which evaluates the impacts of large events or urban developments on road traffic is strongly required. So far, we have developed the first version of AVENUE which includes basic functions to reproduce traffic flow considering drivers' behaviors such as lane choice and route choice, and has been validated its traffic flow model with several real road networks. However, some modifications have been pointed out through the experiences of the model validations. The newer version is therefore improved to incorporate various route choice models and to reduce the calculation time. First, this paper describes the concepts of the traffic model used in AVENUE Ver.2 which is characterized by the Multi-Scan Hybrid Block Density Method and the Multi-Layered Route Choice Model. The traffic model have been verified with several sample networks in terms of vehicle queue setting back, delays at signalized intersections, the decline in capacity of turning movements, and the route choice behaviors. Then, the model validation including its route choice model using the real road network which has about 50 intersections is reported. Based on this field application, the problems associated with the simulation of urban traffic as well as the model validity are disclosed.

INTRODUCTION

For the recent several years, ITS technologies are gathering great expectations to improve mobility of road traffic and traffic assessment tools which can evaluate the impacts of any traffic management strategies are strongly required. So far, we have developed a traffic simulation model for various impact studies, named AVENUE Ver.1, which can reproduce traffic conditions on urban road networks controlled by signals.

AVENUE is characterized by the following features: 1) employing the Hybrid Block Density Method for its traffic flow model so as to reproduce over-saturated traffic conditions, 2) incorporating drivers' route choice behaviors to meet the recent requirements for the evaluation of dynamic route guidances, 3) modeling drivers' lane choice behaviors according to their turning movements, 4) considering conflicts between vehicles at intersections, lane changing, etc. 5) designed and implemented in Object Oriented Programming in order to satisfy various users' needs, and 6) adopting Graphical User Interface and Animation for easy operations and persuasive presentations. Furthermore, the traffic model of AVENUE Ver.1 was validated throughout the several applications to the real road networks which have no alternative route for each O-D pair.

However, some modifications were pointed out through the experiences of the model applications. When the road networks had many alternative routes and contained as much as some dozens of intersections, the route choice strategies were so simple not enough to well simulate the traffic conditions and the calculation cost were so large that it took considerable time for the computation. The newer version is therefore improved to incorporate various route choice models and to reduce the calculation time.

The following chapters describe, first, the concepts of the traffic model used in AVENUE Ver.2 which is characterized by the multi-scan hybrid block density method and the multi-layered route choice model. Then, the traffic model have been verified with several sample networks in terms of vehicle queue setting back, delays at signalized intersections, the decline in capacity of turning movement by interfering traffic, and the route choice behaviors. Furthermore, the model validation including its route choice model using the real road network which has about 50 intersections is reported. Based on this field application, the problems associated with the simulation of urban traffic as well as the model validity are disclosed.

TRAFFIC MODEL OF AVENUE Ver. 2

This chapter describes major modification on the traffic model of AVENUE from the previous version, i.e. the Multi-Scan Hybrid Block Density Method as its traffic flow model and the Multi-Layered Route Choice Model.

Multi-Scan Hybrid Block Density Method

AVENUE employs Hybrid Block Density Method (HBDM) in its traffic flow model[1]. In this method, each link is divided into several blocks of which length is equal to the distance that a vehicle runs at the free flow speed of the link during a scanning interval. The in/out-flow and the density of each block are revised at every scanning interval based on the flow-conservation law, i.e. the flows between two adjacent blocks are calculated by a function of the allowable out-flow of the upstream block and the allowable in-flow of the downstream block both which are determined by the flow-density relationships of the link (Fig. 1).

