MODELING OF FREEWAY RAMP MERGING PROCESS OBSERVED DURING TRAFFIC CONGESTION

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ABSTRACT

This work focuses on modeling vehicle acceleration-deceleration behavior during freeway and ramp merging maneuvers under congested traffic situation. On the Tokyo Metropolitan Expressway, traffic congestion frequently occurs at merging bottleneck sections. There have been only a few research studies concerned with the traffic behavior and characteristics in these situations. Therefore, a three years extensive study has been undertaken to investigate traffic behavior and characteristics during traffic merging processes under congested traffic flow in order to design a safer and less congested merging points as well as a more efficient control at these bottleneck sections. The overall research approach is illustrated in Figure 1, emphasizing the second component, which represents this work. Sets of data capturing a wide range of information were collected using a videotape and image processing techniques. Comprehensive traffic surveys were conducted at two entrance ramps in the Tokyo Metropolitan Expressway. These data provided the fundamental information for investigating the ramp driver merging behavior. A theoretical framework for modeling ramp driver acceleration-deceleration behavior is presented. It uses the stimuli-response concept as a basic rule and is formulated as a modified form of the conventional car-following models. The collected data are used to calibrate the proposed model. The results indicate that on average 0.66 sec time gap exist before ramp drivers respond to stimuli. It is found that the surrounding freeway vehicles affect significantly the ramp vehicle acceleration behavior. In addition, a simulation program was built using the developed acceleration-deceleration model. The simulated time-space trajectories of vehicles consistently fit well the observed data.

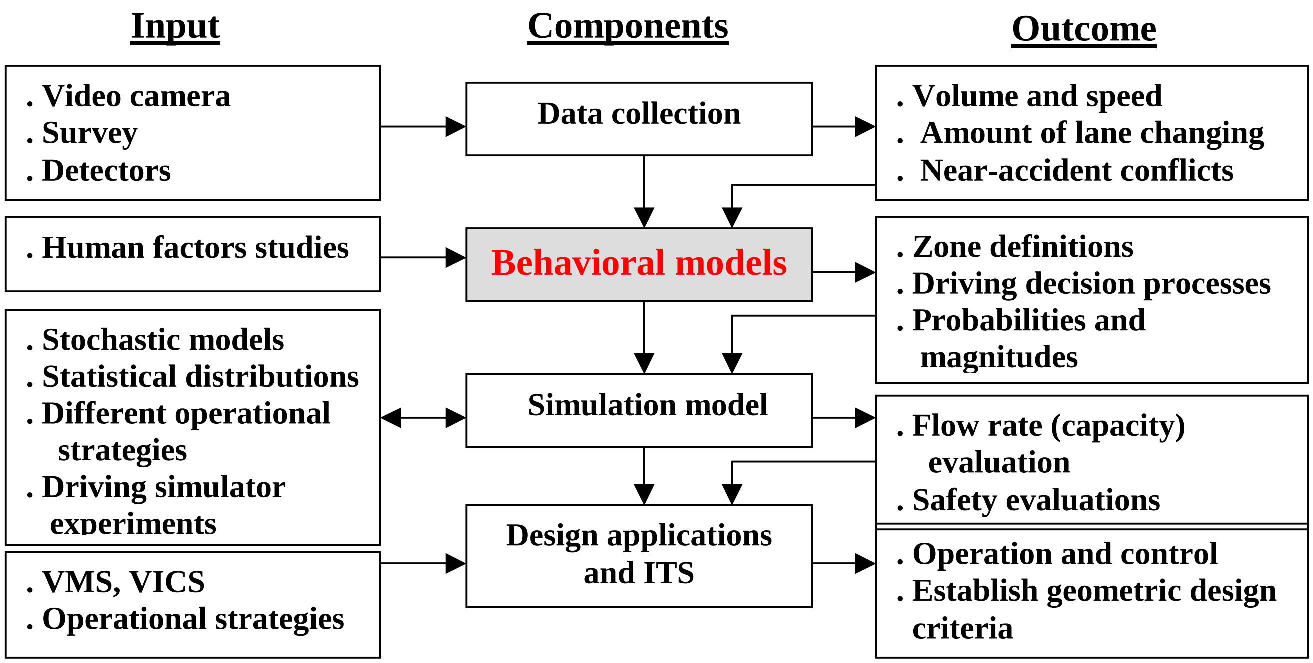

Figure 1. Overall research flowchart with emphasis on the component of this work

1. INTRODUCTION

The acceleration and merging process from an entrance ramp to freeway lanes constitutes an important aspect of freeway traffic operations and ramp junction geometric design. Competing traffic demand for space influence this process regarding both the ramp freeway junction and the upstream freeway lanes. A driver approaching from a ramp must make a series of decisions and carry out control tasks, all within the driver capability to process the roadway and traffic information and interpreted it into speed and position control responses. It is believed that if an available gap is acceptable, the driver on the ramp accelerates and merges directly. If no gap is available the driver may accelerate to create a merge opportunity, or decelerate and wait for later gap. This complex driving situation has both internal factors: driver attitude and vehicle characteristics, and external factors: freeway speed, lane changing maneuvers, relative positions of merging vehicles, and proximity of the merging vehicle to the merge end. Ramp vehicle acceleration-deceleration characteristics are essential components in microscopic simulation modeling for simulating the merging freeway entrance ramp. The major objective of this study was to investigate ramp merging behavior in terms of relative speed and spacing between the ramp vehicle and its corresponding freeway lead and lag vehicles, with respect to various entrance ramp types. Furthermore, to develop a methodology that can be used to model ramp vehicle acceleration-deceleration behavior during freeway merging maneuver under congested traffic flow. For this purpose sets of data capturing a wide range of information were collected using videotape and image processing techniques. Ramp vehicle merging position in conjunction with freeway leader and lag vehicle was analyzed for the both parallel and taper type entrance ramps. Additionally, merging positions with respect to ramp vehicle speed as well as relative speed and time gap between a ramp vehicle and freeway vehicles were examined. The methodology presented in this work uses the stimuli-response equation as a fundamental rule to model a ramp vehicle acceleration-deceleration behavior. The time-base car following model was modified to a nonlinear stimuli-response equation to capture the characteristics of the collected traffic data. Figure 2 shows the conceptual flowchart of the activities to be covered in this work.

