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The Model Validation of Traffic Simulation System for Urban Road Networks: 'AVENUE'

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ABSTRACT

The first version of AVENUE (an Advanced & Visual Evaluator for road Networks in Urban arEas) including the basic functions concerning to the traffic flow reproduction and the driver's route choice behaviors has been developed. It is required that the traffic model used in AVENUE is validated to establish its reliability. This paper examines the applicability of AVENUE with observed traffic data including bus traffic for the system validation. Based on the field application, the problems specific to the simulation of urban traffic are discussed.

1. INTRODUCTION

As traffic congestion has caused serious social and economic problems in urban areas, there is a great demand for traffic simulation that can evaluate impacts of improvements on intersection geometry, traffic regulations, signal control, etc. Such a simulation system can also be an efficient tool for traffic assessment at planning stages of large events or urban developments.

We have developed the traffic simulation system for urban road networks named AVENUE (an Advanced & Visual Evaluator for road Networks in Urban arEas) Ver.1 and have worked with it to improve its utility for the practical traffic assessment[1][2]. The scope of the application of AVENUE is to reproduce the detailed traffic condition within an area which contains dozens of intersections. For this purpose, not only the traffic flow and the route choice behavior but also some microscopic phenomena, such as the lane changing behavior and the spill over from turn pockets, should be incorporated into the system.

In the following chapters, the framework of the traffic flow and the route choice model are described. Afterward, the model is validated using observed traffic data in a real network, which is characterized by the complicated lane usage containing bus lanes and bus bays.

2. TRAFFIC MODEL OF AVENUE

2.1. Hybrid Block Density Method

AVENUE employs the Hybrid Block Density Method as its traffic flow model. The flow calculation of this method has the basis on the Block Density Method[3][4], which treats traffic flow as continuum. In the Block Density 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 and the Q-K relationships shown in Figure 1. This method can reasonably reproduce both undersaturated and oversaturated traffic conditions including propagation of shock waves.

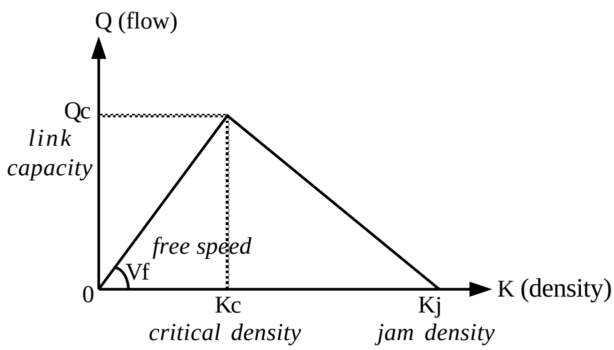

Figure 1: The flow-density relationship used in the Block Density Method

Figure 2 illustrates the variables used in the flow calculation between the two neighboring block with suffix i and i+1. At every scan, the allowable out-flow and the allowable in-flow of each block are calculated according to the Q-K relationship, then the flow between the neighboring blocks is determined by taking the minimum of the allowable out-flow of the upstream block and the allowable in-flow of the downstream block.

