A STUDY ON FREEWAY RAMP MERGING PHENOMENA IN CONGESTED TRAFFIC SITUATION BY TRAFFIC SIMULATION COMBINED WITH DRIVING SIMULATOR

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ABSTRACT

This research studies freeway ramp merging phenomena under congested traffic situation via a Driving Simulator (DS). The main objectives of this study were to initially develop a traffic simulation, which evaluates the capacity of merging section relevant to the geometric design and the flow condition. Furthermore, to form a pilot system of the DS combined with the simulation, from which the driving behavior of freeway ramp merging vehicles can be observed. Based on extensive macroscopic and microscopic study, a behavioral model has been established. In addition and based on the behavioral model the Freeway Merging Capacity Simulation Program (FMCSP) is instituted for simulating the actual traffic conditions. Furthermore, a DS is developed and a pilot study has been performed, to detect the potential deficiencies of combined system of FMCSP and DS. Finally, the main experiment was performed to collect the required data for further study. Driving behavior data of 12 persons was collected while they were driving in the driving simulator and merging at the Ichinohashi merging section. In addition, two participants of DS experiments were asked to drive an instrumented car and perform the merge maneuver in the real driving environment. Driving behavior data of DS, instrumented car, and observed drivers were used to examine differences between simulator's driver behavior and that in the virtual world. Results indicated that not only the FMCSP is capable of simulating actual traffic condition of congested freeway ramp merging process but also DS is a capable and promising substitution tool to study complicated freeway ramp merging phenomena.

INTRODUCTION

Research and the development of driving simulators are tools commonly employed by carmakers, suppliers and transport research laboratories. Driving simulators have already been widely utilized for training purposes, and further becoming an essential component in new vehicle research and development as well as an increasingly favorable study tool for traffic and transportation researchers. The use of driving simulator in traffic and transportation studies is quite a novel concept, yet it has rapidly increased since the 1990s. However, most studies on driving simulator are mainly concerned with the safety aspect of traffic and transportation engineering. There are almost no relevant research could be found which addresses the

application of driving simulator in the freeway ramp merging maneuver study. Therefore, it is for the first time that an attempt is undertaken to utilize driving simulator to study freeway ramp merging phenomena.
A variety of strategies can be applied to improve the traffic flow rate and safety at the merging sections. It is possible to use ITS facilities such as VMS (variable message sign) or navigation systems prior to the merging section to inform the drivers and guide the traffic. Other strategies like lane closure or post cone installation required experimental data, which in most of cases is difficult to achieve because of the possible high costs and risks involved. A substitute for the real examination and evaluation of such strategies can be simulation experiments, which simulate the actual traffic scenarios and allow for the evaluation of effectiveness of the strategies. Thus, one of the main objectives of this study is to establish a link between Freeway Merging Capacity Simulation Program (FMCSP) and a driving simulator (DS) in order to examine the differences between simulator's driver behavior and that in the virtual world at the time of freeway ramp merging maneuver. However, observation of vehicle motions with interaction of surrounding vehicles can be achieved only by combination of FMCSP and DS. For this purpose, developed FMCSP has been modified further to simulate actual traffic condition for DS. The outcome of the DS experiences could be applied directly to FMCSP to enhance its accuracy and reliability (1,2).

A set of detailed activities are defined and followed to achieve the general elements. Figure 1 presents a conceptual flowchart of the activities to be included in this study .

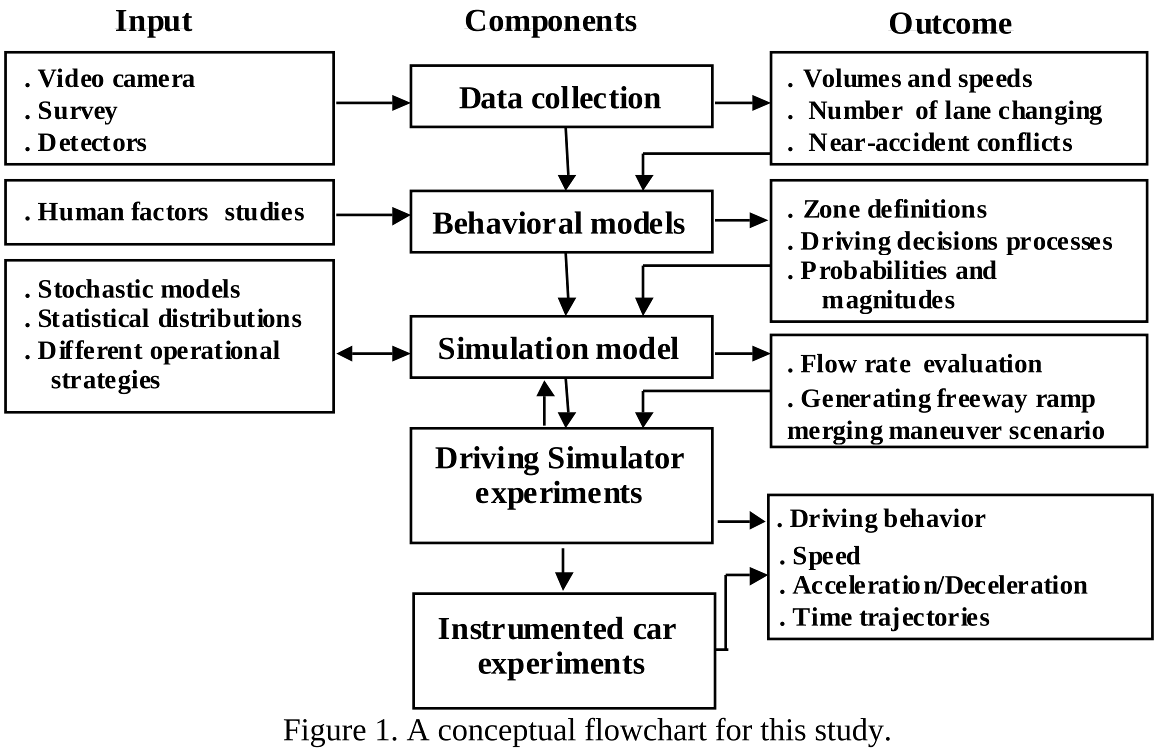

Figure 1. A conceptual flowchart for this study.

