AN ANALYSIS OF THE EFFECT ON DRIVER'S BEHAVIOR OF INFORMATION SYSTEM AT MERGING SECTION OF EXPRESSWAY

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Abstract: The necessity of the development of driving assistance functions at merging section based on information technologies is recognized as the key methods to achieve safer, more efficient and more comfortable driving conditions. The objective of the study is to understand the relationship among driving operation, vehicle movement and circumstances in experimental information system at merging sections of expressway and to give recommendations towards the development and implementation of the system. Several analyses of driver's behavior with and without information are conducted though the experiment of information system at merging section.

Key Words: AHS, Information, Merging Section, Expressway, Experiment

1. INTRODUCTION

The merging sections of urban expressway in Japan such as the Metropolitan Expressway (MEX) have serious problems for their safety, efficiency and comfortability because of the insufficient geometric design condition, the increase of traffic flow rate and the progress of vehicle performance. The improvement of geometric design is difficult because of space constraint in densely developed urban area. Therefore, the necessity of the development of driving assistance functions at merging section is recognized as the key methods to achieve safer, more efficient and more comfortable driving conditions there.

Japanese government already started the research and development of Advanced and cruise –assist Highway System (AHS) to achieve much safer driving condition at intersections and links. 7 major functions of AHS are proposed to reduce the number of fatal accidents in the first phase of implementation. The AHS functions for merging section is now classified as key objectives in the second phase whose deployment objective is the achievement of safe and efficient driving condition.

The microscopic traffic flow simulation model is required to analyze the effect of such assistant systems on traffic flow at merging section. However we never have simulation model that can express the driver's behavior under such systems. In addition, previous simulation models at merging section (including weaving section and work zone) simplify the processes of merging behavior (e.g. Zarean and Nemeth, 1990, Mousa *et al*, 1992, Nakamura *et al*, 1992, Kita and Harada, 1995, Uchiyama, 1999). This results in the inability of expression of complicated processes of merging behavior in detail. An experiment of driving at merging section was conducted in the previous study to grasp the characteristics of merging behavior by microscopic views, and we understood the relationship among driving operation, vehicle movement and circumstances in detail (Shimizu and Yamada, 2000). The successive study is required especially for such relationship under the assistant systems.

The objective of the study is to understand the relationship among driving operation, vehicle movement and circumstances in experimental information system at merging sections of expressway and to give recommendations towards the development and implementation of such system. The effect of information system at merging sections on driver's behaviors is supposed in Chapter 2. The field experiment of information system at merging sections is introduced in Chapter 3. Several analyses of driver's behavior with and without information are conducted in Chapter 4. The attendant's acceptance of information systems is introduced also in Chapter 4. Several conclusions are given in Chapter 5.

2. CONSIDERATIONS OF DECISION PROCESSES OF DRIVER'S BEHAVIOR UNDER THE INFORMATION SYSTEMS AT MERGING SECTION

We assume that the merging section can be divided into three sections, approach section, advancing give-way section and lane change section (Figure 1) considering the driving circumstance and lane. At typical merging sections of the MEX, drivers in approach section cannot see the status of traffic flow of advancing give-way section and drivers in advancing give-way section also cannot see the status of traffic flow in approach way.

The decision processes of merging behavior are considered as Figure 2 in this study. Driver decides his/her speed to enter into merging section to merge smoother and safer taking into account his/her driving skill, and the recognized geometric condition and status of traffic flow of facing merging section. Driver also takes into account the information about the status of traffic flow on outer lane (or lane connected with merging lane). Driver realizes the status of traffic flow on outer lane and forecasts the movement of related vehicles repeatedly as soon as vehicle enters into lane change section. Driver finally decides to merge into appropriate gap after the mutual decision making with driver in related vehicle on outer lane.

The decision processes of behavior of vehicle running in outer lane are considered as Figure 2 as the same manner as last paragraph. Driver decides whether he/she changes lane to inner lane in advance to avoid any conflict with merging vehicle or not taking into account the recognized frequency of merging vehicle and his/her desired speed. Driver also takes into account the information about the status of traffic flow on merging lane. Driver realizes the status of traffic flow on merging lane and forecasts the movement of merging vehicle