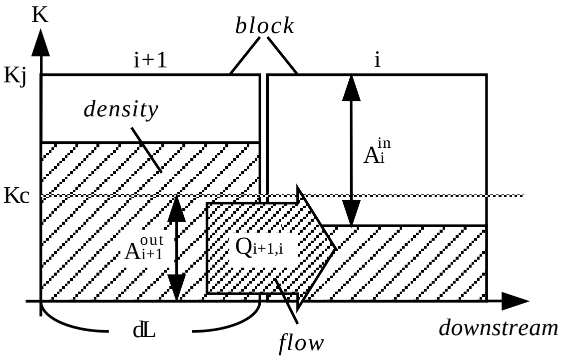

Figure 2: The flow calculation between two neighboring blocks

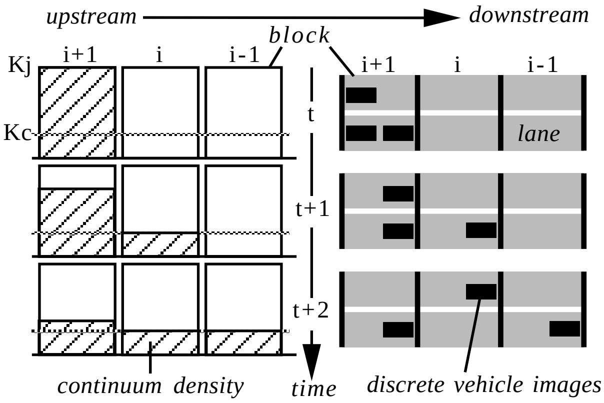

Figure 3: The movements of discrete vehicles in the Hybrid Block Density Method

The densities at the next scan are revised using the in-flow and out-flow of each block. The following equations show the flow calculation of each block with suffix i:

$$A_i^{out}(t) = \min\{Kc_i, K_i(t)\}\frac{dL}{dt} \tag{1}$$

$$A_i^{in} = \begin{cases} \min\{Kc_i, Kj_i - K_i(t)\}\dfrac{dL}{dt}, & K_i(t) \le Kc_i \\ \dfrac{Kc_i\,(Kj_i - K_i(t))}{Kj_i - Kc_i}\dfrac{dL}{dt}, & Kc_i < K_i(t) \le Kj_i \end{cases} \tag{2}$$

$$Q_{i+1,i}(t) = \min\{A_{i+1}^{out}(t), A_i^{in}(t)\} \tag{3}$$

$$K_i(t+1)\,dL = K_i(t)\,dL - Q_{i,\,i-1}(t)\,dt + Q_{i+1,i}(t)\,dt \tag{4}$$

where, $A^{out}{}_i(t)$: allowable out-flow of i,
$A^{in}{}_i(t)$: allowable in-flow of i,
$K_i(t)$: density of i,
$Q_{i+1,i}(t)$: flow from i+1 to i,
Kc_i: critical density of i,
Kj_i: jam density of i,
t: time,
dL: length of block,
dt: scanning interval.

Since the fluid approximation of traffic has some difficulties in handling individual vehicle information such as its destination, the Block Density Method was extended to the Hybrid Block Density Method, i.e. the blocks have not only the continuum traffic density but also the discrete vehicle images containing the various attributes such as vehicle types, destinations and route choice criteria for the convenience of modelling the vehicle behavior. Figure 3 illustrates the movements of discrete vehicles in this method. The number of vehicles which move from block i+1 to i is proportional to the flow from i+1 to i. The difference between the number of vehicles and the continuum flow remains as underflow from i+1 to i and will be treated at the next scan interval so that both cumulative values will be equal throughout the simulation period.

2.2. Route and Lane Choice Behaviors

AVENUE incorporates drivers' route choice behaviors to meet the recent requirements for the evaluation of the influence of ITS technologies.

In the simulation procedure, time dependent traffic demand of each origin-destination pair is input to the model at first. The vehicles generated in proportion to the traffic demand have the information of their destinations and the route choice criteria such as being conservative or sensitive to the route information.

On the other hand, each link contains the route guidance attribute which contains the route information for each destination. The route information shows the candidate of the routes for each destination, the travel time of each route, the traffic regulations along each route, etc. When a vehicle enters a link, it chooses the appropriate route by using the route information of the link according to its destination and its choice criteria. The contents of the route guidance attributes are dynamically updated by the route information module during simulation.

At the same time when a vehicle chooses a route, the vehicle decides the turn movement at the link end and enters an appropriate lane on the next link. Figure 4 illustrates a mechanism of the lane choice in the Hybrid

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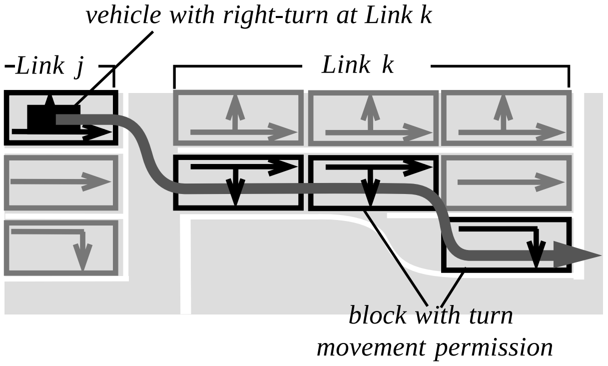


