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# A simulation model for evaluation of merging capacity on the Metropolitan Expressway

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## 1. Introduction

This study is the second phase of a three-year program on freeway merging capacity undertaken by the Kuwahara laboratory. The macroscopic study during the first phase of this research has been described in Seisan-Kenkyu (Sarvi et al.,1999). Presently, the macroscopic research is extended to include a microscopic study in order to predict and evaluate the behavior of drivers at merging sections under heavy traffic condition, and finally estimate the merging capacity. The relationship between geometries and traffic characteristics with merging capacity remains largely unknown. In addition, statistical analyses based on observed volume for various geometries and traffic conditions are quite difficult and time-consuming. Furthermore, quite often sufficient data can not be collected for the purpose of an individual study (e.g. lateral clearance). Therefore, the merging capacity still can not be estimated with sufficient accuracy, though extensive studies on merging sections have been performed mainly in the United States. Instead, this study focused on individual vehicular maneuvers to construct a simulation model for a merging section, since the merging capacity is possibly a consequence of the aggressive behavior of each driver, and is not completely random but follows some fundamental disciplines.

## 2. Modeling concept of vehicular maneuvers

Driving behavior, which affect the capacity of merging sections, are mainly two folds, i.e. the lane changing maneuvers and car-following behaviors. Merging vehicles have to determine their gaps and shift their lanes under restricted time and space.

Particularly under the heavy traffic demand, such maneuver as · accelerating and decelerating for squeezing into the gap, affects motions of the following vehicles and causes their speed reduction.

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Concerning the lane changing behavior, a merging vehicle stays in the merging section until it completes its lane changing, and the behavior can be classified as two maneuvers: optimum speed adjustment so as to enter the target gap (1st step), and the lane changing execution (2nd step). Under light traffic condition when merging vehicles, enter a merging section, at first they start searching gaps considering their relative situations for the adjacent vehicles in terms of spacing and relative speeds. As mentioned in macroscopic study, under heavy traffic condition such as capacity condition, gap searching and acceptance maneuver have no importance. According to macroscopic study, no significant correlation is found between the acceleration lane length and capacity of merging sections. Therefore, in this model the gap searching and accepting maneuver have not been considered.

<1 st step>

Based on the observation at merging sections during heavy condition, when a vehicle enters a merging section initially it keeps the tail of the queue, which is formed from almost terminal section of the taper part of merging section. When vehicles reach to the terminus of merging sections, drivers tend to consider relative situations for the adjacent vehicles in terms of spacing and relative speeds.

<2 st step>

At merging time, drivers not only longitudinally but also laterally move to the terminal part of the taper and merge with the vehicle in the adjacent freeway shoulder lane. In most cases, the squeeze merging can be observed at the end of merging section. Here we define this type of merging as a zip merging, which means vehicles on ramp and those in the freeway shoulder lane merge together one by one regardless of the length of available gap.

Concerning the car-following behavior, spacing-speed (S-V) relationship could be used for the modeling. This relationship is based on the assumption that followers try to keep front spacing S for their own speed V.

## 3. Observations and analyses of merging maneuvers

Traffic surveys were performed at Hamazakibashi interchange and Ikejiri on-ramp on metropolitan expressways in Tokyo area in order to observe the behavior of drivers. Traffic streams were recorded using several video cameras mounted on top of the buildings in the vicinity of merging sections. During the observation period at 1) Hamazakibashi merging section, demand exceeded the capacity and long queues were formed on both inflow legs. At 2) Ikejiri, which was under near-capacity condition, only in a short period of time the queues were observed. From video pictures, positions of merging vehicles and two adjacent vehicles in the neighboring lane, leader and lag vehicles were measured an interval of 0.2 seconds. The measured positions of vehicles on the video screen were converted to map co-ordinates. Through these methods, time series data of vehicle positions and velocity, were stored for almost 70 merging cases.