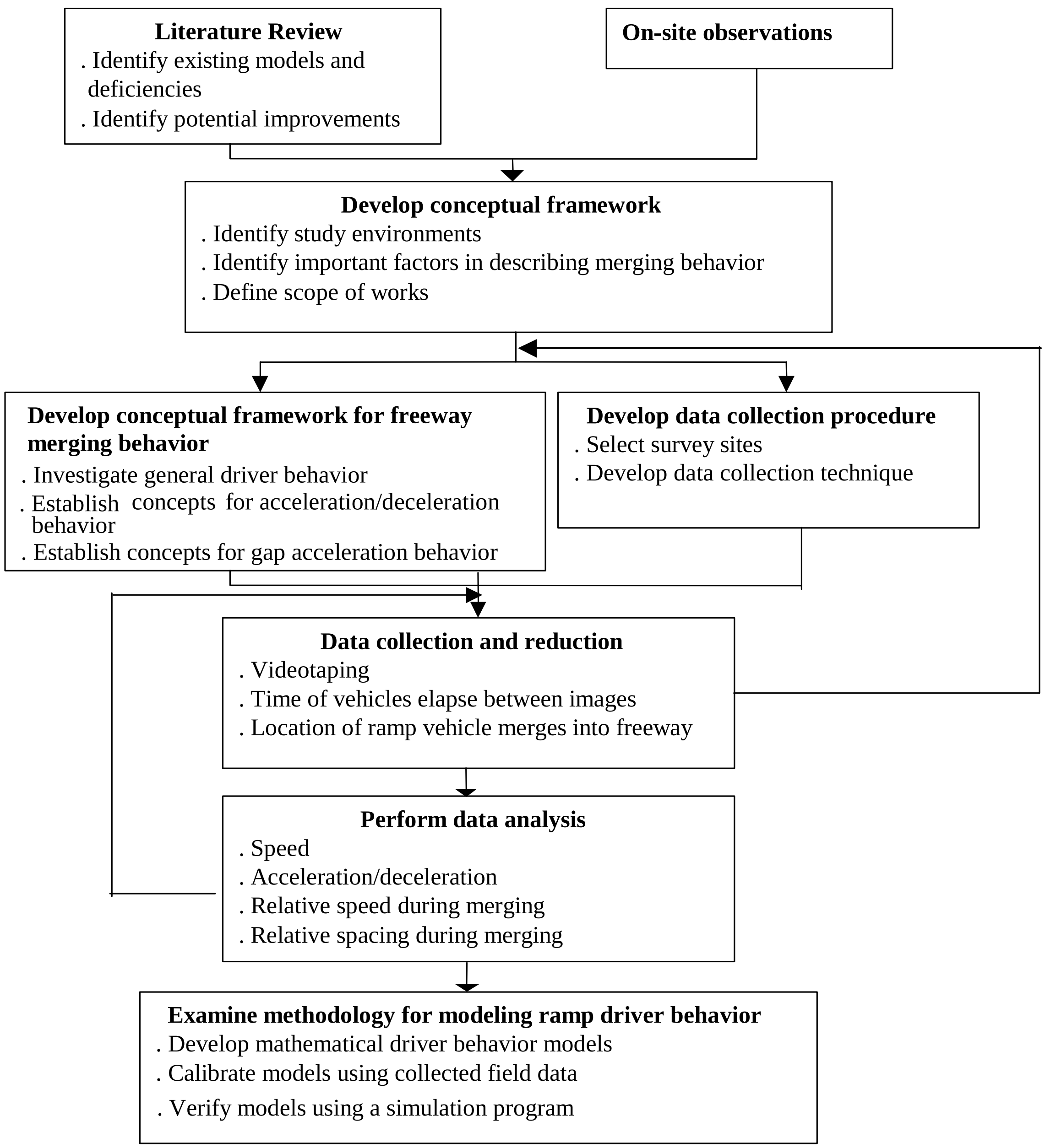

Figure 2. Conceptual research flowchart

The findings of this work may serve future highway geometric design criteria revision. The developed acceleration-deceleration model can also be used to upgrade the ramp vehicle acceleration component of existing microscopic freeway simulation models. Finally the mathematical framework of the developed model may be appropriate to study more driver behavioral aspects of congested freeways.

2. STUDY APPROACH

The study begins with a literature review in order to gain a clear understanding of previous research contributions and possible deficiencies as well as to search for possible directions of future improvements. The study continues with observations of vehicle operational characteristics in freeway entrance ramps at several locations to establish a solid overview of the traffic flow characteristics during a freeway merging process. Preliminary methodologies for modeling freeway merging behavior were then developed conceptually based on knowledge gained from the literature review and on-site observation as well as the objectives to be achieved.

In order to best describe the interaction between ramp vehicle acceleration-deceleration characteristics under congested situation, traffic data were collected and analyzed. During periods of heavy freeway congestion, unstable or stop-and-go traffic flow appears and makes the gap acceptance structure extremely difficult to interpret. In such situations, a ramp driver enters the freeway either by forcing a merge or by accommodating a lag of a freeway vehicle. Consequently, ramp vehicle acceleration-deceleration characteristics behavior cannot be treated as normal and stable behavior. The collected field data, such as freeway and ramp vehicle speeds, acceleration-deceleration rates, and merging positions were used to identify and quantify key variables for use in the freeway merging model.

The field data were applied to the established driver behavior concepts in order to examine the proposed methodologies for freeway merging behavior. Verification and validation of the developed acceleration model has been carried out through a simulation program.

2.1 Freeway Merging Process Analysis

Drivers perform several different tasks during the merging process. Michaels and Fazio (1989) defined these tasks as follows: 1) tracking of the ramp curvature, 2) steering from the ramp curvature onto a tangent acceleration lane, 3) acceleration from the ramp controlling speed up to a speed closer to the freeway speed, 4) searching for an acceptance gap and 5) steering from the acceleration lane onto the freeway lane or aborting. Essentially, drivers tend not to concentrate upon two different tasks simultaneously. They however, will time-share between tasks. It is believed that ramp driver merging behavior is significantly influenced by the geometric configuration of the entrance ramp and the surrounding freeway and ramp vehicles. Despite the abstractness of ramp driver behavior, the merge position and gap acceptance can be clearly defined and observed. The data collected in this study is based on the Ichinohashi and Hamazaki-bashi merging points. Sketches of each entrance ramp are shown in Figure 3.

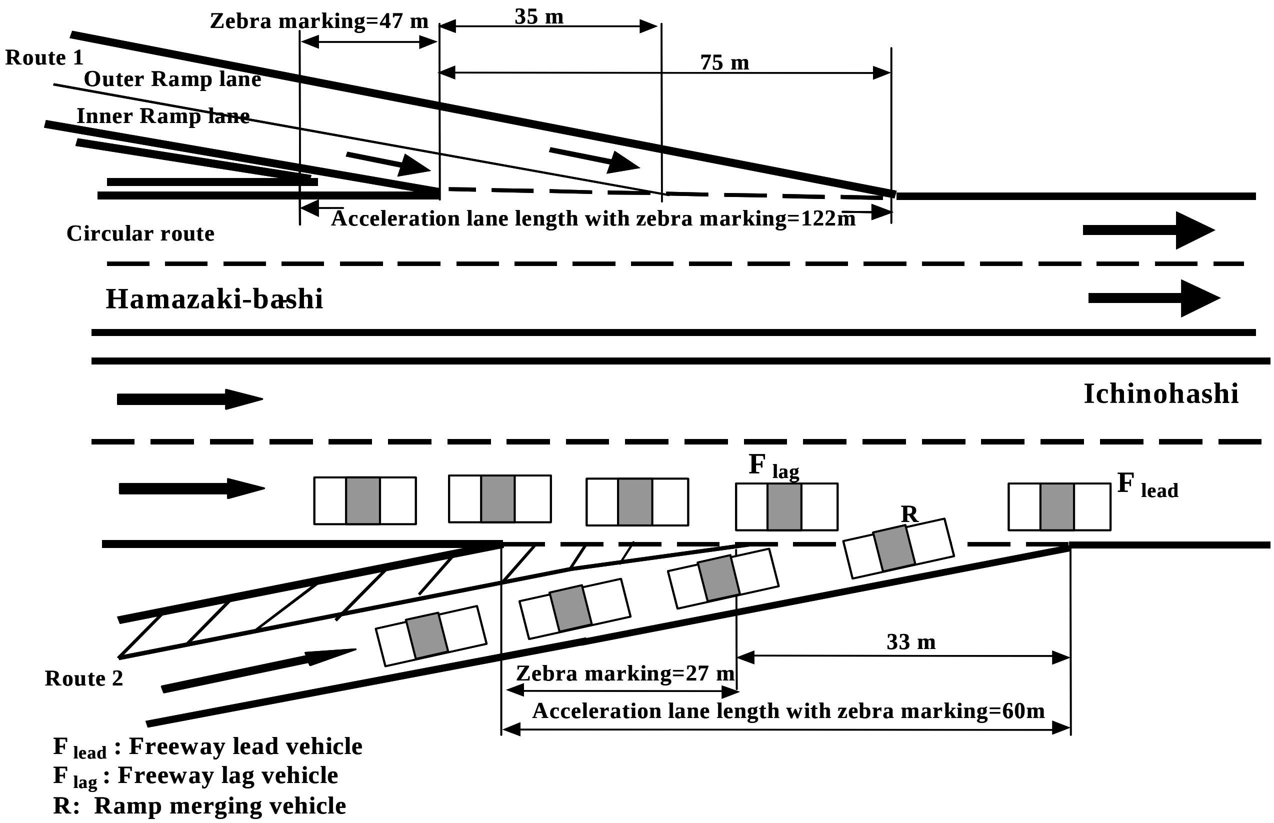

Figure 3. Sketches of Hamazaki-bashi and Ichinohashi merging sections.