Figure 4: The modelling of the lane choice behavior in the Hybrid Block Density Method

Block Density Method. A link is divided into small blocks of which widths cover one lane. Each block has the attribute of the permissions such as traffic regulations for each of turning movements and vehicle types. A vehicle can move into a downstream block according to the flow calculated by the Hybrid Block Density Method only if the block grants permission to the vehicle. In this way, various traffic regulations on lanes including bus lanes can be easily described in the traffic model.

3 . APPLICATION TO A REAL NETWORK FOR THE MODEL VALIDATION

3.1. Input Data

Figure 5 illustrates the network geometry used for the model validation. The network contains 5 intersections systematically controlled by the signals of which cycles are 140 seconds (*A*, *B*, *C*, *D* and *F*) and one intersection without signals (*E*) along the main street lying east and west with the span of about 500 meters. In the center of the network, there are a taxi pool and a bus terminal. Two bus lanes and bus bays are facilitated beside the main street.

The traffic volume passing through the network during 7:50 - 9:10 was observed by license plate matching at every network ends numbered from *0* to *10*. The data was aggregated by each O-D pair for every 10-minute. Main sources and sinks are *0*, *5*, *6* and *9*.

3.2. Traffic Condition on the Network

During the morning peak period, the traffic on the network stays in over-saturated condition. Since the length of the links are mostly less than 100 meters, vehicle queues headed with red signals easily reach the upstream ends of the links and hamper vehicles on the upstream links.

The number of commuting buses coming from the network ends *0*, *1* and *6* is more than 100 during the peak period, and they impede the smooth traffic flow. These buses once stop at either *bus bay G* or *H* for 50 seconds