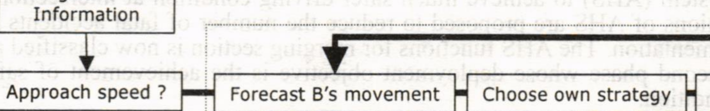

Figure 1. Considered sections at merging area

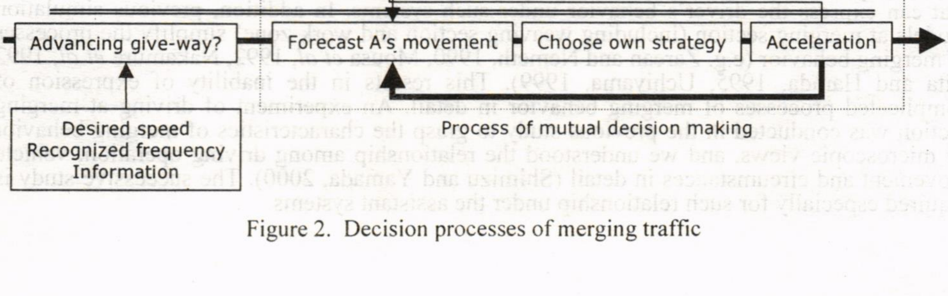

Figure 2. Decision processes of merging traffic

repeatedly as soon as vehicle enters into lane change section. Driver finally decides whether he/she changes lane or makes gap in front or not.

3. EXPERIMENT OF INFORMATION SYSTEMS AT MERGING SECTIONS

3.1 Outline of the Experiment

We conduct the experiment of information system at actual merging sections. The outline is shown in Table 1. Two survey vehicles that can collect data of vehicle movement such as speed, headway and so on, and data of driver's operation such as acceleration, break, handling and so on in every 0.1 second are used (Figure 3). The video images to capture the driver's face and the movement of surrounding vehicles are also obtained. Besides, video image of merging sections is recorded from the roof of roadside building to make time-space data of surrounding vehicles. 10 drivers with different driving experiences such as driving frequency and licensing years (no professional drivers) attend this experiment. Every driver rides on survey vehicle and passes focused merging sections repeatedly for both merging vehicle and vehicle on lane connected to merging lane. The questionnaire survey is conducted just after the experiment.

Three merging sections with different geometry and demand condition are selected as Figure 4. All sites have flat straight advancing give-way section and lane change section. Approach section of Higashi-ikebukuro is downward slope, that of Katsushima is upward slope and that of Yokohama Machida is flat. The length of acceleration lane of Yokohama Machida is about 200m, while that of Higashi-ikebukuro and Katsushima is less than 50m. The flow rates of approach section are averagely 160 veh/h (Higashi-ikebukuro), 60 veh/h (Katsushima) and 700 veh/h (Yokohama Machida) during survey time from 9 a.m. to 5 p.m.. The flow rates of

Table 1. Outline of the experiment

Date	Sep. 20 to Sep. 29, 2000
Sites	1)Higashi-ikebukuro, Line 5 of Metropolitan Expressway
	2)Katsushima, Line 1 of Metropolitan Expressway
	3)Yokomhama Machida, Tomei Expressway
Used devices	Survey vehicles, Cellar phones, DV cameras
Contents	1)Merging behavior with and without information
	2)Give-way behavior with and without information
Attendants	10 (male, aged from 21 to 33)
Obtained data	1)Vehicle movement data (speed, headway,...)
	2)Driver's operation data (acceleration, break, handle,...)
	3)Heart beat data (only for merging vehicle)
	4)In-vehicle Video image (driver's face, surrounding vehicles)
	5)Video image of merging section
	6)Evaluation of information system

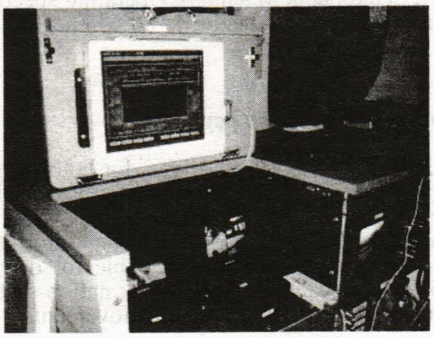
Figure 3. In-vehicle data collection system