Under light traffic flow condition the vehicles, which enter a merging section, start to search for a gap considering their relative positions in terms of spacing and relative speeds. However, based on a comprehensive macroscopic study and observations in the Tokyo Metropolitan Expressway (Sarvi et al. 1999, 2001b) gap searching and acceptance maneuvers do not occur under heavy traffic flow conditions. According to these macroscopic studies, no significant correlation was found between the acceleration lane length and maximum flow rate of merging sections (See Figure 4-a). In addition, it is found that under heavy traffic situations a squeeze merging can be observed at the end of the merging section. Here this type of merging is defined as a **zip merging,** which means that the ramp vehicles and those in the freeway shoulder lane merge together one by one regardless of the length of available gap. Figure 4-b shows the observed percentage of zip merging at Ichinohashi and Hamazaki-bashi merging sections under congested traffic flow (more than 97% of merging maneuvers are of zip merging type). Similar merging behavior was observed by Sarvi et al. (2001a) through Driving Simulator experiments.

Therefore, in this study the gap searching and acceptance maneuver will not be addressed. The following section examines the relative speed between ramp vehicles and the corresponding freeway leader and lag vehicles, as well as the relative spacing between ramp vehicles and freeway leader vehicles (See Figure 3).

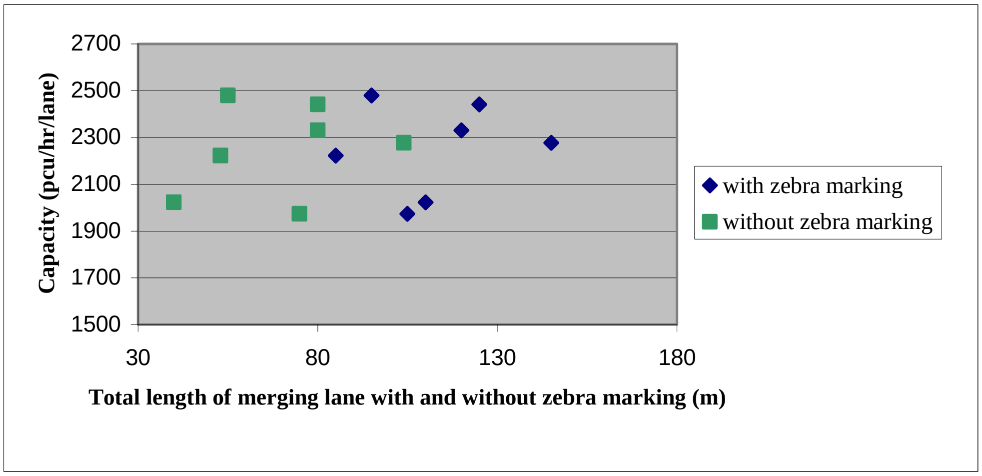

Figure 4-a. Relationship between total length of merging lane with and without zebra marking and merging capacity (15 minutes detector data extended to 1 hour).

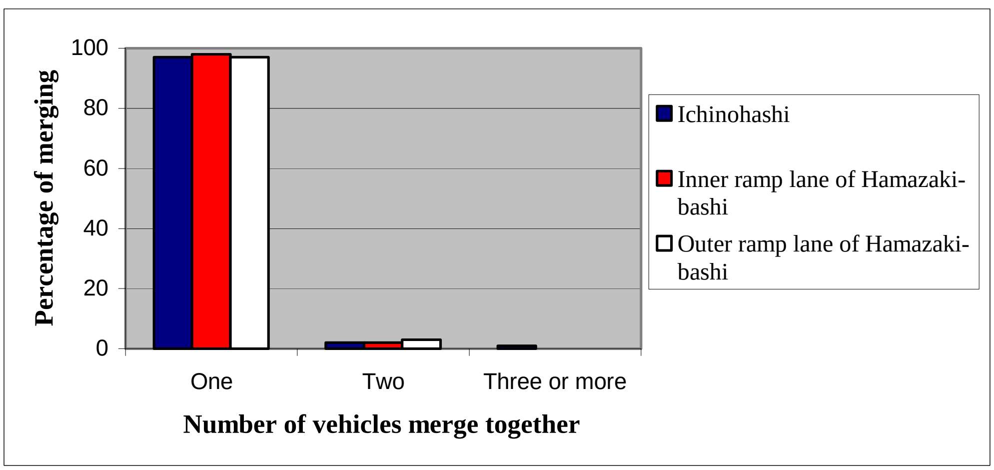

Figure 4-b. Percentage of number of vehicle merging together observed at Ichinohashi, and Hamazaki-bashi merging sections.

2.1.1 Relative speed between ramp vehicles and freeway leader vehicles

Figures 5-a and 5-b show the data between the ramp vehicle acceleration and its relative speed for ramp vehicles and freeway leader vehicles. The relative speed measured with respect to the freeway lead vehicles is defined as follows:

Relative Speed (Vfleadr)=freeway lead vehicle speed- ramp vehicle speed

Relative speed is one of the most important variables that affect the freeway merging behavior. Under free flow situation if a ramp vehicle enters the acceleration ramp with a higher speed than the freeway lead vehicle, a negative relative speed, the ramp driver can then either accelerate to overtake the freeway lead vehicle and merges in front or decelerates to look for later gaps. In contrast, based on Figures 4-a, and 4-b under congested condition it keeps the tail of the queue formed from the ending point of the taper of the merging section. When vehicles reach the end part of the merging section at the starting point of the taper, their relative situations with their adjacent vehicles are in terms of spacing and relative speeds. That is if the freeway leader is faster than the ramp vehicle, the latter will accelerate and vise versa for performing the zip merging process

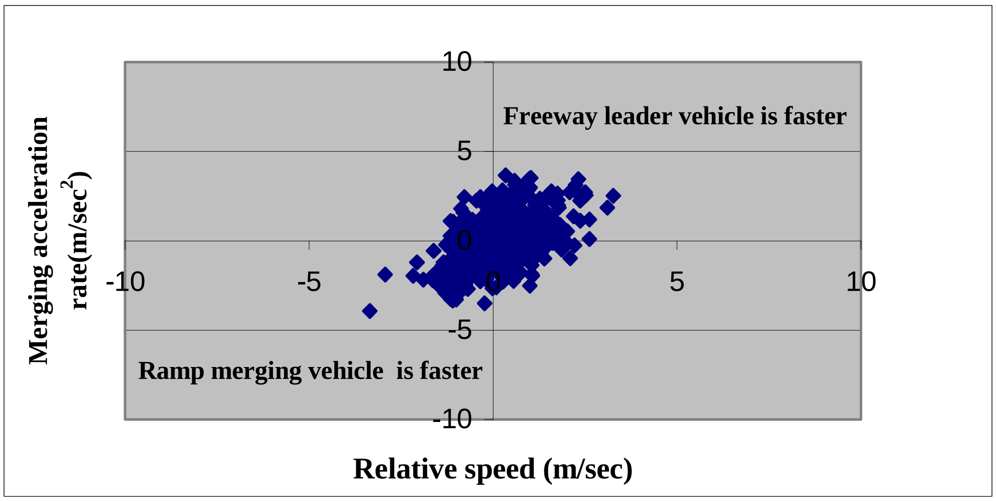

Figure 5-a. Ramp vehicles merge acceleration rate vs. relative speed for ramp vehicles and freeway leader vehicles at Ichinohashi merging section.

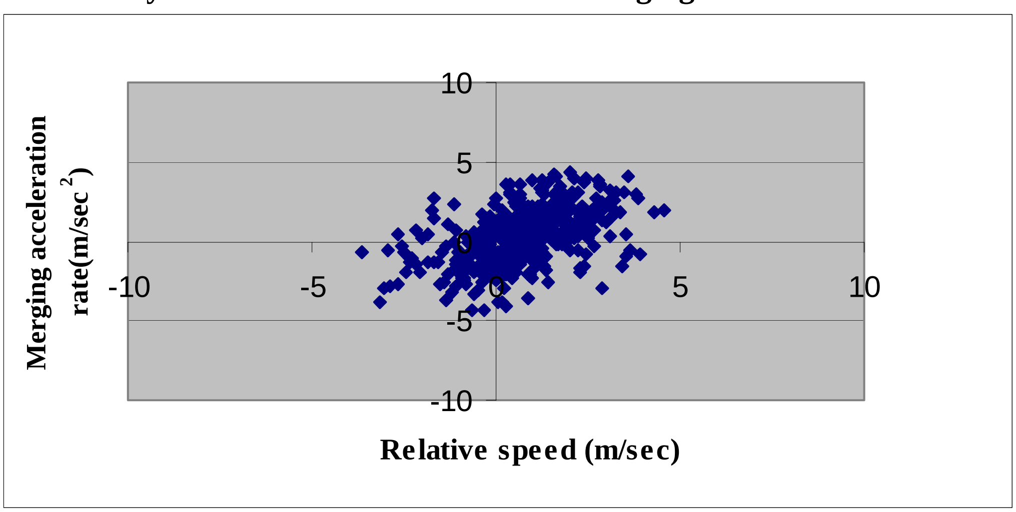

Figure 5-b. Ramp vehicles merge acceleration rate vs. relative speed for ramp vehicles and freeway leader vehicles at Hamazaki-bashi merging section.