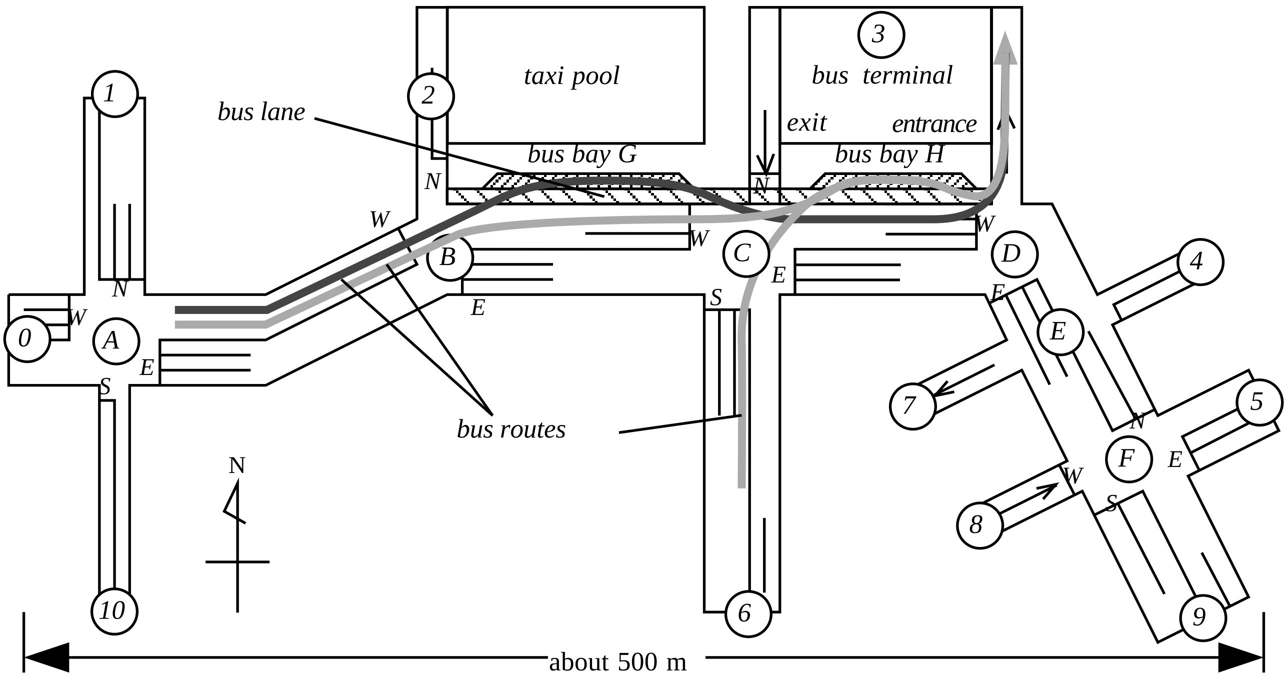


Figure 4: The road network used for the model validation

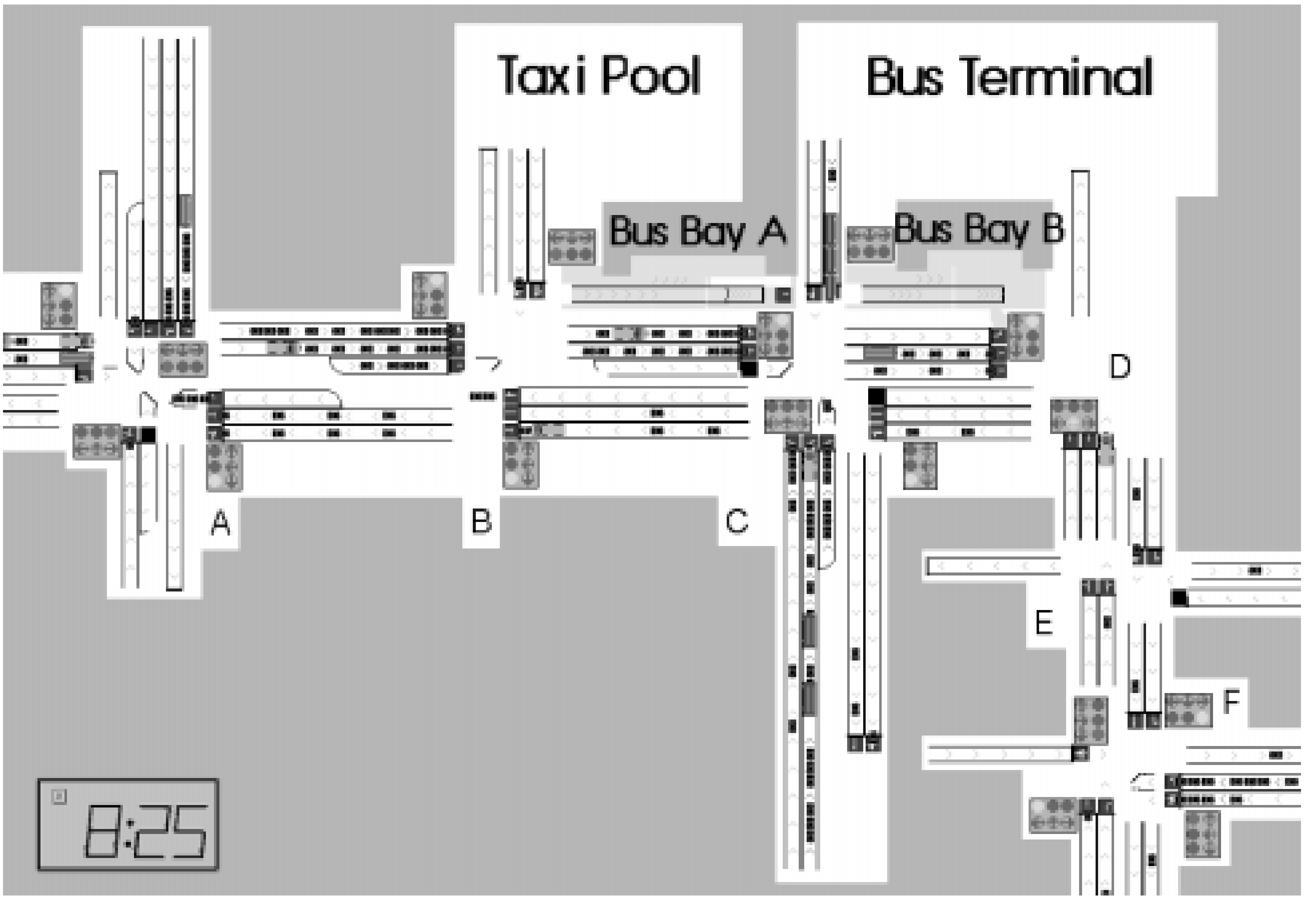


Figure 5: The displayed image of the network for the model validation

n average, then they start moving toward the bus terminal; however they often spill over from the bus bays and even from the bus lanes sometimes.

Furthermore, since the buses exiting from the bus terminal through *C-N* are lot during the peak period, the right-turn vehicles at *C-S* is interfered by these buses and consequently they spill over from the right-turn pocket of *C-S* (*C-N* means approach *N* at Intersection *C* in Figure 4).

3.3. Comparison with Simulation

Figure 5 shows the displayed image of the network. From visual inspection, the simulation model seems to well reproduce the over-saturated condition upon the main street and the spilling over from the right turn pocket of C-S. In order to discuss the validity of the simulation model, let us compare the observed data with the simulated values in regard to the throughput traffic volumes, the queue lengths and the travel times.

The observed throughput volumes at the sections listed in Table 1 during 8:00 - 9:00 are compared with each of the simulated ones. Since the saturation flow rate at each section is fitted to the reasonable value in a range from 1600 to 1800 [veh/hr/lane], most of the simulated values are close to the observed ones and the appropriate number of vehicles flowing into the network.