MODELING

VEHICLE INTERACTION AND TRAFFIC BEHAVIOUR

Driver's Decision Process

There are different driver tasks and decision-making processes under free-flow compared to congested-flow conditions while approaching freeway merging points. Three zones are established to explain the driver decision-making process in these situations as shown in Figure 2. They include:
Ramp zone one (preliminary zone): A decision about how to arrive at zone two (from lane one or two),
Ramp zone two (merging zone): A decision about between which two vehicles to merge (to be inserted),
Ramp zone three (downstream zone): A decision about at what distance and speed to follow the vehicle in front,
Freeway zone one (preliminary zone): Same as ramp zone one,
Freeway zone two (merging zone): A decision as to which vehicle oncoming from ramp merging should be permitted,
Freeway zone three (downstream zone): Same as ramp zone three.

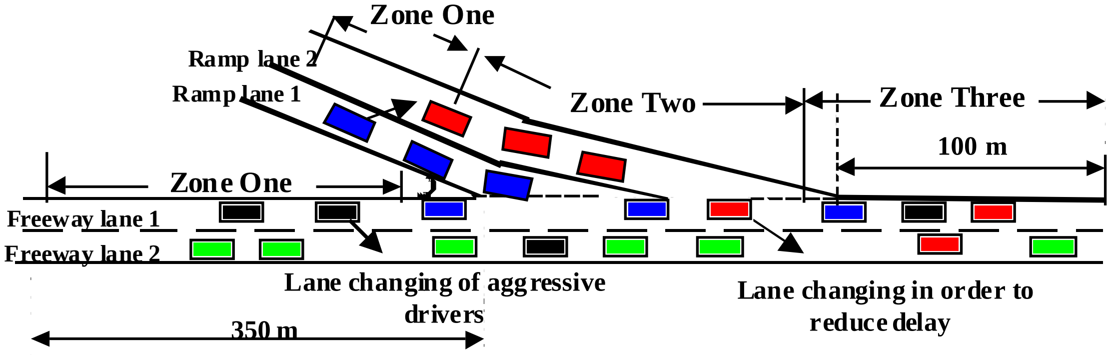

Figure 2. Tokyo Metropolitan Expressway freeway layout.

The first driver decision is highly affected by the surrounding traffic situation such as the traffic volume in the two lanes, traffic flow speed, desirable gap, drivers attitude, vehicle type, drivers familiarity with the area, etc. The second decision about a proper gap searching and accepting has been extensively studied in the free flow merging condition. In the congested flow based on extensive macroscopic study and observations in the Tokyo Metropolitan Expressway (MEX) it was found that drivers mostly merge one by one at the terminus part of the merging section (more than 94%) (3). The third driver decision is related to the known car-following behavior and will be discussed later.

Vehicles interactions and lane changing behavior

The possible traffic interaction between vehicles approaching and engaging the merging area under congested traffic condition based on comprehensive observation is described in Table 1 (3,4). Table 1 includes lane changing in zone one before engaging the merging section, merging at zone two, lane changing within zone two, and car following behavior between vehicles. For example, driver **i** in freeway lane one may interact with driver **j** in freeway lane two by changing lane to the adjusted freeway lane. This lane changing could be achieved either in zone one or two. Research on lane changing behavior has been focused on gap acceptance behavior and its application. In this study, lane-changing behavior in the merging area under congested situation has been investigated at the macroscopic (not individual vehicle) level. Two types of lane changing behavior are observed frequently in the merging sections. In zone one, in an attempt to avoid merging interactions, aggressive drivers force their vehicles onto the freeway/ramp lane two. In zone two, while trying to avoid more delay for a second merging some drivers might force their vehicles into freeway lane two. These lane-changing behaviors affect the flow rate at the merging section, e.g. decrease the flow rate at the freeway in lane two and increase the flow rate at the ramp (2). FMCSP explicitly models both of these lane changing.

		FREEWAY		**RAMP**	
		LANE 1	**LANE 2**	**LANE 1**	**LANE 2**
FREEWAY	**LANE 1**	Car following	Lane changing	Slow down to Provide right of way	Slow down to provide right of way
	LANE 2	None	Car following	None	None
RAMP	**LANE 1**	Merging	None	Car following	Lane changing
	LANE 2	Merging	Almost none	Almost none	Car following

Table 1. The Possible Types of Vehicle Interactions.

METHODOLOGIES FOR MODELING RAMP DRIVER ACCELERATION-DECELERATION BEHAVIOR

Freeway merge maneuvers are complex and may involve a lane change, continuous acceleration, deceleration, and finally merging into a gap. The acceleration and merging process from an entrance ramp to the freeway lanes constitutes an important aspect of freeway traffic operations and ramp junction geometric design. A ramp driver must make a series of decisions and carry out control tasks, all within the driver's capability in order to process the roadway and traffic information and translate that information into speed and position control responses. Ramp vehicle acceleration-deceleration characteristics in acceleration lane are essential components in all microscopic simulation model designs for simulating freeway entrance ramp merging. The major objective of this part of the study was to empirically investigate ramp driver merge 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 merge maneuver under congested traffic situation.