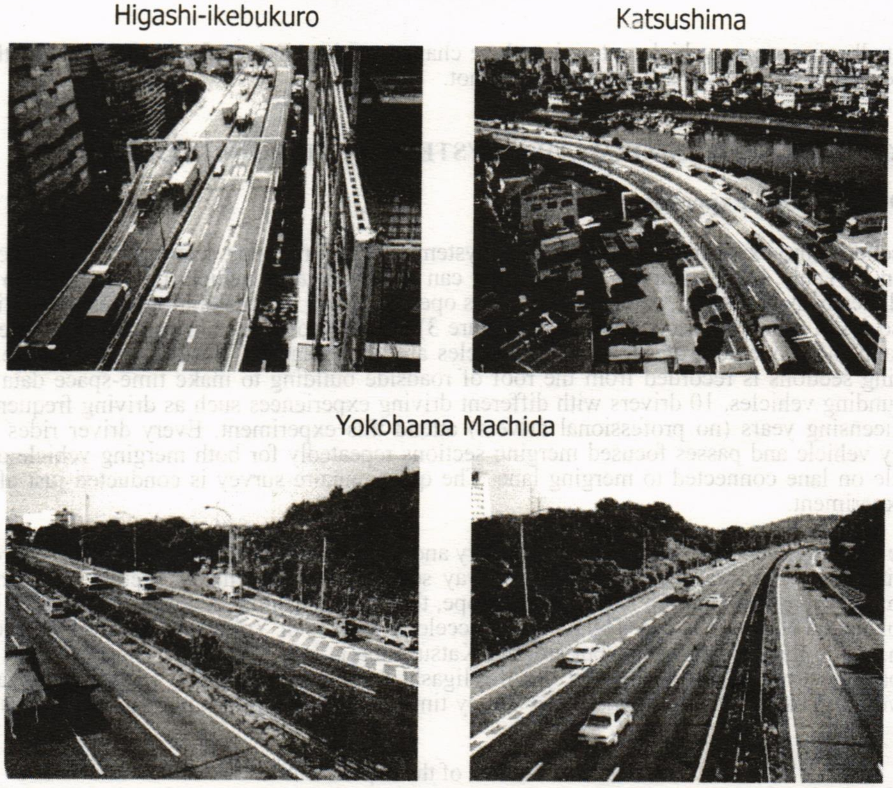

Figure 4. Geometric conditions of survey sites

Table 2. Service contents of experimental information

Sort	Contents
Existence	"No encounter"
	"Encounter"
Position	"No encounter"
	"Coming near"
	"XXX(m) behind (ahead)"
Recommendation	"Decrease speed" (only for merging)
	"Keep speed"
	"Lane change" (only for give-way)

advancing give-way section are averagely 1800 veh/h (Higashi-ikebukuro), 2000 veh/h (Katsushima) and 2200 veh/h (Yokohama Machida). Operating speeds of advancing give-way section are averagely 70km/h (Higashi-ikebukuro), 80 km/h (Katsushima) and 100 km/h (Yokohama Machida).

3.2 Outline of Information System in the Experiment

We consider three types of information given to drivers for both merging vehicle and vehicle on lane connected to merging lane. The service contents examined in this experiment are shown in Table 2. “Existence” information is considered to be easiest service both for supplier and driver using simple vehicle detection devices. “Position” information is considered to be more difficult to understand and judge but more valuable for drivers. “Recommendation” information is considered to be most valuable one if information system is highly reliable for drivers, however system requires the forecast of vehicle movement.

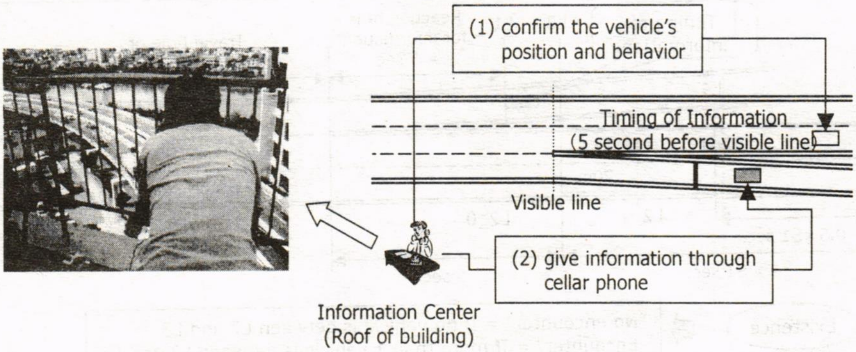

Figure 5. Outline of manual information system

We use hands-free cellar phones for primitive information system at focused merging section like Figure 5. The operator at control center "detects" the status of related vehicles manually and "gives" some information to driver though cellar phone using the algorithm in Figure 6. The operator gives information 5 seconds before vehicle will arrive at the beginning of lane change section taking into account required reaction time to the information. Driver knows what kind of information he/she can get previously.