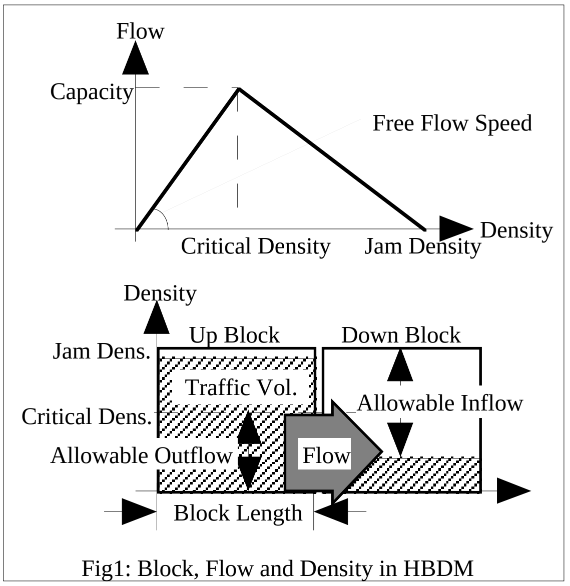


Fig1: Block, Flow and Density in HBDM

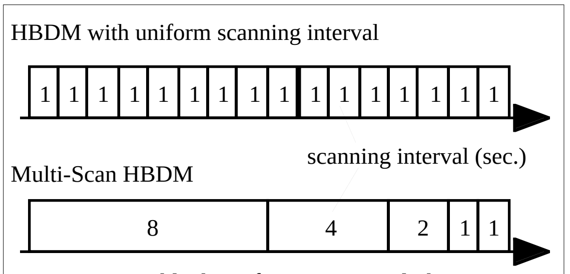


Fig2: block configurations in a link

Since the fluid approximation of traffic has some difficulties in handling individual vehicle information, this flow calculation was extended so as to move not only the continuum traffic density but also the discrete vehicle images containing the various attributes such as vehicle types, origins and destinations, route choice criteria and turning movements, etc.

In the previous version, the scanning interval of each block is uniform and usually equal to 1 second, so that the flow calculation cost proportionally increases as getting longer the total length of the links. This may lead to inefficiency in practical use of the simulation model. It is possible to reduce the calculation cost by adopting longer scanning interval, but there will be inaccuracy at the signalized sections.

The Multi-Scan HBDM can reduce the calculation cost while keeping the accuracy of the calculation. The scanning intervals are set to 1 second at the most downstream blocks in each link, and doubled as going upstream. The length of each block is equal to the distance that a vehicle runs at the free flow speed during the scanning interval of the block (Fig. 2). The longest scanning intervals are limited to as much as 2 - 16 seconds by each link depending on the requirements for the preciseness. For each block, the allowable in/out-flow is evaluated at every its own scanning interval. Then, at the same time, the in-flow between the block and its upstream block is computed and the densities inside them are also revised. It is clear that the calculation cost would be drastically reduced in this way, since not only the number of the blocks decreases but also each block is not always evaluated in every 1 second.

Multi-Layered Route Choice Model

In the previous version, AVENUE only had the simple strategy of the drivers' route choice such that they always choose the minimum cost paths that were updated every certain minutes. Each vehicle decided its turning movement at every intersections, based on the minimum path information toward its destination. It is obviously difficult for the previous model to handle the various drivers layers that have different route choice criteria, although such situation must be frequently considered in the impact studies. Furthermore, too much simple strategy in a simulation easily leads to traffic conditions very far from real world.

In order to improve these problem, the Ver.2 now can treat multiple user layers on a network. Each of the layers can be distinguished by vehicle types, travel purposes, and especially route choice strategies. There are two types of the route choice strategies: stochastic route choices and prefixed route traverses. Drivers in the stochastic route choice layers choose their paths when they enter the network according to the logit model:

$$P_{ij} = \exp(-q_j * c_{ij}) / \sum_{k} \exp(-q_j * c_{kj}) \quad (1)$$

where P_{ij} means the choice probability of the i-th path for the j-th user layer, q_j is the logit parameter for the j-th layer, and c_{ij} is the cost of the i-th path for the j-th layer expressed as a function of the distance, the travel time and the number of turns on the path.

In this model, alternative paths are given a priori for each O-D pair, instead of popular Dial's algorithm because it sometimes eliminates quite relevant paths due to the definition of "the efficient paths". In the actual implementation, the alternative paths are automatically enumerated as well as system users can add or delete arbitrary paths.