For this purpose sets of data capturing a wide range of information were collected using manual and videotape methods and manually reduced through image processing technique. Comprehensive traffic surveys were conducted at two entrance ramps in the MEX. This freeway merge traffic data provides fundamental information for use in investigating ramp driver freeway merge behavior.

A theoretical framework for modeling freeway merge ramp vehicle acceleration-deceleration behavior was presented and utilized (see Equation 1). This is based on comprehensive microscopic observation (2). This methodology used the stimulus-response concept as a fundamental rule and was formulated as a modified form of conventional car-following models. The first and second terms in Equation 1 represent a conventional model of ramp driver's reactions to the change of speed of corresponding freeway leader and lag vehicles, whereas the third term represents a spring action of spacing in which the follower accelerates being sucked ahead when the spacing is larger than the desired value.

Data collected at two merging points of MEX were used to calibrate the hypothesized ramp vehicle acceleration-deceleration models. Results indicate that a time gap of 0.7 sec. before the ramp drivers respond to stimuli does exist. The nonlinear and linear functional forms have been used for the calibration of Equation 1. In terms of statistical properties, nonlinear form had R-value of 0.7 and linear model of 0.6. In order to simplify the acceleration-deceleration model, which will be extensively used in development of the FMCSP the linear model Equation 2 is selected as the best model (2). Furthermore, the stability of equation parameters obtained in different sites of observation for the linear model was greater than the nonlinear model. In addition, it is shown that low order car following model can reasonably reproduce the vehicles interaction (7).

$$a_R(t+T) = \alpha 0 + \alpha 1 \frac{V_R^m(t+T)}{[X_{Flead}(t) - X_R(t)]^{l1}}[V_{Flead}(t) - V_R(t)]$$

$$+ \alpha 2 \frac{V_R^m(t+T)}{[X_R(t) - X_{Flag}(t)]^{l2}}[V_R(t) - V_{Flag}(t)]$$

$$+ \alpha 3 \frac{1}{[X_{Flead}(t) - X_R(t)]^{l3}}\{S(t) - f[v(t)]\} \qquad (1)$$

Where:

$a_R(t+T)$: Acceleration rate of ramp vehicle at time t+T

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

$X_{Flead}(t)$: Location of ramp vehicle's corresponding freeway lead vehicle at time t

$X_{Flag}(t)$: Location of ramp vehicle's corresponding freeway lag vehicle at time t

$V_R(t)$: Velocity of ramp vehicle at time t

$V_{Flead}(t)$: Velocity of ramp vehicle's corresponding freeway lead vehicle

$V_{Flag}(t)$: Velocity of ramp vehicle's corresponding freeway lag vehicle

$S(t)$: Spacing between the ramp vehicle and corresponding freeway leader vehicle

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

T : Time lag or driver response time

$\alpha 0, \alpha 1, \alpha 2, \alpha 3, m, l1, l2, l3$ are parameters to be estimated.

$$a_R(t+T) = \alpha 0 + \alpha 1[V_{Flead}(t) - V_R(t)] + \alpha 2 \frac{[V_R(t) - V_{Flag}(t)]}{[X_R(t) - X_{Flag}(t)]^b} \quad (2)$$

Where the magnitude of “b” is given

FMCSP: A SIMULATION MODEL

Outline of FMCSP

A periodic scanning method at intervals of 0.05 seconds is used for this simulation model. In FMCSP the study areas are not only the merging sections but also the upstream/downstream sections (5). These sections are treated as three types with different characteristics (see Figure 2).

FMCSP considers the following: (1) Preliminary segments (Ramp and freeway lanes 1 and 2 prior to the merging point): the purpose of these segments is to generate vehicles at the most upstream end, and to form platoons while traveling through the 350m segment. At the beginning of freeway segment, vehicles are dynamically generated based on the travel time on the shoulder and median lane of the freeway. Therefore, since the travel time of vehicles on the freeway shoulder lane is greater than the median lane because of the merging maneuver, fewer vehicles are generated on this lane (most of the familiar drivers try to utilize the freeway median lane). Moreover, the size and acceleration/deceleration performances of each vehicle such as truck and light vehicle are simulated by FMCSP. Each driver has a desired speed, which follows the normal distribution. The parameters of this distribution are provided when vehicles are generated. (2) Merging segment (Ramp and freeway lanes at the merging area): The merging maneuvers of the merging vehicles are implemented in these segments in addition to the lane changing situations of the freeway shoulder lane vehicles onto the freeway median lane. The 10 meters segment between zones two and three is defined as the terminal segment in which non-merging vehicles are forced to merge. (3) Downstream segments (Freeway lanes at zone three): In this 100m-section, free flow traffic conditions after the merging section are simulated. (4) Aggressive driver’s lane changing model: The lane changing behavior of the aggressive drivers in the freeway shoulder lane is implemented by this model before the merging section. The term aggressive drivers indicate those in the freeway shoulder lane who then change lane immediately before the merging section to avoid merging interactions. Based on direct observation and video data collections, this lane changing behaviors reduced the flow rate of the freeway median lane and therefore affected the total output flow rate of the freeway. (5) Avoidance lane changing model: The lane changing of vehicles from the freeway shoulder lane (within the merging section) into the freeway median lane is implemented by this model. Often vehicles change their lane, especially where the two ramp lanes merge, after their first merging to avoid more delay for the second merging situation.