2.1.2 Relative speed between ramp vehicles and freeway lag vehicles

Figures 6-a and 6-b show the data between the ramp vehicle acceleration and its relative speed for ramp vehicles and freeway lag vehicles. The relative speeds measured with respect to the ramp vehicles is:

Relative Speed (Vrflag)=ramp vehicle speed- freeway lag vehicle speed

Based on Figures 6-a and 6-b where a ramp vehicle having a lower speed than the freeway lag vehicle, a negative relative speed, will accelerate and force a merge in order to merge as early as possible. Conversely, if a ramp vehicle having a higher speed than the freeway lag vehicle, there is no need to accelerate and consequently to merge smoothly in front of the lag vehicle. Figure 6-c shows a 3D least square fitted surface to the relative speed of the ramp and its freeway leader and lag vehicles at Ichinohashi merging section.

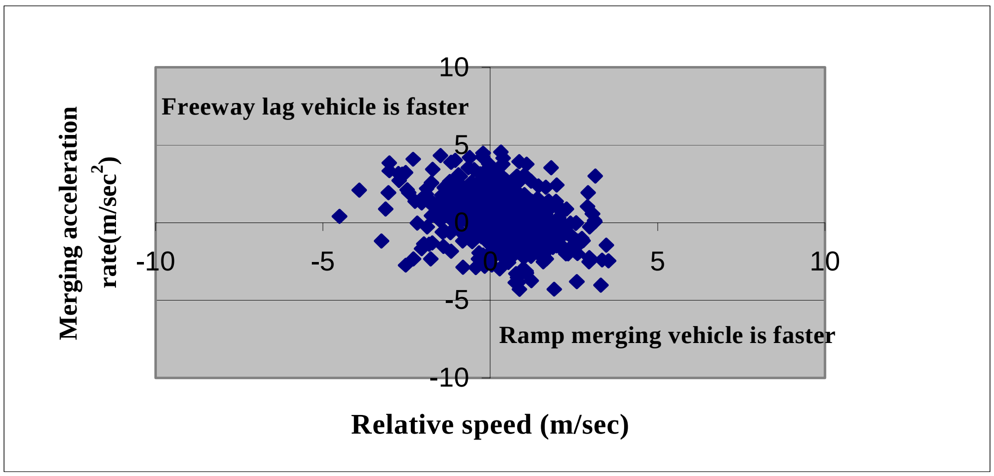

Figure 6-a. Ramp vehicles merge acceleration rate vs. relative speed for ramp vehicles and freeway lag vehicles at Ichinohashi merging section.

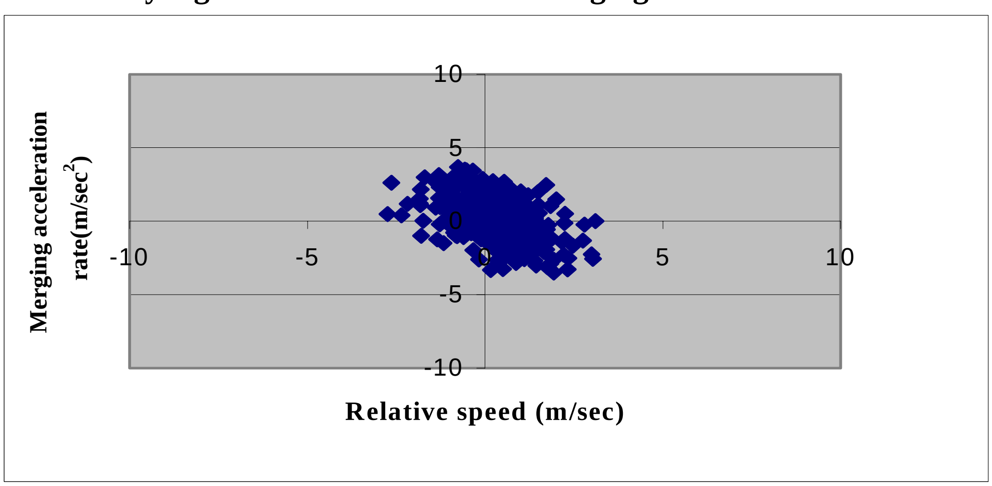

Figure 6-b. Ramp vehicles merge acceleration rate vs. relative speed for ramp vehicles and freeway lag vehicles at Hamazaki-bashi merging section.

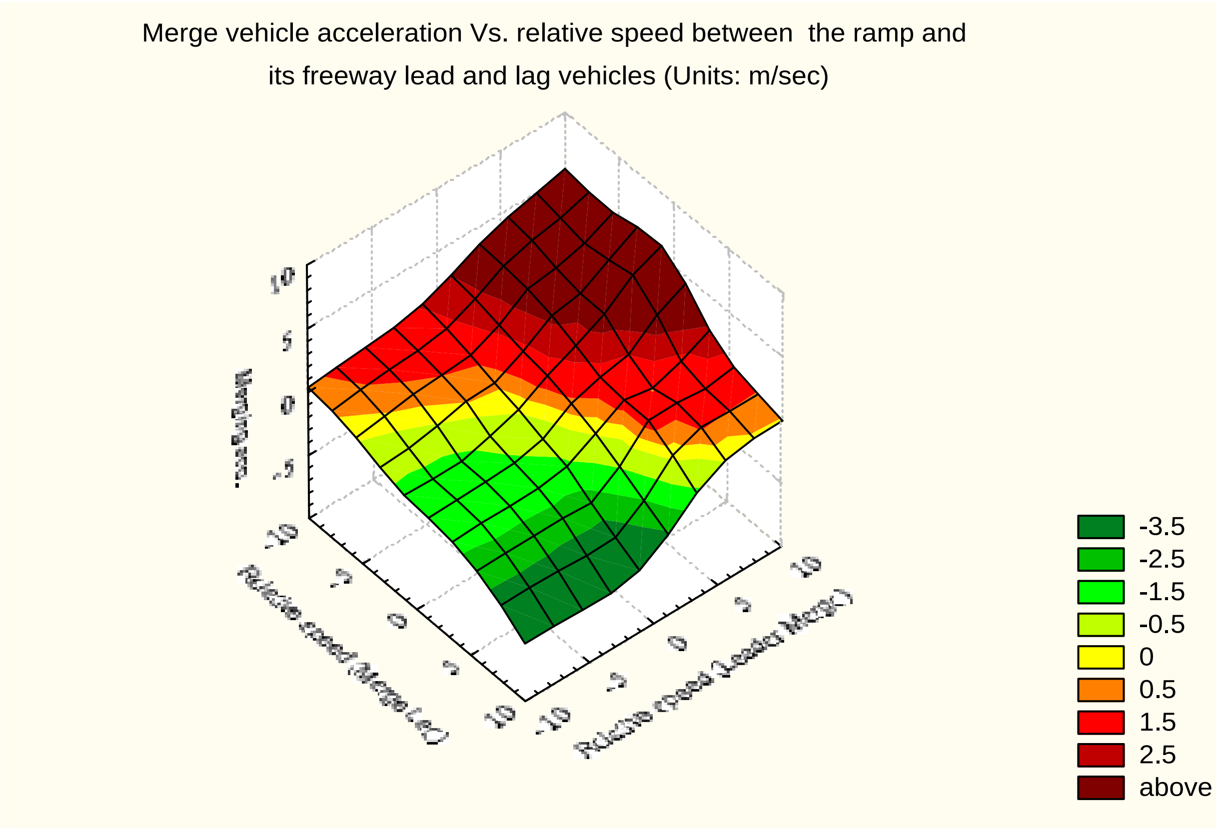

Figure 6-c. 3D least squares fitted surface plot of ramp vehicle merge acceleration vs. relative speed between the ramp and its freeway leader and lag vehicles at Ichinohashi merging section.