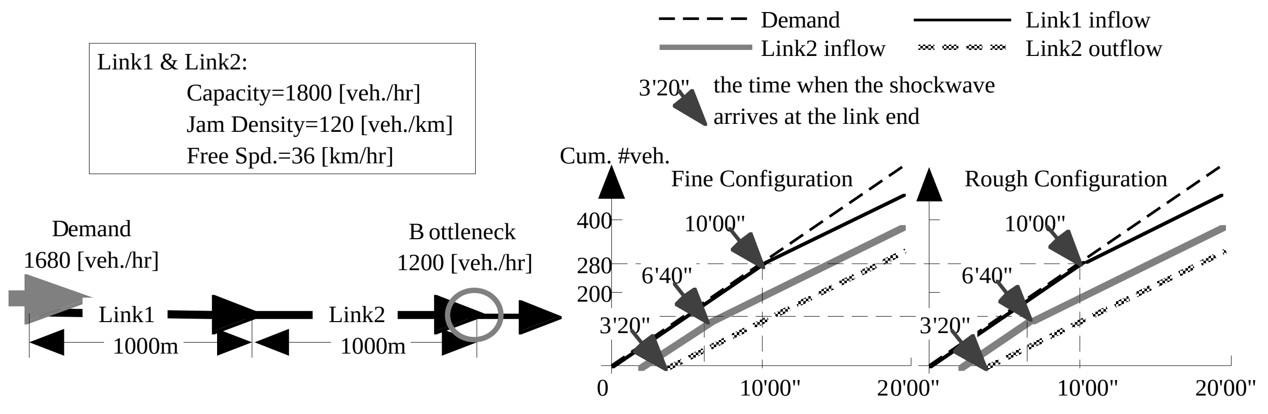
MODEL VERIFICATION

This chapter describes the verification of the traffic model of AVENUE with several sample networks. The flow model is examined in terms of vehicle queue setting back, delays at signalized intersections and the decline in capacity of turning movement by interfering traffic. Another verification refers to the route choice model comparing with the theoretical user equilibrium state.

Vehicle Queue Setting Back

First, the ability to reproduce vehicle queue setting back is examined using a sample network shown in Fig. 3 (a), of which demand exceeds the bottleneck capacity at the downstream end of Link2. The links are divided into blocks in two way, i.e. the fine configuration such as the scanning intervals of the blocks are up to 2 seconds and the rough configuration up to 16 seconds.

Fig. 3 (b) illustrates the cumulative flow diagrams at each link end for both configurations. The arrows in the diagrams figure out the time points when the shockwave reaches each link end at the theoretical speed. The flow rate at each link end obviously declines to the bottleneck capacity after the shockwave arrives there. Furthermore, there are no



(a) A sample network and the parameters (b) The cumulative flow diagram at each link end

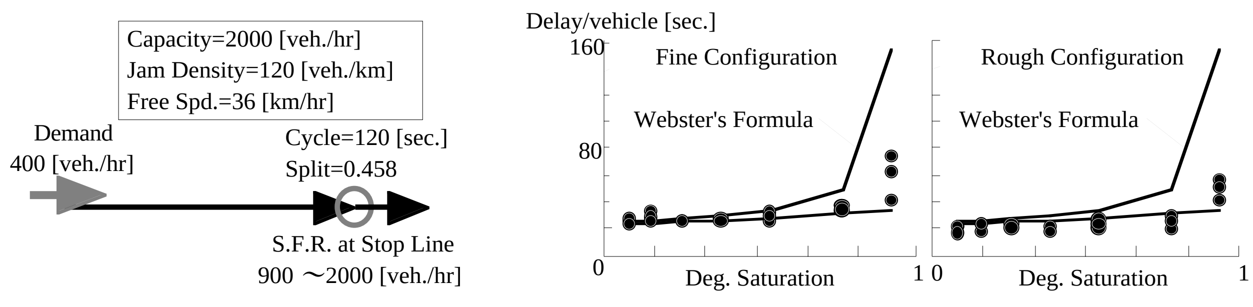
Fig. 3: Verification for Vehicle Queue Setting Back

differences between the two diagrams. Thus, it may be concluded that the Multi-Scan HBDM can properly reproduce queue setting back including shockwave propagations, even if the links are roughly divided.

Delays at Signalized Intersections with Under-Saturated Traffic Conditions

Fig. 4 (a) shows the network used for the delay verifications. The average delay of each vehicle are collected over 10 signal cycles, varying the saturation flow rate at the stop line of the link while keeping the traffic conditions under-saturated. The random arrival is assumed in the simulation. Both the fine and the rough configurations are examined same as above.