The current version of the traffic simulation model considers the parallel and taper types of acceleration lane, the length of the taper as well as the convergence angel of the merging segment. In addition, the output of FMCSP during the simulation run is saved in text files at the end of simulation for future analysis. By the aid of the graphic interface of FMCSP, the ramp-freeway configuration of the merging section as well as the movement of vehicles along the traffic lanes are displayed.

Calibration process

Model validation is probably the most difficult problem to be overcome in the development of the model. The validation of FMCSP has been performed at microscopic and macroscopic levels using the observation flow, and lane changing maneuver at the Hamazakibashi, and Ichinohashi interchanges of MEX where the traffic demand exceeds the capacity resulting in upstream queues. At the microscopic level, the trajectories from FMSCP were compared with those from the field data (Figure 9); whereas at the macroscopic level, average speed, density, and especially volume computed in FMCSP were compared with the values from real world traffic conditions (Figure 3).

For validation of simulation model, two lane-changing maneuvers, one before the merging nose (Lane changing of aggressive drivers) and second within the merging section (Avoidance lane changing) with four discharged volumes were compared with observation. The simulation discharged volumes of freeway shoulder lane, freeway median lane after the merging section, the discharged volumes of ramp volume and freeway shoulder lane volume before merging section, number of lane changing maneuver before merging nose, and lane changing within the merging section fit well with that observed as shown in Figure 3.

The comparison between simulated and observed trajectory of vehicle are shown in Figure 9. The result shows that the solid line (simulated trajectory) and the dashed line (observed trajectory) are quite close and show sufficient similarity for the purpose of this study. In other words, the slopes of trajectory lines (speed) of simulated vehicles before as well as after merging into freeway lane are consistent with the observed one. In addition, a significant speed reduction immediately prior to the merging maneuver into the freeway lane could be observed in both simulated and observed trajectories.

Furthermore, by the aid of the graphic interface of FMCSP the ramp-freeway configuration of the merging section as well as the movement of vehicles along the traffic lanes are displayed. Therefore, the movement of the vehicles prior to the merge end, the merging maneuver of vehicles at merging section, as well as lane changing maneuver of vehicles in FMCSP are validated using the videotape of the vehicle movement in the real world. In addition, to have a more accurate perspective of FMCSP validation, the effect of heavy vehicle percentage on maximum flow rate of Ichinohashi merging section has been studied via the FMCSP and compared with the data obtained from the detectors. Results indicated that the negative effect of heavy vehicles on maximum flow rate of Ichinohashi merging point based on FMCSP and detector data is identical.

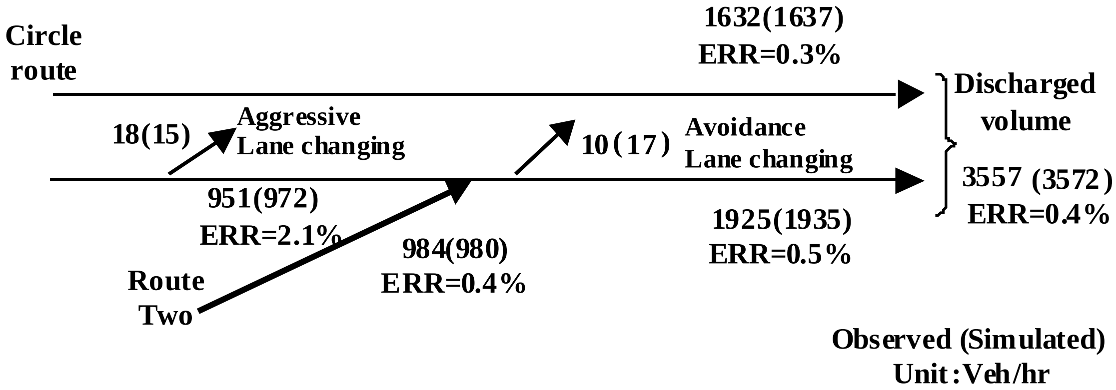

Figure 3. Observed versus simulated traffic volumes (Ichinohashi interchange).

DRIVING SIMULATOR EXPERIMENTS

INTEGRATION APPROACH

To gain a better understanding of previous research deficiencies and search for possible future improvements related literature has been reviewed. Unfortunately it appeared that almost no related study could be found in literature, which addressed the freeway ramp merging phenomena. Software and hardware are the most important components in successful development and performance of the DS experiments. FMCSP has been extensively calibrated, improved, and modified to become capable of simulating the actual traffic scenarios of driving simulator. Additionally, the driving simulator that was originally designed for driving in the straight freeway segments was adjusted to become appropriately suited for simulating a virtual driving at freeway ramp merging scenarios. Due to the sophisticated nature of this problem, performing a pilot study to investigate the feasibility and deficiencies of combined system of FMCSP and DS is desired before major efforts are undertaken. Therefore, a pilot study was conducted to detect the potential deficiencies, and problems associated with combined system of FMCSP and DS. Subsequently, the main experiment was carried out to collect the required data. Finally, to have a clearer perspective of DS driver's behavior, two participants of DS experiments were asked to drive with an instrumented car at Ichinohasi merging section.

OUTLINE OF THE DRIVING SIMULATOR

The configuration of the driving simulator system used in this study is shown in Figure 4. Described below is the flow of data and test procedures implemented.

Computer graphics of virtual space created by a workstation (Onyx Reality Station) are displayed on a 120-inch screen. Response of the subject to the image on the screen is input through the driver's seat. Increase of accelerator or brake use is input in 1 % increments of acceleration or deceleration rates, respectively. The information input through the driver's seat is used to control the creation of following computer graphics. The speedometer at the driver's seat indicates the velocity calculated based on the rate at which computer graphics are created. In the calculation of vehicle velocity, the effects of air resistance, road surface resistance and the gravity acceleration acting on the vehicle according to the vertical alignment are considered.