2.1.3 Relative speed between freeway lag vehicle and its corresponding freeway leader vehicle

Figures 7-a and 7-b show the data between the freeway lag vehicle acceleration and its relative speed for freeway lag vehicles and freeway leader vehicles. The relative speed measured with respect to the freeway lead vehicles is:

Relative Speed (Vfleadflag)=freeway lead vehicle speed- freeway lag vehicle speed

Another perspective of the freeway ramp merging behavior is the acceleration-deceleration characteristics of freeway lag vehicles regarding the behavior of their corresponding freeway lead vehicles. Based on Figures 7-a and 7-b and similar to the conventional car-following model (where the speed of a freeway lag vehicle is lower than its freeway leader vehicle) a positive relative speed, will accelerate and tries to minimize relative spacing. However, if the speed of a freeway lag vehicle is higher than its freeway leader vehicle (with a negative relative speed) it doesn't need to accelerate and consequently will decelerates in order to avoid collision.

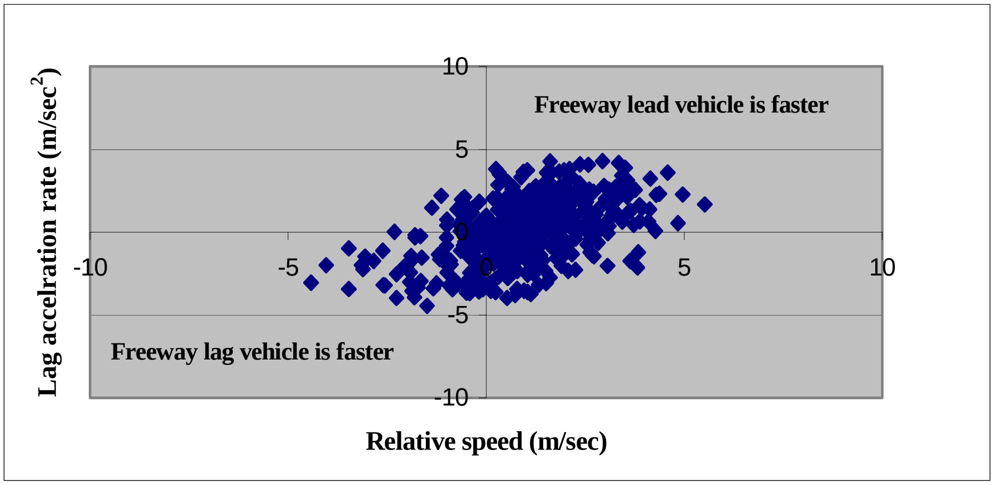

Figure 7-a. Freeway lag vehicles acceleration rate vs. relative speed for freeway lag vehicles and freeway lead vehicles at Ichinohashi merging section.

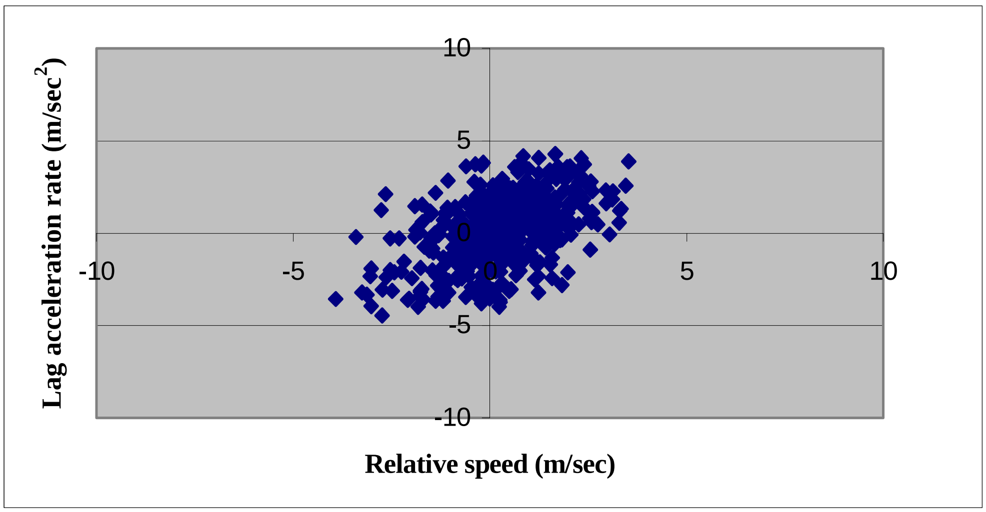

Figure 7-b. Freeway lag vehicles acceleration rate vs. relative speed for freeway lag vehicles and freeway lead vehicles at Hamazaki-bashi merging section.

2.1.4 Spacing between ramp vehicles and freeway leader vehicles

Figures 8-a and 8-b show the data between the ramp vehicle acceleration and its spacing for ramp vehicles and freeway leader vehicles. The spacing measured with respect to freeway lead vehicles were defined as follows:

Spacing (Sfleadr)=(Spacing between the ramp vehicle and freeway leader vehicle) -
(Desired spacing as a function of speed)

Figure 8-a and 8-b represent a spring action of spacing in which the follower accelerates being sucked ahead when the spacing is larger than the desired value. In other words, if the follower feels unsatisfied with his spacing, too long or too short this will inspire him driving faster or slower to keep or recover a comfortable spacing he wants. In this study the desired spacing is referred to as the spacing, which is a function of the speed.

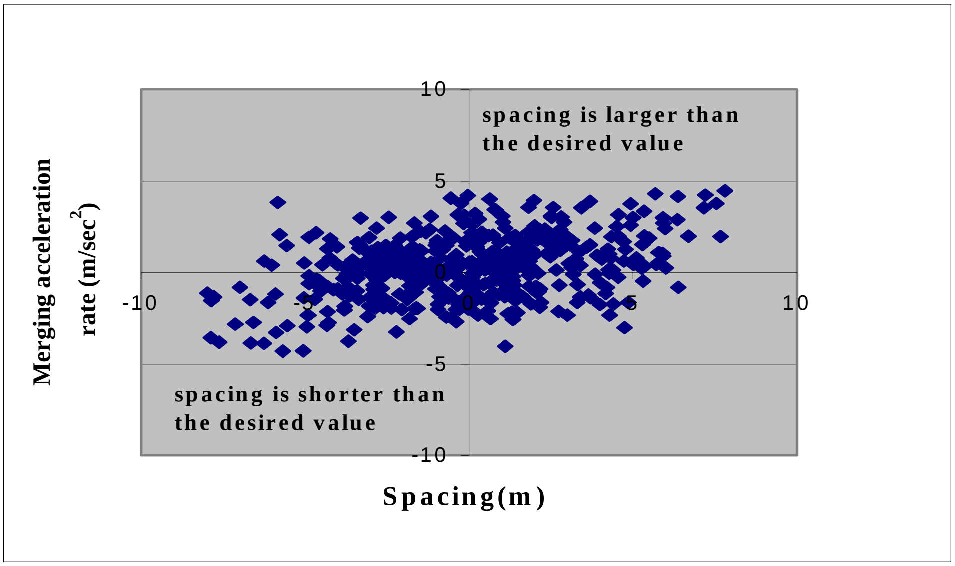

Figure 8-a. Ramp vehicles merge acceleration rate vs. spacing between the freeway leaders and ramp vehicles at Ichinohashi merging section.