Each dots in the diagrams of Fig. 4 (b) represent the delay per vehicle obtained from the simulation. The upper curve means the delay calculated by Webster's formula assuming random arrivals and the lower means the delay of uniform arrivals. In the fine configuration case, as Webster's formula closes infinity when the saturation degree approaches to 1.0, it seems reasonable that the dots are distributed between two curves. On the other hand, in the rough configuration case, the dots are mostly distributed beneath the curve of the uniform arrivals. The reason is probably that the random arrival pattern would be rounded to the uniform pattern at the most upstream block of which scanning interval is 16 seconds, and moreover the travel time of each vehicle would be fastened at the block.

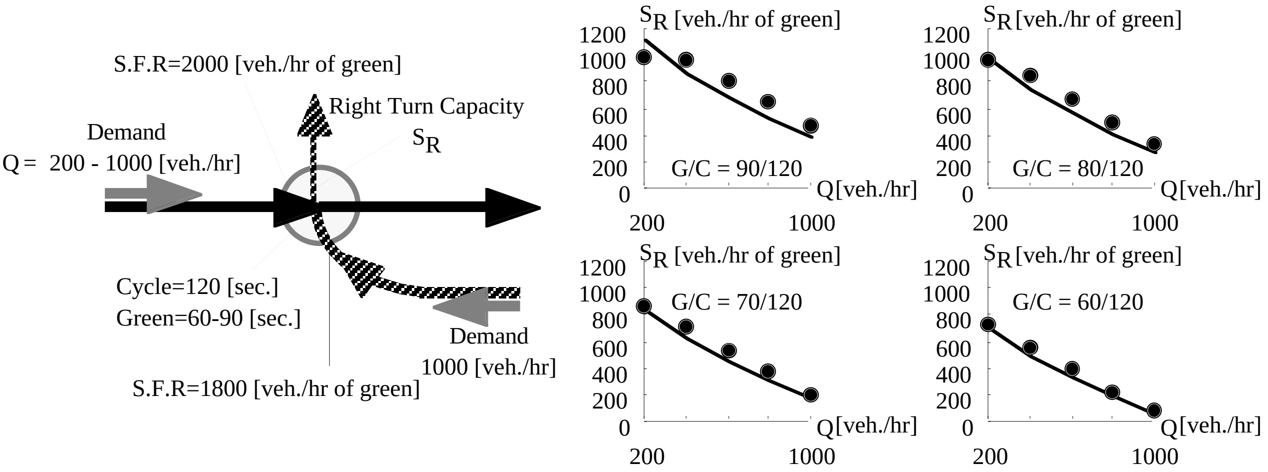


(a) A sample network and the parameters (b) Delay/vehicle by Webster's Formula and by the simulation

Fig. 4: Verification for Delays at Signalized Intersections with Under-Saturated Traffic Conditions

Decline in Capacity of Turning Movement by Interfering Traffic

Fig. 5 (a) illustrates a network used for the verification of the declines in capacities of turning movements. The throughput at the intersection is counted over 1 hour, varying the demand of the opposite direction and the green time. Fig. 5 (b) shows the comparisons of simulation results denoted by the dots with the theoretical right turn capacities