### 3.1 Exact location of Bottleneck

In order to recognize the exact location of bottleneck, for which capacity could be observed, based on the above observation, time trajectories of vehicles have been used. Since after merging drivers tend to adjust their space, the real bottleneck is possibly after merging section. Based on time trajectories analyses the bottleneck of merging sections occurs exactly when drivers merge and change lane from ramp to freeway and at that time the flow rate is maximum.

## 4. Car-following model by the spacing-speed relationship

A vehicle is assumed to maintain a certain amount of front spacing from the vehicle in front defined as a function of its speed. In this model two kinds of spacing-speed relationship have been used. The first one is for vehicles present upstream or downstream of merging area (1st S-V ), and the second one for vehicles within the merging section (2nd S-V).

<1st S-V> Based on the observations on the Tokyo Metropolitan expressways, we employed the spacing-speed (S-V) relationship shown in Figure 1, for the upstream or downstream of merging area in which the spacing is a piecewise linear function of the speed. When the actual front spacing is less than the spacing given by the S-V relationship, the vehicle is considered as being under the car-following (constrained) condition, and it should decelerate to maintain the specified spacing for its speed. Depending on this relationship, maximum flow can be 2800[pcuphpl] at the speed of 60[km/hr], assuming that all the vehicles are moving with their spacing derived from this relationship.

On the other hand, if the actual spacing is greater than the specified spacing, the vehicle is not following a vehicle ahead. However, the driver is assumed to adjust the speed so as to maintain desired speed, which is provided when it is generated. Several values of acceleration available for non-following vehicles, are assigned previously depending on their cruising speeds.

<2nd S-V> When a merging vehicle is laterally shifting towards the target gap, the vehicle is assumed to follow a vehicle in front based on the spacing-speed (S-V) relationship shown in Figure 2. In this model, based on macroscopic study and direct observations, we calibrated the spacing-speed (S-V) relationship so that the simulation output matched the observed capacity. Furthermore, in the case when a merging vehicle reaches the terminus of merging section before completing its merge, as is often the case in heavy traffic, most of the adjacent vehicles are forced to

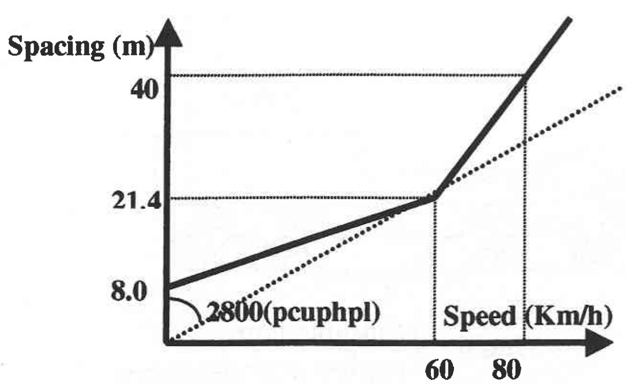


Fig. 1

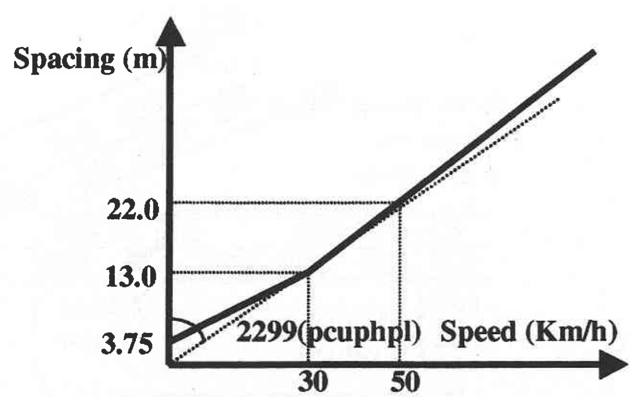


Fig. 2

Figure 1 and 2 The (S-V) relationship for car-following model provide sufficient gap for the merging vehicle to complete merging maneuver.