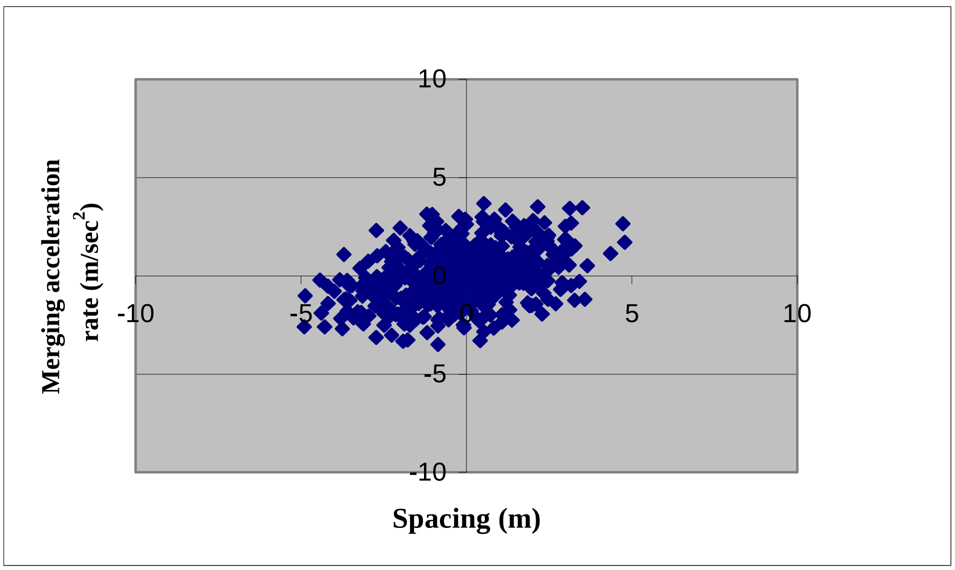

Figure 8-b. Ramp vehicles merge acceleration rate vs. spacing between the freeway leaders and ramp vehicles at Hamazaki-bashi merging section.

2.1.5 General behavior of ramp vehicles in the acceleration lane

A ramp driver in the acceleration lane performs different tasks in a timesharing mode before merging onto the freeway stream. These behaviors vary across drivers. The outcome of this variations depicts the fundamental aspects of the entrance ramp operations. Following is an overview of the observed phenomena during real merging operations.

2.1.6 Speed and acceleration data

The primary data of interest is the speed of vehicles traveling the acceleration lane and entering the freeway. It provides the speed change profile during the ramp freeway transition, indicating where and with what magnitude vehicles were accelerating or decelerating and the speed at which vehicles were entering the freeway along the merging area.

Speed data was calculated by measuring the travel distance between sequential image intervals where a vehicle moves from one image to the next. Figure 9-a shows the calculated ramp vehicle average speed profile based upon distance from the twenty meters prior to the physical nose. The curve illustrates that on an average sense a ramp driver decelerates first after entering the freeway stream due to speed adjustments regarding his freeway leader. Then the driver continuously accelerates and follows its leader. Acceleration profiles of ramp vehicles and their corresponding freeway leader and lag vehicles calculated based on the average speeds described above is shown in Figure 9-b.

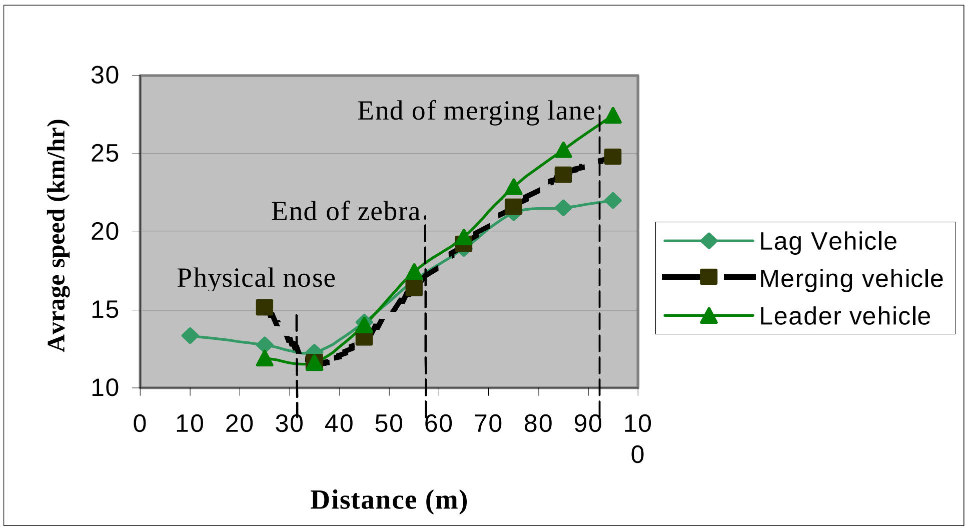

Figure 9-a. Average ramp vehicle and corresponding freeway leader and lag vehicles speed profile (Ichinohashi merging section).

Figure 9-a illustrates also that in an average sense either the freeway lag driver decelerates (to accommodate the merging ramp vehicle) or the ramp driver accelerates (to force a merging) on the first step of the freeway ramp merging maneuver. In this situation the speed of the ramp vehicle is somehow higher than the speed of the freeway leader vehicle. Following this step the ramp vehicle is positioned parallel to a freeway gap and maneuvers into it while adjusting the speed regarding its leader. For the remaining freeway ramp merging maneuver the freeway leader vehicle has higher speed than the ramp vehicle. In addition, this figure shows a clear speed decline due to the interaction between the ramp vehicle and its freeway lag and leader vehicles during the freeway ramp merging maneuver. It is interesting to note that similar merging behavior was observed through the use of a Driving Simulator as it is reported by Sarvi et al. (2001a).

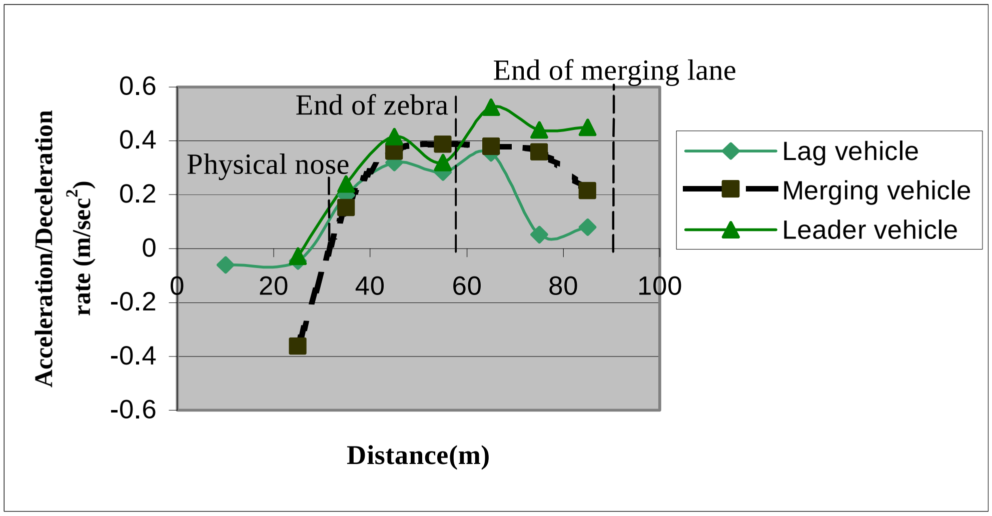

Figure 9-b. Average ramp vehicle, and corresponding freeway leader and lag vehicles acceleration profile (Ichinohashi merging section).

2.2 Methodology for Modeling Ramp Driver Acceleration Behavior

The movement of a vehicle along a freeway entrance ramp involves successive navigational decisions, pursuit tracking, positional control relative to other vehicles and roadway elements, and steering into the freeway stream. The acceleration-deceleration characteristics for each task are different. At the ramp entrance drivers normally have to adjust their speed in order to accommodate the controlling conditions of the ramp curvature and super elevation and to make a decision of possible lane changing into the adjacent ramp lane. As the ramp vehicle approaches the merging end in a free flow condition, the traffic in the freeway merging lane becomes visible and allows for the ramp driver to begin to evaluate available gap. However, in a congested traffic situation the ramp driver stays in the queue of vehicles and waits to force a merging. This procedure may involve deceleration, acceleration reduction, maintaining a constant speed, maintaining a current acceleration, or acceleration increase according to the existing congested condition as it is observed and analyzed by Sarvi and Kuwahara (1999) and Sarvi (2000a). When attempting to model the ramp driver behavior naturally attention is given to the known car-following models. However, it is certain that the acceleration-deceleration performances of a ramp vehicle on acceleration lanes are much more complicated than what the conventional car-following models can describe.