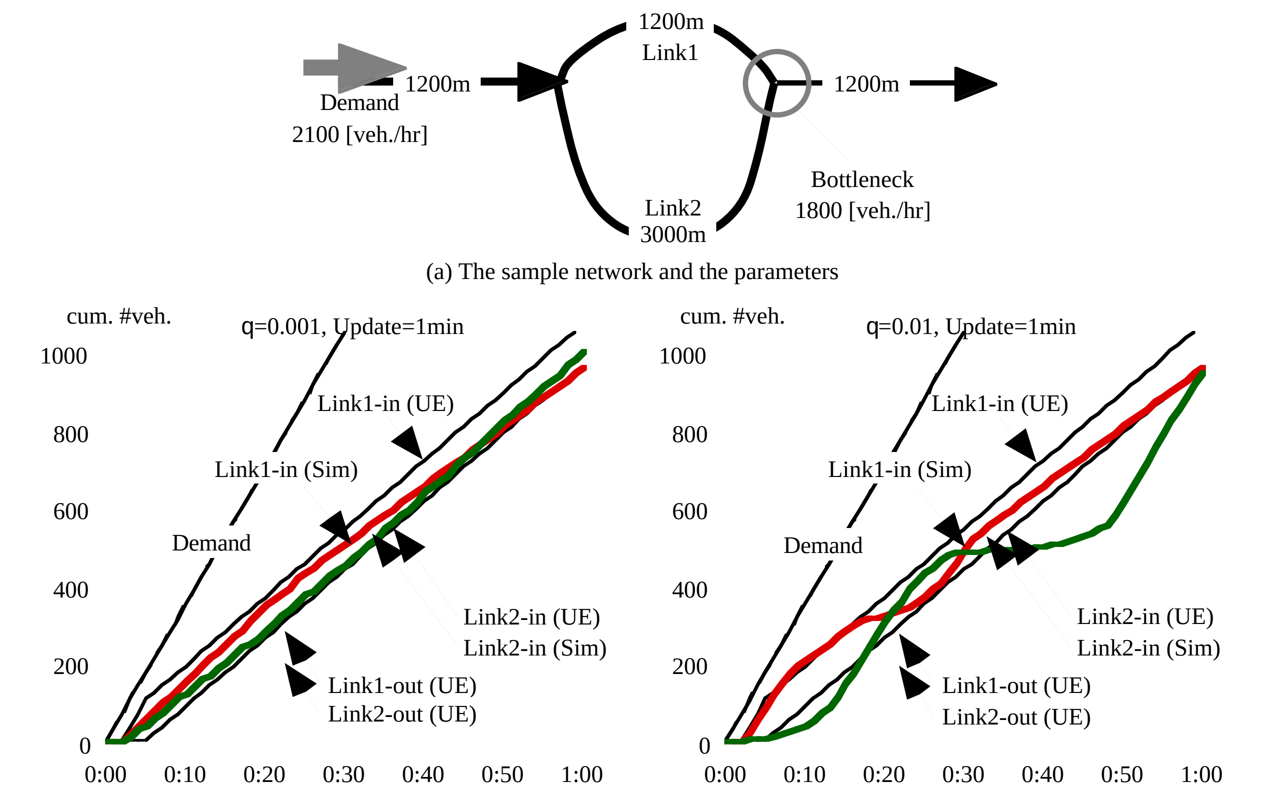
(a) A sample network and the parameters (b) The decline of right turn capacity

Fig. 5 : Verification for the Decline in Capacity of Turning Movements

which is derived from the gap acceptance model assuming random arrival of the opposite flow. Though the simulation values are slightly over above the theoretical values, the model reveals the tendency to decline the turning capacities at intersections as the traffic volume of the opposite direction increases.

Behavior of Route Choice Model

Fig. 6 (a) shows a network used in the verification of the route choice model. There are two routes on the network



(b) The comparisons of the simulation result with UE

Fig. 6 : The verilication of the route choice model

and the merging point of Link1 and Link2 will be the bottleneck. Drivers select the routes with the logit choice probabilities based on the current travel time when they enter the network. The cumulative flows of Link1 and Link2 are observed over several variations of the logit parameter and the cost updated interval.

Fig. 6 (b) illustrates the cumulative flows of Link1 and Link2 in the case of q=0.001 and 0.01. The cost update interval is equal to 1 minute for both cases. The cumulative flows assuming user equilibrium state (UE) are also illustrated for the reference. The simulation results of both cases oscillate around UE because the route costs when a vehicle enters the network is different from route cost that driver actually spends. Therefore, in the simulation model, drivers tend to over-react in selecting the shorter route. The amplitude of the oscillation becomes larger when q is larger.