## 5. Traffic simulation at merging sections

A periodic scanning method at intervals of 0.2 seconds is used for this simulation model. In this simulation model, study areas are not only merging sections but also upstream/downstream sections, and are basically treated as three types of segments with different characteristics (see Figure 3). (1) Preliminary segments (link 1&2): The purpose of these segments is to generate vehicles at the most upstream end, and to form platoons while traveling through the 250m segment. At the beginning of freeway segment (link 1), vehicles are dynamically generated based on travel time on shoulder and median lane of freeway. For both ramp and freeway vehicles, the generated headways follow Negative Exponential distribution. Inflow traffic demand is converted to passenger car unit using the passenger car equivalent of 1.7[pcu/heavy veh.]. Moreover, the size and acceleration/deceleration performance of every passenger car is assumed the same. Each driver has a desired speed, which follows the Normal distribution. Parameters of these distributions is provided when vehicles are generated.

(2) Merging segment (link 3&4): Merging maneuver of merging vehicles are implemented in these segments in addition to lane changing of freeway shoulder lane vehicles to freeway median lane. The 10 meters segment at the end of link 4 is defined as the terminal segment in which non merging vehicles are squeezed to merge.

(3) Downstream segments (link 5): In this 100m-section, free flow traffic condition after merging section is simulated.

(4) Hisou lane changing model: Lane changing of aggressive drivers present in freeway shoulder lane implemented by this model before nose of merging section (Link1). The term aggressive drivers implicate those present in freeway shoulder lane who then change lane immediately before merging nose in order to avoid merging maneuver. Based on direct observation, this lane changing behavior decreased the flow rate of freeway median lane and therefore affected the total output flow rate of freeway.

(5) Hisou1 lane changing model: Lane changing of vehicles present on freeway shoulder lane within the merging section into the freeway median lane is implemented by this model (Link3). Often vehicles change their lane, especially where two ramp lanes merge, after first merging in order to avoid more delay for the second merge if sufficient gap and higher average speed are available in adjacent freeway lane. In other word, drivers after first merging maneuver in order to avoid the second merge may move over into the freeway median lane. This lane-changing maneuver not only decreases the flow rate of freeway median lane but also increases the ramp flow rate.

The current version of traffic simulation model considers the parallel and taper types of acceleration lane, the length of taper as well as the divergence angel of merging segment. The final objective with respect to the second phase of this study is to complete the simulation model considering the effect of lane width, lateral clearance, and vertical alignment.

## 6. Validation of the simulation model

The traffic simulation model is validated using the observed flow, and lane changing maneuver at the Hamazakibashi interchange, where the traffic demand exceeded the capacity resulting in formation of upstream queues. Figure 4 shows the comparison of observed versus simulated traffic flows. For validation of simulation model, two lane changing maneuvers, one before