Essentially, the basis for modeling the ramp vehicle acceleration deceleration behavior is different from that of the conventional car-following model. Nevertheless, the fundamental psychophysical concept, *Driver Response(t+T) = Sensitivity factors(t) * Stimulus (t)* where t is the time and T is the reaction time, of the car-following models can still be appropriately adopted as long as the stimuli can be well specified. As is explained in the precede sections for congested traffic situations, the relative speed between the merge vehicle and its freeway lead and lag vehicles as well as the spacing between the ramp and its freeway lead vehicle can be identified as the main stimuli.

In general, the maneuver of a ramp vehicle is mainly influenced by its freeway lag, freeway lead, and the ramp lead vehicles. Significant behavioral differences across different traffic conditions are expected. For instance, when no freeway vehicles are present, a ramp driver can travel at a desired speed. In this study it is assumed (based on observation in congested situation) that the ramp vehicle is a leader of a ramp vehicle platoon in the acceleration lane at the time of merging. Three stimuli are considered for evaluating the ramp driver response: relative speed regarding the freeway leader, relative speed regarding the freeway lag vehicle and the spacing regarding the freeway leader. The equation for the follow the leader car-following model is expanded linearly to incorporate the influence of both the freeway lag and the lead vehicles. Herman and Rothery (1963) have proposed a similar concept with regard to a three-car car-following situation.

The hypothesized expression of ramp vehicle acceleration-deceleration behavior of a ramp platoon leader is given as follows:

$$a_R(t+T) = \alpha_0 + \alpha_1 \frac{V_R^m(t+T)}{[X_{Flead}(t) - X_R(t)]^{l_1}}[V_{Flead}(t) - V_R(t)]$$

$$+\alpha_2 \frac{V_R^m(t+T)}{[X_R(t) - X_{Flag}(t)]^{l_2}}[V_R(t) - V_{Flag}(t)]$$

$$+\alpha_3 \frac{1}{[X_{Flead}(t) - X_R(t)]^{l_3}}\{S(t) - f[v(t)]\} \quad (1)$$

Where:

$a_R(t+T)$: Acceleration rate of the ramp vehicle at time t+T (in m/s^2)

$X_R(t)$: Location of the ramp vehicle at time t (in m)

$X_{Flead}(t)$: Location of the freeway lead vehicle at time t (in m)

$X_{Flag}(t)$: Location of the freeway lag vehicle at time t (in m)

$V_R(t)$: Speed of the ramp vehicle at time t (in m/s)

$V_{Flead}(t)$: Speed of the freeway lead vehicle at time t (in m/s)

$V_{Flag}(t)$: Speed of the freeway lag vehicle at time t (in m/s)

$S(t) = X_{Flead}(t) - X_R(t)$: Spacing between the ramp vehicle and the freeway leader vehicle at time t (in m)

$f[v(t)]$: Desired spacing as a function of speed (in m)

T : Time lag or driver reaction time (in s)

$\alpha_0, \alpha_1, \alpha_2, \alpha_3, m, l_1, l_2, l_3$ are parameters to be estimated.

Eq. (1) has a nonlinear form. However, by assigning constant values to some of the parameters, Eq. (1) can be transformed to a linear form. A nonlinear and linear regression techniques are performed in order to calibrate the parameters in Eq. (1) for different T values.

2.2.1 Acceleration models

The data collected in this study is not large enough to cover all the geometric characteristics. Instead, it can demonstrate general phenomena in order to gain more understanding about the freeway merging process under congested traffic conditions. Based on available data at the Hamazaki-bashi and Ichinohashi locations the following scenarios are analyzed for calibrating the proposed model.

Scenario 1: Hamazaki-bashi including inner ramp lane and outer ramp lane

Scenario 2: Ichinohashi and inner ramp lane of Hamazaki-bashi

Scenario 3: Inner ramp lane of Hamazaki-bashi

Scenario 4: Outer ramp lane of Hamazaki-bashi

Scenario 5: Ichinohashi

Scenario 6: Ichinohashi and Hamazaki-bashi

2.2.2 Calibrating linear acceleration model

The calibration of linear acceleration-deceleration models for scenarios 1 to 6 are based on Eqs. (2) and (3):

$$a_R(t+T) = \alpha_0 + \alpha_1[V_{Flead}(t) - V_R(t)] + \alpha_2 \frac{[V_R(t) - V_{Flag}(t)]}{[X_R(t) - X_{Flag}(t)]^b} \qquad (2)$$

$$a_R(t+T) = \alpha_0 + \alpha_1 \frac{V_R^m(t+T)}{[X_{Flead}(t) - X_R(t)]^1}[V_{Flead}(t) - V_R(t)]$$
$$+ \alpha_2 \frac{V_R^m(t+T)}{[X_R(t) - X_{Flag}(t)]^1}[V_R(t) - V_{Flag}(t)] \qquad (3)$$

In this study the magnitude of b in Eq. (2) is chosen as 1 and the value of m in Eq. (3) is set to 0,1,2 and unfixed parameter. All possible combinations of the explanatory variable components of Eqs. (2) and (3) are examined individually. The statistical analysis software, STATISTICA, was used to solve the linear regression problems. The analysis performed for T= 0 second, 0.33 second, 0.66 second, 1.3 second, 2 second, and 2.67 second. The model that has the largest R value is chosen. The results of analysis appear in Sarvi (2000a).

The best fitted linear acceleration-deceleration model for scenarios 1-6 is given by

$$a_R(t+T) = -0.134 + 0.73[V_{Flead}(t) - V_R(t)] - 0.51 \frac{[V_R(t) - V_{Flag}(t)]}{[X_R(t) - X_{Flag}(t)]^1} \qquad (4)$$

with the R = 0.6 and T= 0.66sec.

The evidence that the best model is obtained when T, the reaction time, is equal to 0.66 second supports the intuitive knowledge that there exist a time lag between the time a ramp driver detects the stimuli and response time. The positive sign of second term in Eq. (4) illustrates, assuming all other elements remain constant, that the ramp vehicle decelerates while approaching its freeway lead vehicle in order to create sufficient space for merging.

2.2.3 Calibrating nonlinear acceleration model

The calibration of the nonlinear acceleration-deceleration model in Eq. (1) is estimated using a nonlinear regression procedure.

Similar to the linear models all possible combinations of the explanatory variable components of Eq. (1) are examined individually and appeared in Sarvi (2000a).

The best fitted nonlinear acceleration-deceleration models is:

$$\begin{aligned} a_R(t+T) = 0.103 + 1.84 \frac{V_R^{0.0002}(t+T)}{[X_{Flead}(t) - X_R(t)]^1}[V_{Flead}(t) - V_R(t)] \\ -0.5\frac{V_R^{0.0002}(t+T)}{[X_R(t) - X_{Flag}(t)]^0}[V_R(t) - V_{Flag}(t)] \\ +0.134\frac{1}{[X_{Flead}(t) - X_R(t)]^0}\{S(t) - f[v(t)]\} \end{aligned} \quad (5)$$

with the R = 0.7 and T= 0.66sec.

The signs of the regression coefficients all have reasonable explanations. The positive sign of first term in Eq. (5) illustrates, assuming all other elements remain constant, that the ramp vehicle decelerate while approaching its freeway lead vehicle. The negative sign of the second term, conversely, indicates that if the speed of ramp vehicle is lower than its corresponding freeway lag vehicle, then the ramp vehicle accelerates in order to force a merging. Finally the positive sign of the third term indicates that the ramp driver always trying to maintain a desirable spacing based on its speed. These results are consistent with the phenomenon demonstrated in Figures 5-a to 8-b. The inclusion of the ramp vehicle current speed as one of the explanatory variables is necessary due to its significant regression coefficient.

2.2.4 Comparison between the linear and nonlinear models

In general, the results of the linear and nonlinear response models show acceptable consistency in both sign and magnitude. For example, the best models for scenarios 3, 5,and 6 are found for T= 0.66sec and the freeway leader and lag vehicles are present in the best models. The sign of the coefficients of the best linear and nonlinear models except scenario 4 are all identical. Based on R-values, the nonlinear models, as expected, are slightly better than the linear models for all scenarios. The differences, however, are not significant. This insignificant difference indicates that the best linear acceleration-deceleration model is a good approximation as well as its capability to reproduce reasonably the interaction between the vehicles as is mentioned by Newell (1999).