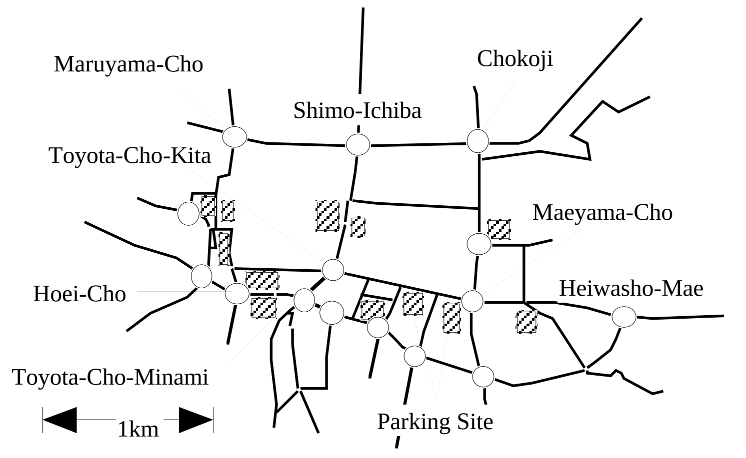


Fig. 7 : The applied network in Toyota-City

MODEL VALIDATION WITH REAL ROAD NETWORK

This chapter describes the model validation of its applicabilities to the real traffic. We have already applied the simulation model to simple but real networks which has no alternative route for each O-D pair and validated its applicability comparing the simulation result with the observed data in terms of travel times, queue lengths, etc.[2] As the next step, the network which has number of alternative routes is used to validate the applicabilities not only of the traffic flow model but also of the route choice model.

Road Network and Input Data

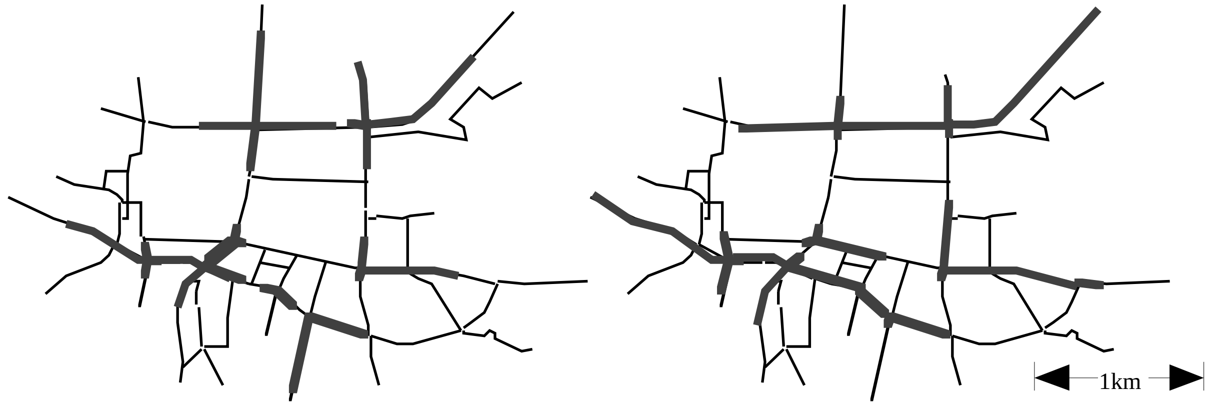
The network in Toyota City has 84 nodes and 193 links and covers about 3x3 sq. km. (Fig. 7). Inside the network, there are several factories involving some parking sites of large capacities. During the morning peak period, vehicles commuting to these factories occupy a half of traffic flowing into the network and traffic jams are frequently observed at bottleneck intersections such as Toyota-Cho-Kita and Toyota-Cho-Minami.

The O-D traffic volume is estimated for every 15 minutes from 6:30 am to 9:30 am, including the morning peak period, based on traffic counts observed at the major intersections in 1993 and the survey of parking users. Totally about 20,000 vehicles are flowing into the network. The flow-density curves and the saturation flow rates of the links are estimated from the intersection geometries. The logit parameter for the route choice model is brought from other simulation study similar to this network.