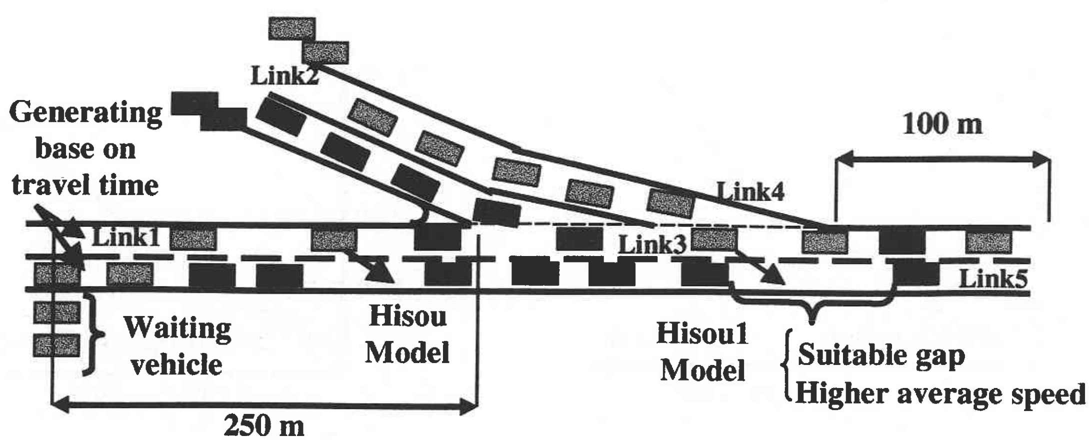


Fig. 3 Outline of Simulation model

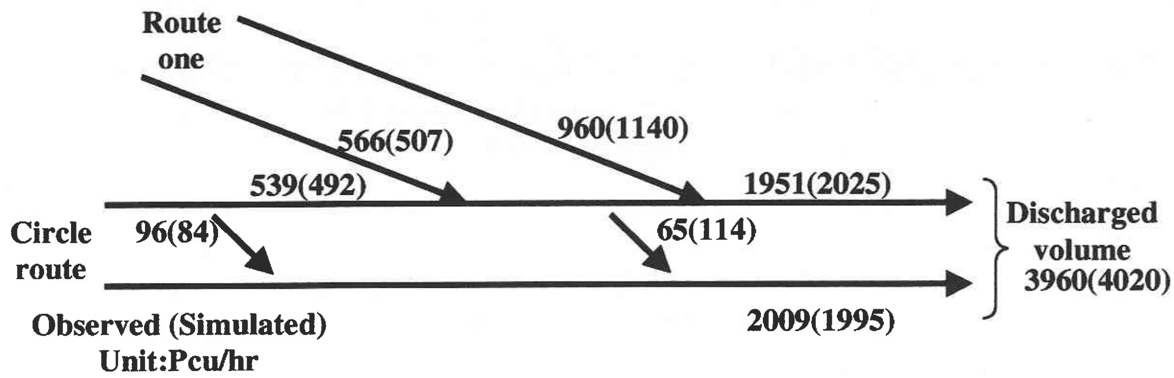


Fig. 4　Observed versus simulated traffic volumes (Hamazakibashi interchange)

merging nose and second within the merging section with five discharged volumes are compared with observation. The simulation discharged volumes of freeway shoulder lane and median lane fit well with the observed. The discharged volumes of ramp and freeway shoulder lane before the second merge is not as good as freeway shoulder lane after both the merge and median lanes. Number of lane changing maneuvers before merging nose fit well with the observed, while number of lane changing within the merging section are inconsistent with the observed. In this model, we only used the fixed average acceptable gap and average speed for modeling the lane-changing maneuver within the merging area. However, to obtain a more accurate maneuver it is necessary to increase the complexity of the model.

## 7. Conclusions and future research prospects

### 7.1 Conclusion

(1) Traffic surveys and macroscopic studies are performed at several merging sections on the metropolitan expressway. Consequently, a specific method to deal with these observed data is established. By elaborate analyses of macroscopic and observed data, it is proved that such zip merging maneuver of ramp vehicle to the adjacent freeway shoulder lane vehicle should be considered in order to explain the merging maneuver under capacity condition. In addition, these studies suggest that gap searching and accepting maneuver are not important for capacity analyses.

(2) A model to express the acceleration/deceleration maneuver is developed, which focus particularly on the merging vehicles moving to the target gap. The spacing-speed (S-V) relationship has been used for representing the drivers behavior, especially within the merging section. Furthermore, lane changing maneuver for aggressive drivers before merging nose and within the merging section to avoid more delay is taken into consideration.

(3) A simulation program for estimating capacities of merging sections is developed, and it is validated for Hamazakibashi interchange under capacity condition. The simulated values of discharged volumes are found to be consistent with the observed. This simulation model can take into account the difference between parallel and taper acceleration type of merging lanes as well as divergence angel of merging section.

### 7.2 Future research prospects

(1) The lane changing within the merging area model of this simulation program should be further developed in order to be consistent with observations.

(2) The effects of vertical alignment, lane width, lateral clearance, and heavy vehicles are expected to be incorporated.

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