Table 1

Comparison of the observed throughput volume with the simulated one at each section during 8:00 - 9:00

Section	*A-N*	*A-W*	*C-N*	*C-S*	*F-E*	*F-S*
Observed	672	1086	148	511	605	978
Simulated	679	1095	150	510	609	974

Figure 6 illustrates the maximum queue length of both observed and simulated values at each intersection during 8:00 - 9:00. Although the definitions of both queue length are different (i.e. the observed ones were measured with the eye by the observer, on the other hand the simulated ones are defined as the total length of the blocks where the spatial speed are less than 10 km/hr), the result may say that the simulation model has a tendency to reproduce the over-saturated traffic condition reasonably. However, the differences between the both queue lengths in some peripheral links flowinf into the network are large. This is because the vehicle arrival rate

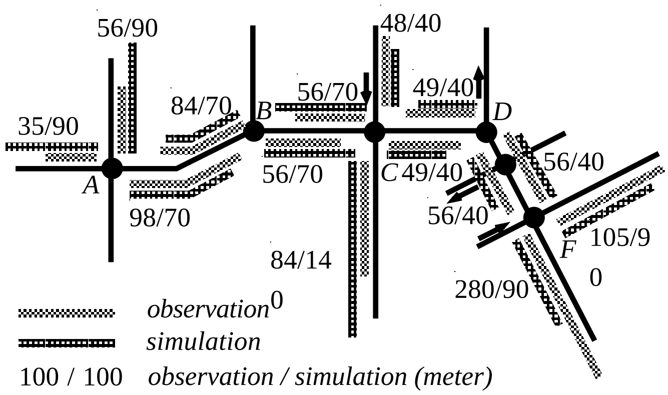


Figure 6: The comparisons of the queue lengths

at the upstream end of the link flowing into the network is designated by the observed throughput volume at the downstream stop line of such link, therefore the vehicle arrival patterns in the simulation are different from the real ones.