Running noise of the vehicle is also an output. At present, however, no noise variations according to the speed or roadside condition are reproduced.

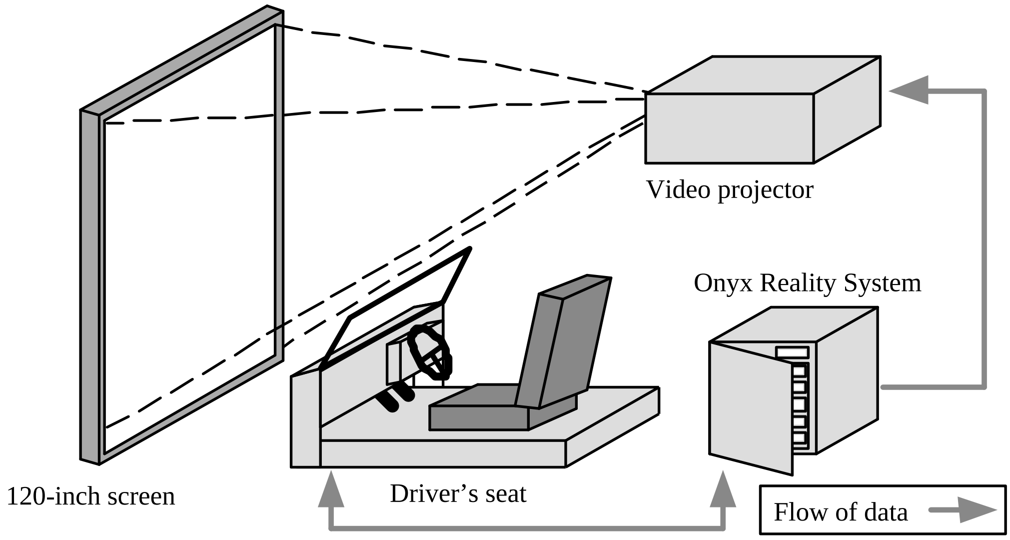

Figure 4. Driving simulator configuration.

DATE COLLECTION AND EXPERIMENTAL OPERATION

One of the major tasks of this part of the research was the collection and reduction of experimental operation data of driving simulator to be used in freeway ramp merging behavior model study. This data includes freeway and ramp flow rate, freeway and ramp vehicle speeds, freeway and ramp vehicle acceleration-deceleration, type of vehicles, freeway and ramp vehicle positions in the network, and angle of ramp vehicle steering wheel including any other data necessary to compare the driving behavior of driving simulator's drivers and the real world's drivers.

In this research, initially it was planned to collect the driving behavior data of about 12 persons while they were driving in the driving simulator. For this purpose each of the 12 drivers, who were male and mostly students ranging from 20-46 years of age were asked to drive in the driving simulator. No information related to driving history such as accident or traffic violations was required from the volunteers. The only requirement was a valid driving license. The participants were selected from students and faculty staffs. The procedure of experiments and data collections for each participant is described as follows:

1) Due to the difference in the nature of DS and real world driving environment, before running of the final experiment, each participant was asked to drive in the driving simulator along an ordinary section of designated highway with high-speed as much as he/she wants. The main objective of this driving exercise was that drivers became familiar with the operation and control nature of the DS driving.

2) Furthermore, in the second step each driver was asked to drive under main scenario and drive from the on-ramp and merge onto the freeway stream when the traffic situation was congested. Each driver was allowed to drive from the section almost 350 meters prior to the merge end.

3) Finally, after sufficient driving exercise in driving simulator each participant was asked to drive under main scenario, namely merging from on-ramp to freeway stream under congested

traffic situation for three times and the required data was collected during the experiments.

At the end of experiments a questionnaire was given to the drivers to investigate the capability and reality of driving simulator from the viewpoint of participants for future studies. Figure 5 illustrates two graphical images of DS (Ichinohashi merging point of MEX).

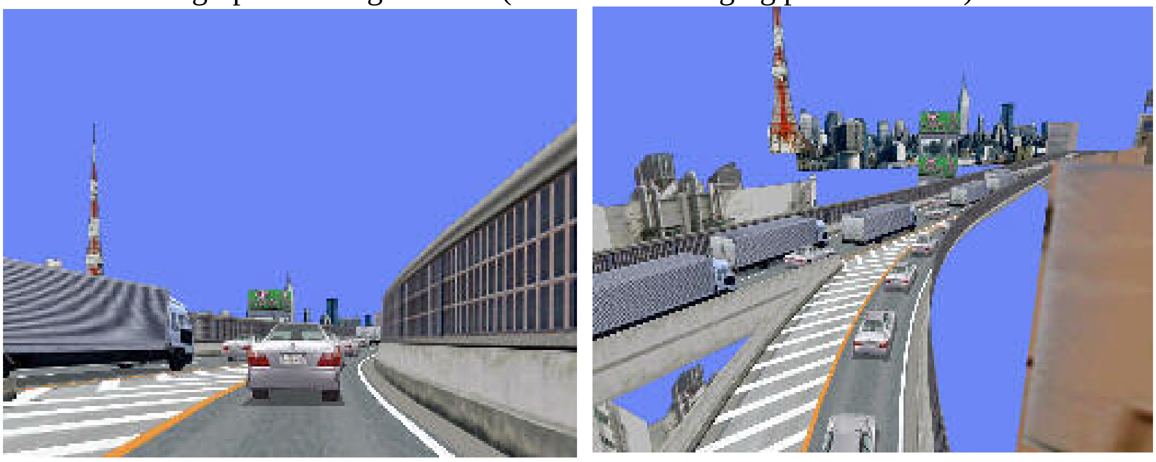

Figure 5. Driving simulator images.