4. ANALYSES OF THE EFFECT OF INFORMATION AT MERGING SECTIONS

4.1 The Effect on Running Speed in Approach Section

Table 3 shows the differences of average running speed and its standard deviation in the end of approach section at Higashi-ikebukuro. We have hypothesis that the usage of information is different by driver's skill and driver's reliability toward information. Average driving speed is regarded as one of the indicator of driver's skill. Table 3(a) shows that driver with higher running speed in approach section tends to drive at higher speed when he/she knows that information is given, whereas driver with lower running speed tends to drives at the same speed as "without information" case. In addition, the standard deviation in the case of "with information" for driver with higher speed becomes smaller than in the case of "without information". This indicates that driver who has better driving skill will try to merge in better condition with information. Table 3(b) shows that driver who feels information system reliable tends to drive at higher speed. This indicates that reliable information system will assist drivers to merge in better condition.

The running speed is affected by repeated driving because driver continues to drive though the merging section for over 10 times in the experiment. Table 4 shows the difference of average speed and standard deviation in the end of approach section between first half and second half of experiment hours. We can understand that information affects lesser when driver gets used to this system.

4.2 The Effect on Merging Behavior

We analyze real effect of information on acceleration and break operations firstly. Figure 7 shows the comparison of time series driving operation and vehicle behavior with and without information in the case of independent merging (means no vehicle runs on outer lane near merging section) by same driver at Higashi-ikebukuro. We call such figure as "Driver's Operation and Vehicle Movement Diagram". Time passed 0(s) expresses the time when merging vehicle can see the status of outer lane firstly. Information "No encounter" is given at time –0.9(s) when driver cannot see the outer lane. We can understand that driver can stop braking quicker and start accelerating quicker to merge into outer lane when information is given, and that driver can accelerate smoother with the information. This result indicates that information system will possibly helps drivers drive smoother at merging section.