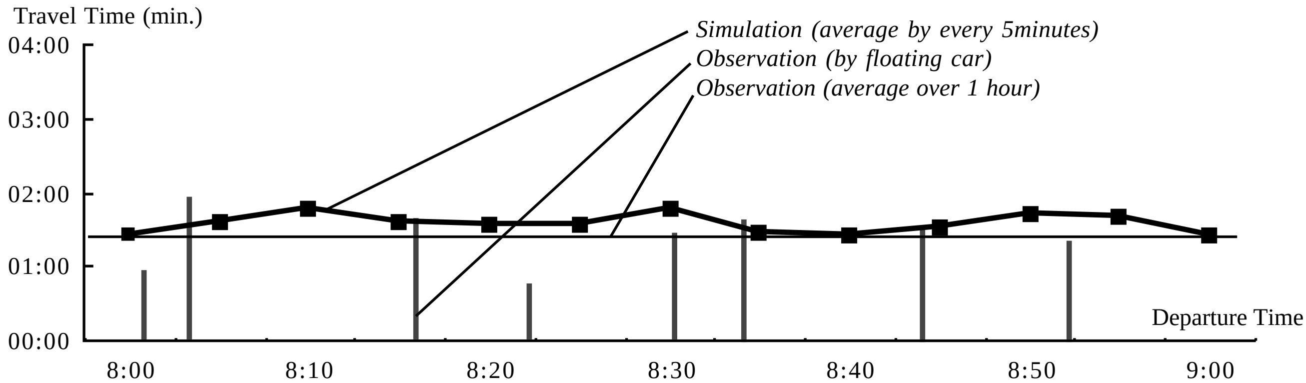
Furthermore, the travel time along the main street between A and F are compared as shown in Figure 7. The observed data is collected by several test runs of floating vehicles, on the other hand, the simulated data represents the sum of each link average travel time along the main street in every 5 minutes.

Figure 7a illustrates the comparison within the section from *A* to *F*. In this direction, the simulated data well agrees with the observed one. Since the flow of this direction is relatively smooth comparing with the opposite direction, the numbers of stops in every trips from A to F are almost same. Consequently, the simulated data is close to the average travel time of all floating runs.

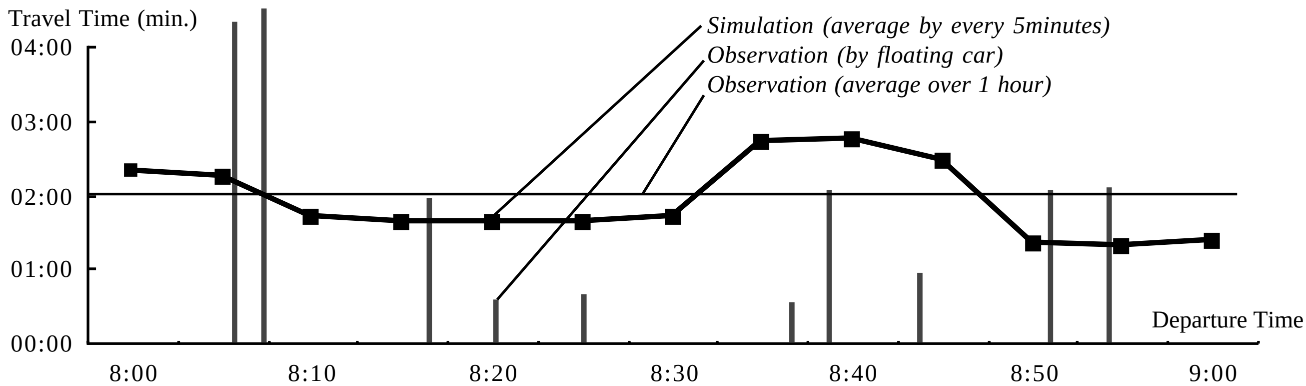
Figure 7b shows for the opposite direction. In this case, the fluctuation of each observed travel time are very large. This means the number of stop by the red signal in the trip greatly varies depending on the departure time of each floating run. However, though the number of the floating run is still insufficient, the average of the observed travel time seems close to the simulated one.