Simulation Results

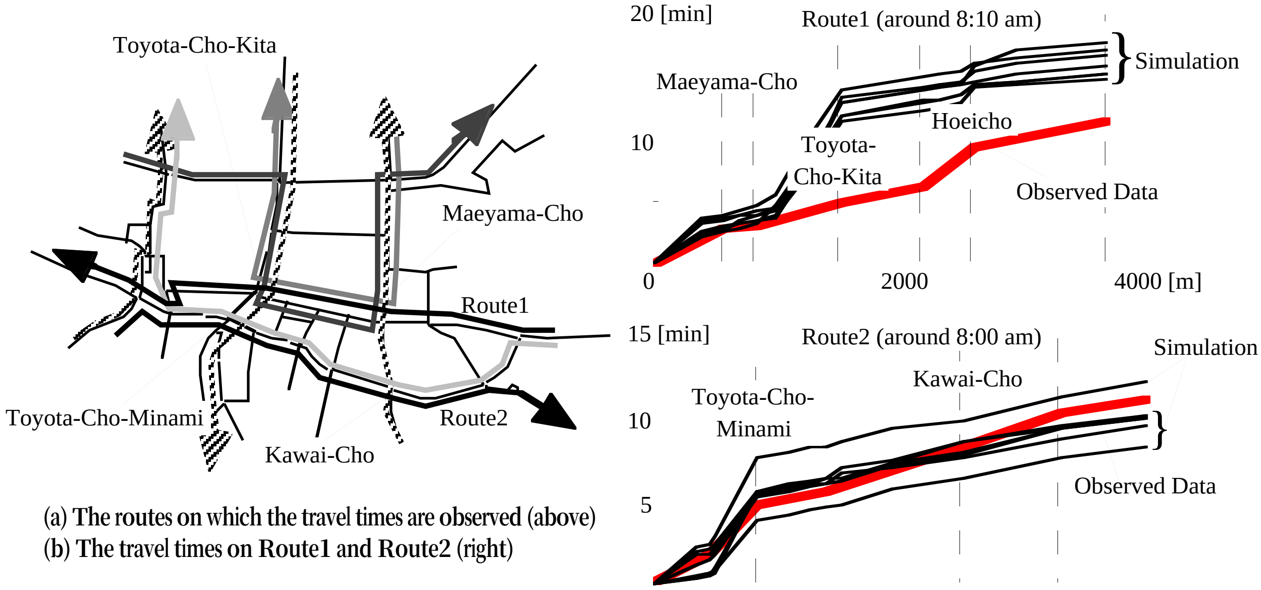
Fig. 8 illustrates the comparison between the observed and simulated queue lengths at 8:00 am when the traffic conditions are heavily congested. As the definition of observed queue lengths is not quantitatively clear, it is difficult to compare them precisely, but the simulation result reveals the actual bottleneck intersections.

Fig. 9 (a) figures out routes that floating cars recorded their travel times. Each floating car ran twice on each route. Fig. 9 (b) are the comparisons between travel time of the floating car and the several simulation cars which departure at around the same time of each floating car. In the simulation, too many vehicles selected the routes passing from Maeyama-Cho to Toyota-Cho-Kita such as Route1, the simulation travel times in the section become larger than the observed one, since the drivers' route choice behaviors are not sufficiently analyzed. However, the results reveal other actual bottlenecks such as Hoeicho on Route1 and Toyota-Cho-Minami on Route2.



(a) Observed traffic jams (8:00 am)   (b) Traffic jams in the simulation (8:00 am)

Fig. 8 : The comparison in queue length



(a) The routes on which the travel times are observed (above)
(b) The travel times on Route1 and Route2 (right)

Fig. 9 : The comparison in travel times

CONCLUSIONS

This paper presents the concept and abilities of the traffic model used in AVENUE. The model verification concludes that the Multi-scan HBDM can well reproduce vehicle queue setting back, delays at signalized intersections and the declines in capacities of turning movements, and that the route choice strategy based on current route costs let drivers over-react in selecting the shorter route and makes the traffic condition unstable being far from user equilibrium state.

Throughout the experiments of its applications, we find the following future research needs:

(1) to analyze route choice behavior in relation to drivers' characteristics,
(2) to develop a method which automatically tune various parameters in simulation models,
(3) to research a method which precisely estimate O-D traffic demand for applied networks, and
(4) to examine observations on traffic conditions which is conscious of impact analysis with a traffic simulation.

ACKNOWLEDGEMENT

We would like to express our sincere thanks to Ministry of Construction, Toyota City Government, Toyota Motor Co., Ltd., and Toyota Transportation Research Institute who kindly provided the traffic data for the research.