2.3 Verification of the Proposed Acceleration Model Using a Simulation Program

The validation of the proposed model has been performed through a simulation program. For this purpose the outcome of the proposed acceleration model has been used for the development of the simulation program (Sarvi et al. 2000b). The simulation program has been extensively and precisely calibrated and validated at microscopic and macroscopic levels using observed traffic flows, and lane changing maneuvers at the Hamazaki-bashi, and Ichinohashi merging points where the traffic demand exceeds the capacity and resulting in upstream queues. The validation of the acceleration model has been carried out through a comparison of the trajectories of vehicles generated in the simulation program with those from the field data.

The results presented in Figure 10 show that the simulated and the observed trajectories have similar speeds. In other words, the slopes of the trajectory lines (speeds) of the simulated vehicles before and after the merging process are consistent with the observed ones. Additionally, a significant speed reduction immediately prior to the merging maneuver is observed in both the simulated and the observed trajectories. Finally, the time distance between ramp vehicle and its leader vehicle is almost the same in the simulation and the observed trajectories.

3. CONCLUSIONS

The freeway merging maneuvers represent a complex process and involve lane changing, acceleration, deceleration, and merging into a gap. This work presents methodologies for collecting field data, analyzing freeway merging behavior data and developing and calibrating a ramp vehicle acceleration models. Wide ranges of data were collected using videotape and image processing techniques. Comprehensive traffic surveys were conducted at two entrance ramps in the Tokyo Metropolitan Expressway.

A theoretical framework for modeling the ramp driver acceleration-deceleration behavior is presented. This methodology uses the stimuli-response psychophysical concept as a fundamental rule, and is formulated as a modified form of the conventional car-following models. Data collected at the two merging points of the Tokyo Metropolitan Expressway are used to calibrate the hypothesized ramp vehicle acceleration models. It is found that the surrounding freeway vehicles affect significantly the ramp vehicle acceleration behavior. Furthermore, the trajectories of a simulation program, which has been developed using the outcome of the developed acceleration, model, shows reasonable consistency with the observed data. It is believed that the results of this study can serve as an initial guidance for modeling freeway ramp merging phenomena.

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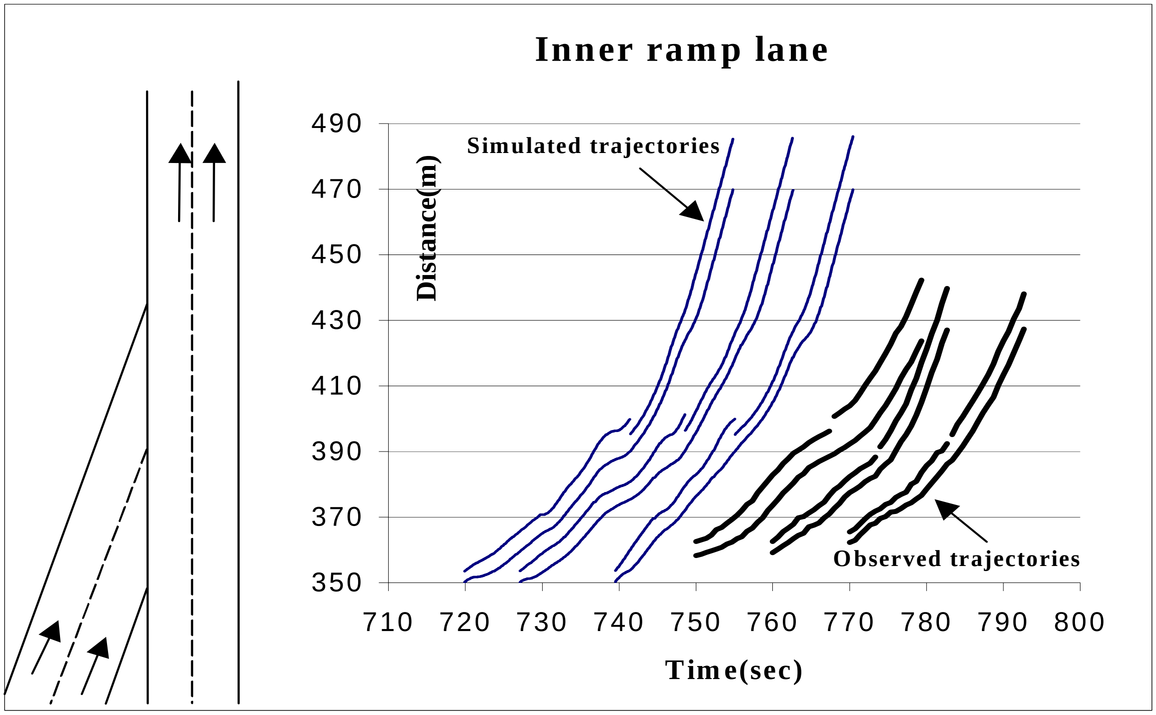

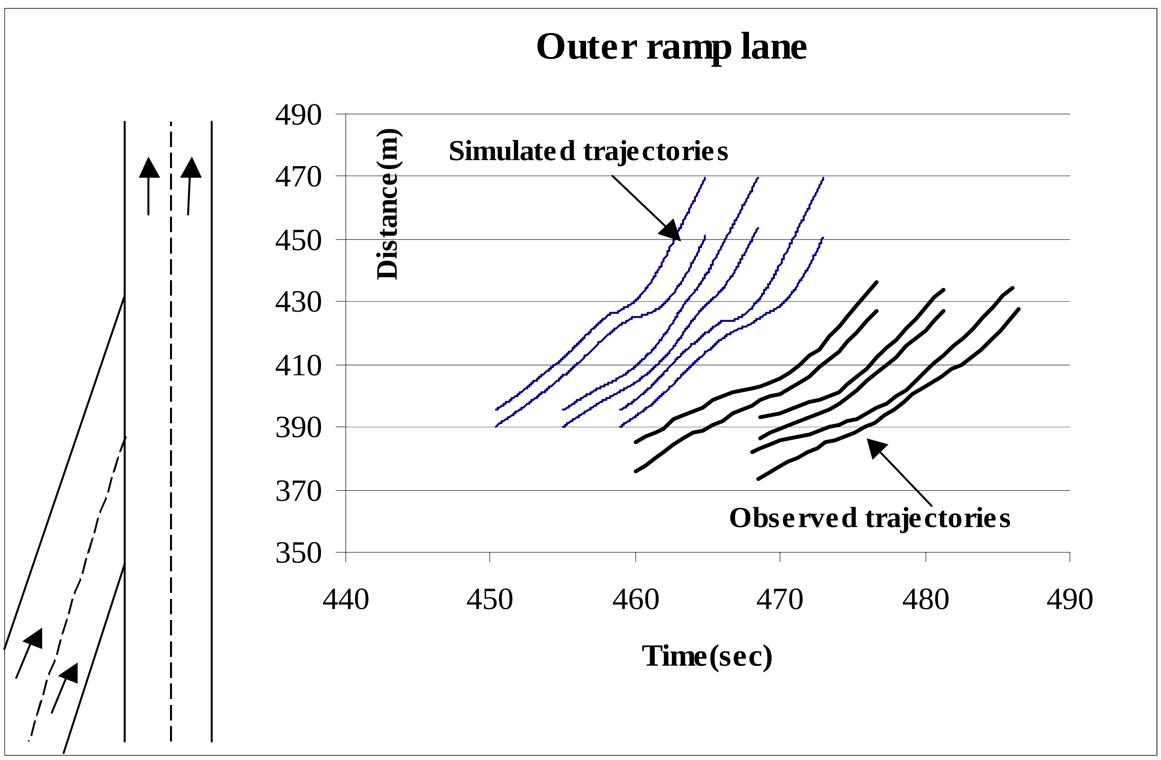

Figure 10. Simulated versus observed time-trajectories at Hamazaki-bashi merging section (Each pair of lines include ramp vehicle and its freeway lead vehicle).

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