RESULTS AND DISCUSSION

General Behavior of Driving Simulator's driver

A driver in the real world performs several different tasks during the free flow merging process. Michaels and Fazio (6) 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. It is very important to study drivers' performance and behavior when they drive in the driving simulator and compare it with the real world. It is believed that ramp driver merge behavior is significantly influenced by the geometric configuration of the entrance ramp and the surrounding freeway and ramp vehicles. In addition, to compare DS and the real world as well as FMCSP for modeling freeway merges behavior recognition and investigation of the main characteristics of driver merge behavior is fairly important. Therefore, an experimental study was conducted utilizing DS to investigate the general driving behavior of driver merge behavior under congested situations. For this purpose, the Ichinohasi merging point was selected. Based on the experimental study utilizing the DS described above, the following general behavior may be described connecting the driving behavior of DS and real world's driving behavior during merging maneuver on congested freeway.

1- Comparing driving behavior of DS with that of a real world, it appeared that a driver performs several different tasks during the merging process under congested situation as follows: 1) tracking of the ramp curvature, 2) steering from the ramp curvature onto a acceleration lane when the driver keeps the tail of the queue, which is formed from almost terminal section of the taper part of merging section, 3) considering the relative situations for the corresponding freeway lag and leader vehicles in terms of spacing and relative speeds at the terminus of merging section, 4) steering from the acceleration lane onto the freeway lane either by making a forced merge or accommodating corresponding freeway lag vehicle.

2- It appeared that similar to the real condition of merging under congested situation almost all drivers merge at the terminal part of taper. In most cases, the squeeze merging can be observed at the end of merging section.

3- It appeared that Under heavy traffic condition gap searching and acceptance maneuver is not significant.

4- Comparing driving behavior of DS with that of a real world, it appeared that unlike the real condition of merging under congested situation that almost all drivers consider the corresponding freeway lag vehicle at the time of merging maneuver, due to the fact that DS is not equipped with back and side mirrors, therefore, DS driver can not fully consider the corresponding lag vehicle. Hence, DS driver's behavior is more affected by freeway lead vehicle.

General Behavior of Ramp drivers in the acceleration lane

A ramp driver in the acceleration lane must perform many different tasks in a timesharing mode before merging onto the freeway stream as described in the previous section. Interaction with freeway vehicles and variability with drivers renders the observed behavior different from driver to driver. The outcomes of these variations depict the fundamental aspects of entrance ramp operations. The following discussion encompasses the fundamental phenomena of merging operations as obtained from DS data analysis.

The primary data of interest was the speed of vehicles traveling along the acceleration lane and entering onto the freeway. These speeds provide a vehicle speed change profile during transition, indicating where and with what magnitude vehicles were accelerating or decelerating, the speeds at which vehicles were entering the freeway along the merging area.

Speed data was obtained from the output file of DS experiments in 0.05-second interval. Figure 6 shows a sample of time trajectory, speed, and acceleration profiles of two driver participants in this study.

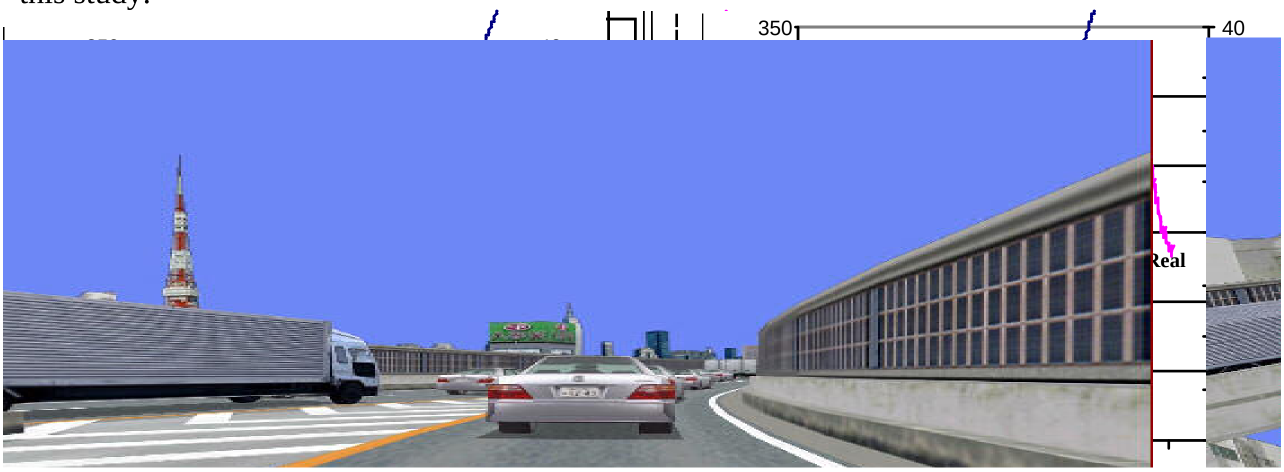

Figure 6. Speed profile of two participants of DS experiments.