ENDNOTES

1. R. Horiguchi, M. Katakura, H. Akahane, and M. Kuwahara, "A Development of a Traffic Simulator for Urban Road Networks: AVENUE", *Proceedings of Vehicle Navigation & Information Systems Conference in Yokohama*, pp. 245-250, 1994
2. R. Horiguchi, M. Kuwahara, and I. Nishikawa, "The Model Validation of Traffic Simulation System for Urban Road Networks: AVENUE", *Proceedings of the Second World Congress on Intelligent Transport Systems in Yokohama*, Vol. IV, 1977-1982, 1995

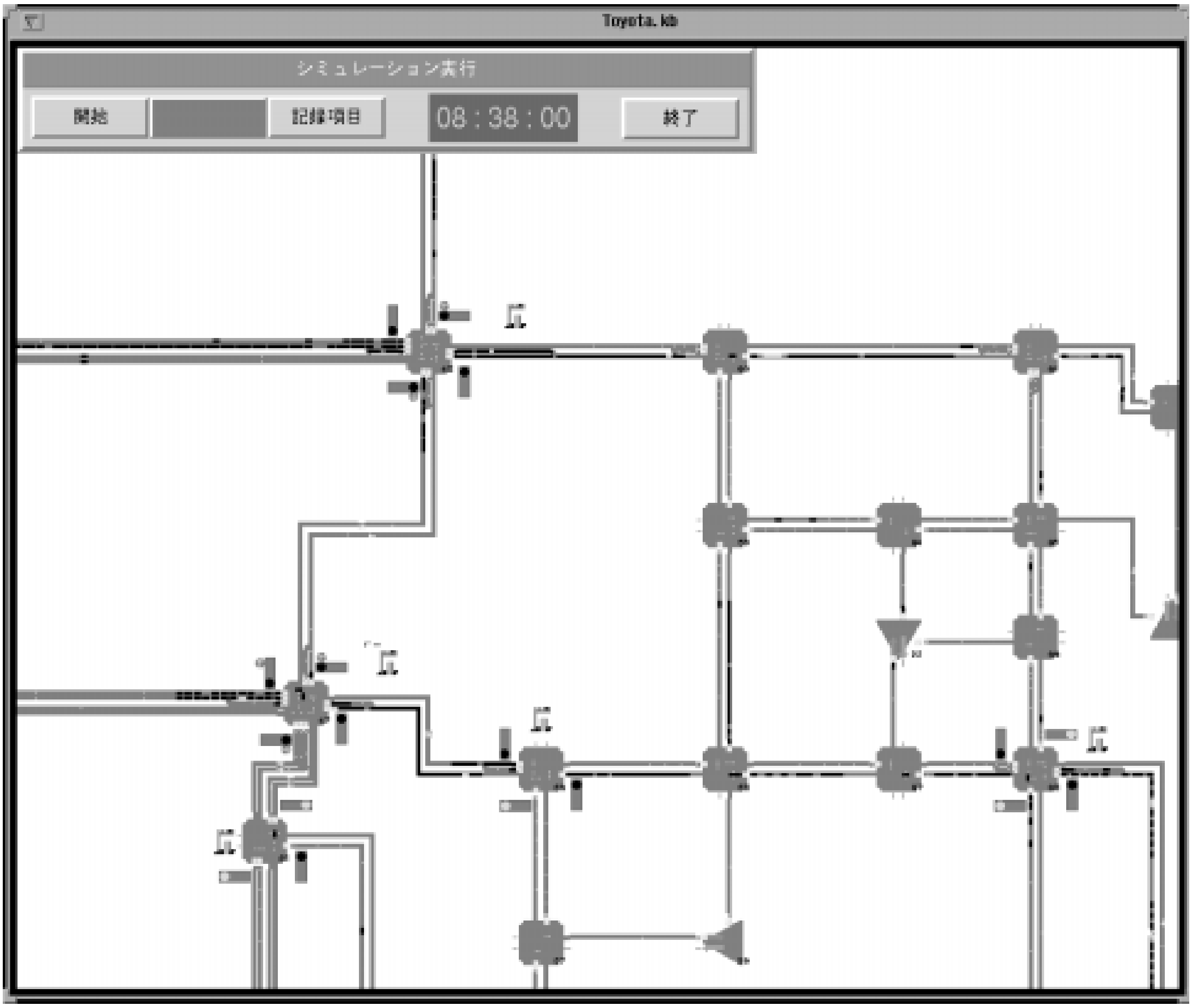


Fig. 10 : The display image of the simulation