3.4. Problem in Lane Changing Model

In this application, it is not necessary to incorporate lane change behaviors within a link because the lengths of every link are quite short so that there are few chance to change lanes. The lane choice model is employed instead such that each vehicle chooses an appropriate lane when it enters a link according to its turning movement at the end of the link. In a real case, a vehicle often changes lanes considering the turning movement at further downstream



a) Travel time from A to F



b) Travel time from F to A

Figure 7: The comparison of travel times

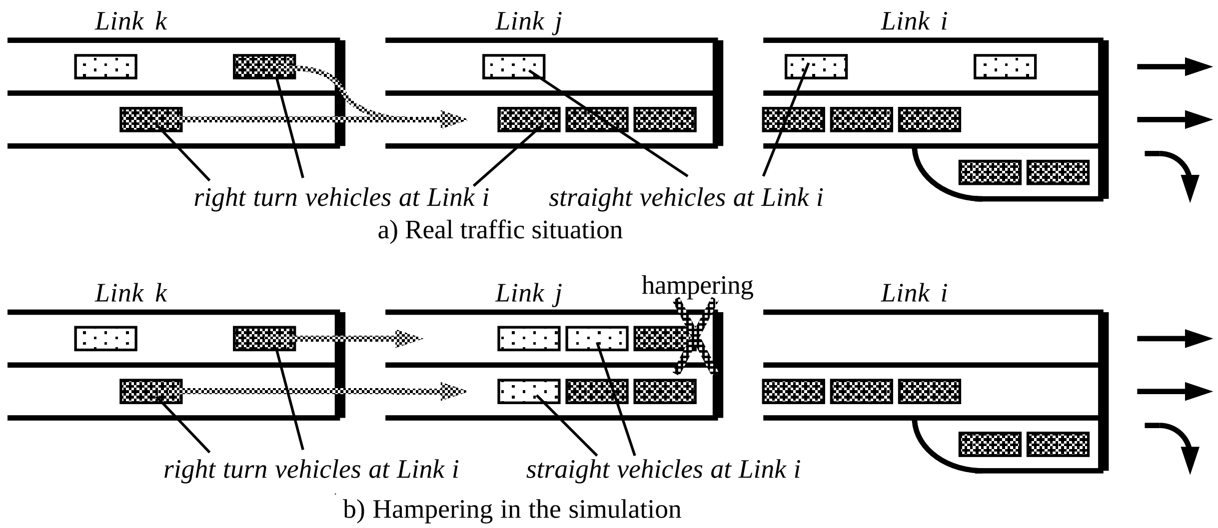


Figure 8: The problem in the lane choice model in the simulation

intersection. Figure 8a illustrates a typical situation such that a vehicle which turns at the downstream end of Link i changes the appropriate lane on Link j beforehand, then the traffic on the other lane keeps smooth. This kind of situation easily happens when the traffic is congested and the lengths of the links are relatively short.

In the simulation, a vehicle cannot find the appropriate lanes until it reaches the link where the vehicle turns at the downstream end. Therefore, as shown in Figure 8b, a vehicle sometimes hampers the upstream traffic at the downstream end of the Link j, then the throughput volume at the downstream intersection decreases. This kind of hampering sometimes detected around Intersection *C* and *F* in the simulation.

We are now revising the lane choice model to incorporate this kind of lane changing as well as the lane changing in the middle of a link.

4. SUMMARY

In this paper, the Hybrid Block Density Method and the concept of the route and lane choice model used in the traffic model of AVENUE were briefly described. The traffic model was applied to a real network for the model validation. Although the availability of the observed data used in the comparison with the result of the simulation is limited, we may conclude that the traffic model has the ability to reproduce over-saturated condition of urban traffic which involves complicated lane usages.

For the future issues, the lane choice model should be improved to incorporate the lane changing in the previous links to the turning intersection as well as the lane changing in the middle of a link.

Furthermore, the route choice model will be improved so as to be applied to more complicated and larger networks. The current route choice model takes the way that some vehicles always select pre-fixed paths and the others always select the minimum time paths revised in every certain minutes, but this way is too restricted to be applied to more complicated network than the one used in this paper. The later route choice behavior will be changed to the stocastic one to fit the recent demand for traffic simulations in the next version.

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