In order to have appropriate perspective of drivers' behavior, the average speed profile of 12 drivers from DS experiments was calculated. Figure 7 illustrates calculated ramp vehicle average speed profile based upon distance from ten meters prior to the merge end (physical nose). The curve depicts that on average a ramp driver keeps a constant speed while he is in the queue up to near the merge end. Therefore, the driver continuously accelerates until reaching near the end of zebra marking. At this time, he is the leader of ramp vehicles platoon. The merging driver will decelerate to adjust his speed with his corresponding freeway lag and leader vehicles. Subsequently, the ramp driver will accelerate to join the freeway stream by either making a forced merge or accommodating with the corresponding freeway lag vehicle. The ramp vehicle will decelerate first after entering the freeway stream because the driver starts to adjust his speed considering the speed of his freeway leader. Finally a driver will continuously accelerate and follow the leader ahead.

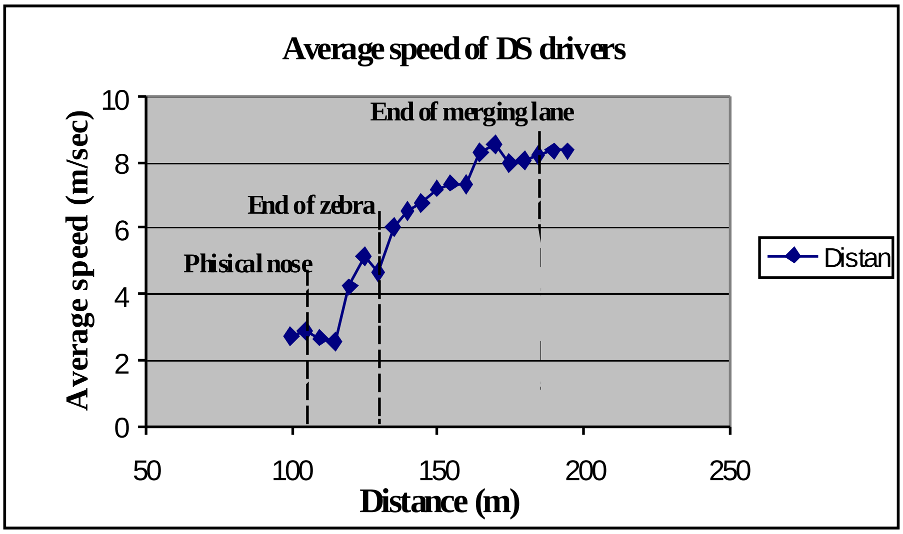

Figure 7. Average speed profile of DS drivers.

Comparison of driving behavior of DS and an instrumented car

To gain a clearer understanding and further to compare the DS driving behaviors and virtual world driving behaviors, an experimental test was performed using the instrumented car. For this purpose two participants of DS test, drivers number 7 and 12 were asked to drive twice with an experimental car at the same merging point (Ichinohashi merging section) that was used for the DS experiments. Figure 8 shows the comparison between time trajectories and speed profiles of DS and instrumented car of drivers 7 and 12, respectively. The over reaction and sudden acceleration-deceleration amplitude of DS is partly due to the insufficient sensitivity of braking and acceleration pedals of DS and partly due to the fact that in virtual world, driver's perception of speed at the time of acceleration-deceleration comes from the gravity acceleration action while the DS driver's perception is only based on surrounding views and traffic. On the other hand, one should consider the merge timing adjustment when comparing the real and DS trajectories. Positions of corresponding lag vehicles of DS and real ramp vehicles are not the same. By considering the all aforementioned factors, a dashed line can be drawn for both cases as shown in Figure 8, so that one can compare the similarities between the driving behavior of DS and instrumented car drivers (The identical slope of speed profiles). In other words, quite similar acceleration/deceleration behavior as described in previous section can be seen for the DS and experimental case.

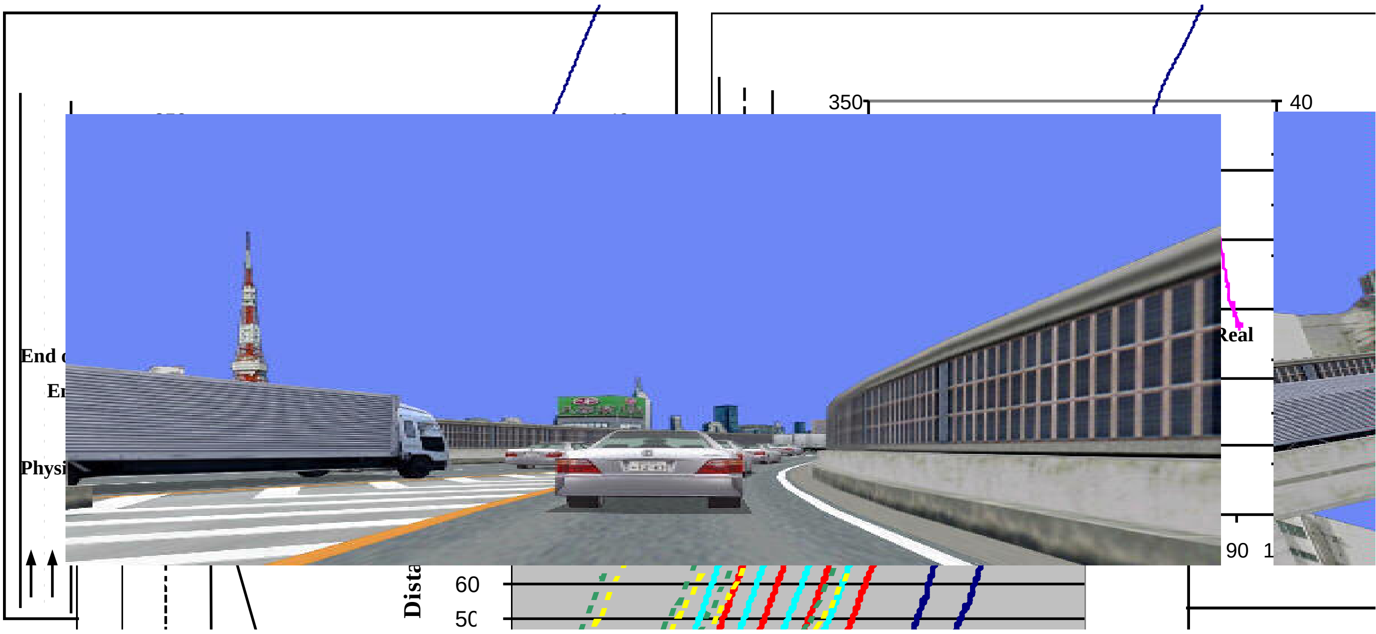

Figure 8. Comparison of DS and instrumented car driving behavior of drivers 7 (left) and 12 (right) at Ichinohashi merging pint.

Finally, Figure 9 shows the observed time trajectories of merging vehicles at Ichinohasi merging point, the time trajectories of FMSCP, and the time trajectories of DS experiments together. The curves depict that the general behaviors of freeway ramp merging drivers are similar, when comparing the slopes of trajectories. On the other hand, the time distance between ramp and its corresponding leader vehicle of DS is greater than the simulated and observed trajectories. As mentioned earlier, it is partially due to the insufficient sensitivity of braking and acceleration pedals, as well as inherent feature of DS, which is not completely similar to the real world. However, more investigation to overcome this deficiency is warranted.

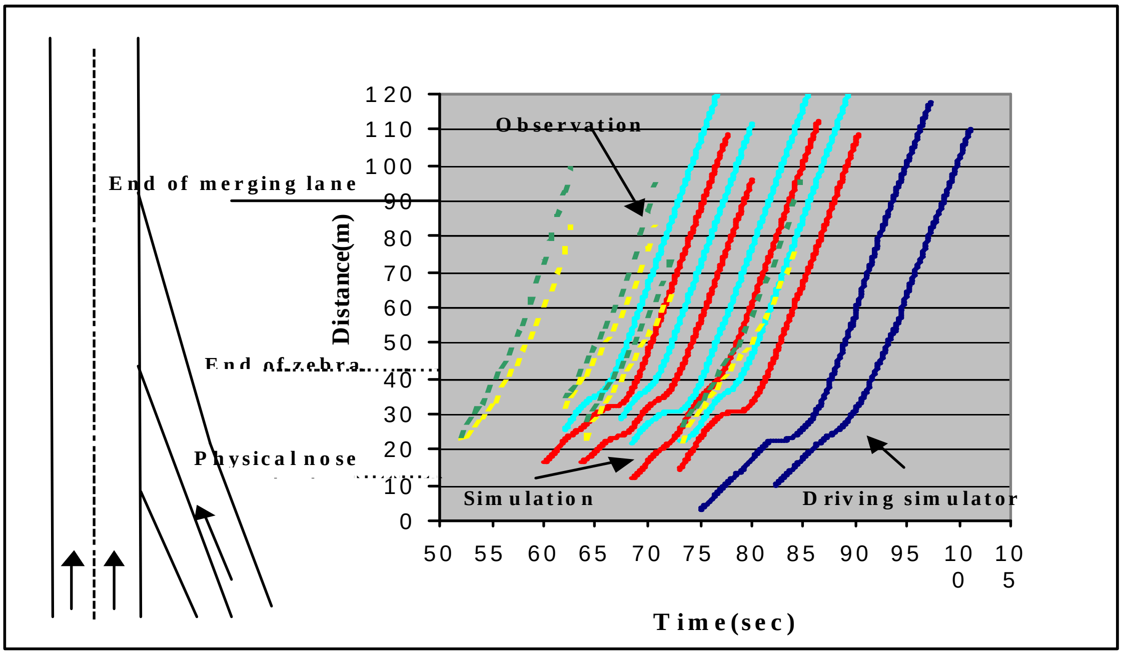

Figure 9. Comparison of observed, simulation, and DS trajectories at Ichinohashi merging point (Each pair of lines include ramp vehicle and its corresponding freeway lead vehicle).

CONCLUSIONS AND RECOMMENDATIONS

This study has presented the methodologies used to establish a link between FMCSP and a driving simulator to examine the differences between simulator's driver behavior and that in the virtual world at the time of freeway ramp merging maneuver under congested traffic situation. For this purpose, the developed FMCSP has been modified further to simulate the actual traffic condition for DS. In addition, to have a clearer perspective of DS driver's behavior, two of the DS experiment participants were asked to drive with an instrumented car at Ichinohasi merging point.

Comparison between observed time trajectories of merging vehicles at Ichinohasi merging point, the time trajectories of FMSCP, and the time trajectories of DS experiments demonstrated that the general behaviors of freeway ramp merging drivers are quite similar. This shows that not only the FMCSP is capable of simulating actual traffic condition of freeway ramp merging phenomena under congested situation but also DS is fairly a capable and promising substitution tool to study complicated freeway ramp merging phenomena.

Studies using driving simulators as data collection tool are potentially feasible as proved in this study. Therefore, DS experiments offer many advantages and deserve further evaluation using larger data sets.

However based on the results of this experiments, contribution of the full vehicle cab to create a more realistic driving atmosphere is suggested. In addition, merging maneuver of ramp drivers who tend to use back and side mirrors, especially in the congested traffic situation, is highly affected by the corresponding freeway lag vehicles. Driving simulator in its current configuration cannot simulate the back and side mirrors therefore, development of the current driving simulator to overcome this deficiency is highly recommended.

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