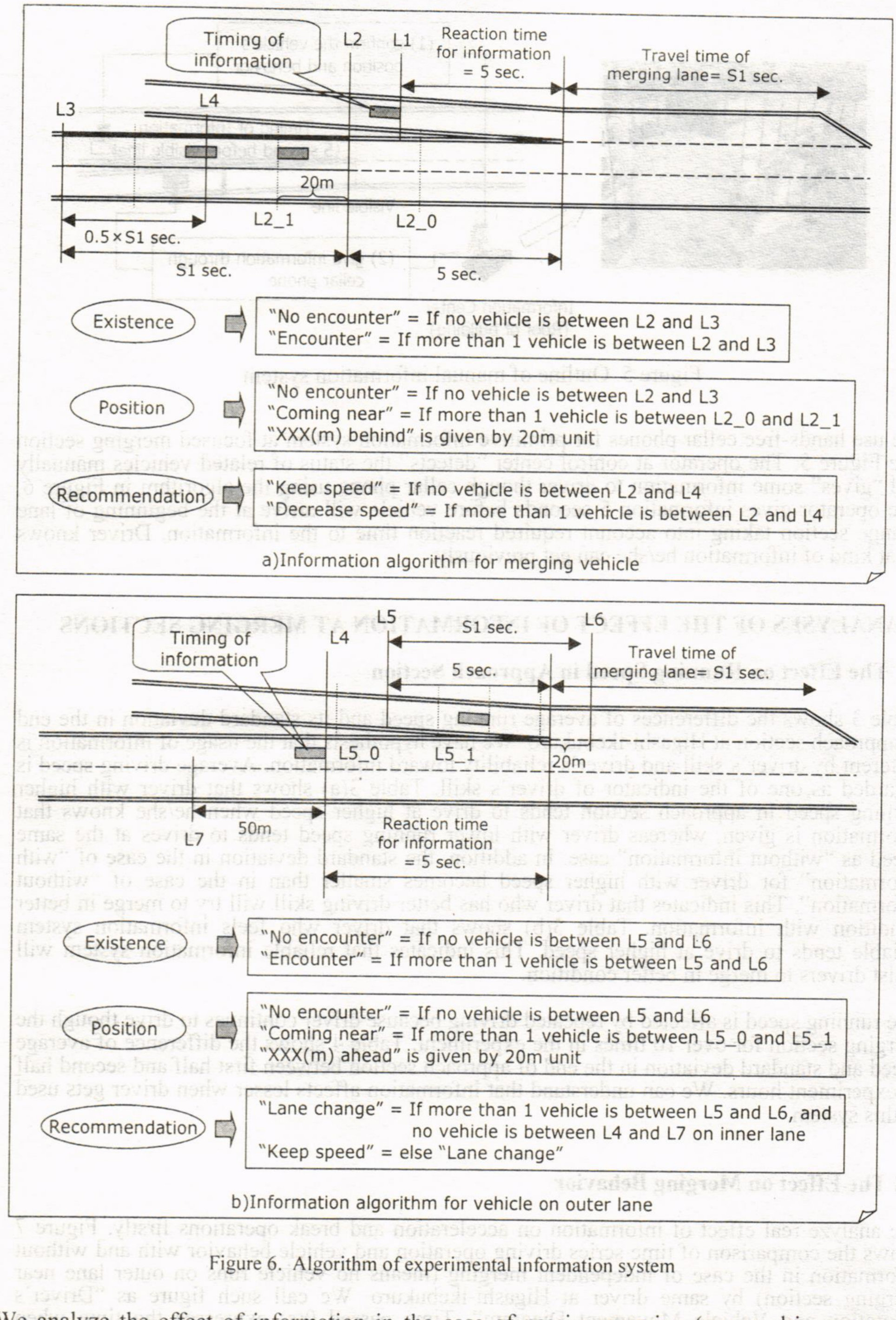

Figure 6. Algorithm of experimental information system

We analyze the effect of information in the case of passing merging (means driver passes several gaps to merge on merging lane) next. Figure 8 shows the comparison of time series driving operation, vehicle behavior and heart beat with and without information by same driver at Higashi-ikebukuro. We use moving average of RR-interval value (time from last heart beat to present heart beat) for heart beat data. It is hypothesized that driver feels some stress when RR-interval is small in this study. It is remarkable that driver starts braking after "time passed 0" when information is given and he can choose gap to merge quicker unless he

Table 3. The effect of information on running speed in approach section

(a)Difference of driver's skill

	Higier speed		Lower speed	
	Without	With	Without	With
Average(km/h)	54.9	58.0	44.9	44.2
Standard Deviation(km/h)	4.73	2.77	2.49	3.50

(b)Difference of reliance for information system

	Higier Reliance		Lower Reliance	
	Without	With	Without	With
Average(km/h)	52.1	54.4	50.3	51.3
Standard Deviation(km/h)	6.70	7.09	4.14	4.11

Table 4. The effect of repeated practice

	First Half		Second Half	
	Without	With	Without	With
Average(km/h)	50.6	53.6	51.7	52.3
Standard Deviation(km/h)	5.85	5.26	5.55	6.56

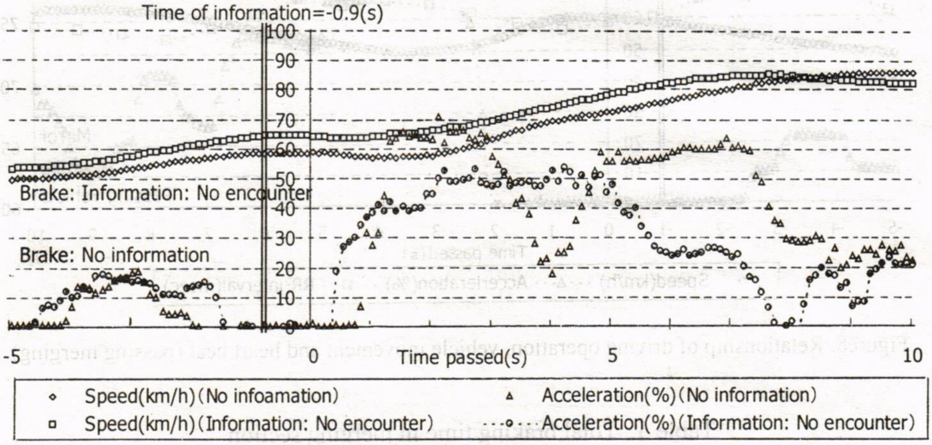

Figure 7. Effect on acceleration and break of information (independent merging)

does not reduce vehicle's speed much. This also indicates that information system will possibly help drivers smoother driving at merging section. It is also remarkable that RR-interval in the case of "without information" is much smaller than that of "with information" when passing merging lane. This indicates that information system possibly mitigates the stress for merging behavior.

We check the effect of information on driving operation together with data from all attendants. Table 5 and 6 shows the effect of information on the mitigation of driving operation for independent merging and passing merging at Higashi-ikebukuro. It is remarkable that information can reduce total braking time significantly in the case of independent merging. Table 7 and 8 shows the effect of information on reaction behavior. We can understand that information can assist driver to react quicker. These results indicate that information system possibly helps driver behave quicker.

4.3 Attendant's Acceptance for Information System

We conduct questionnaire survey that asks whether the information system at merging section

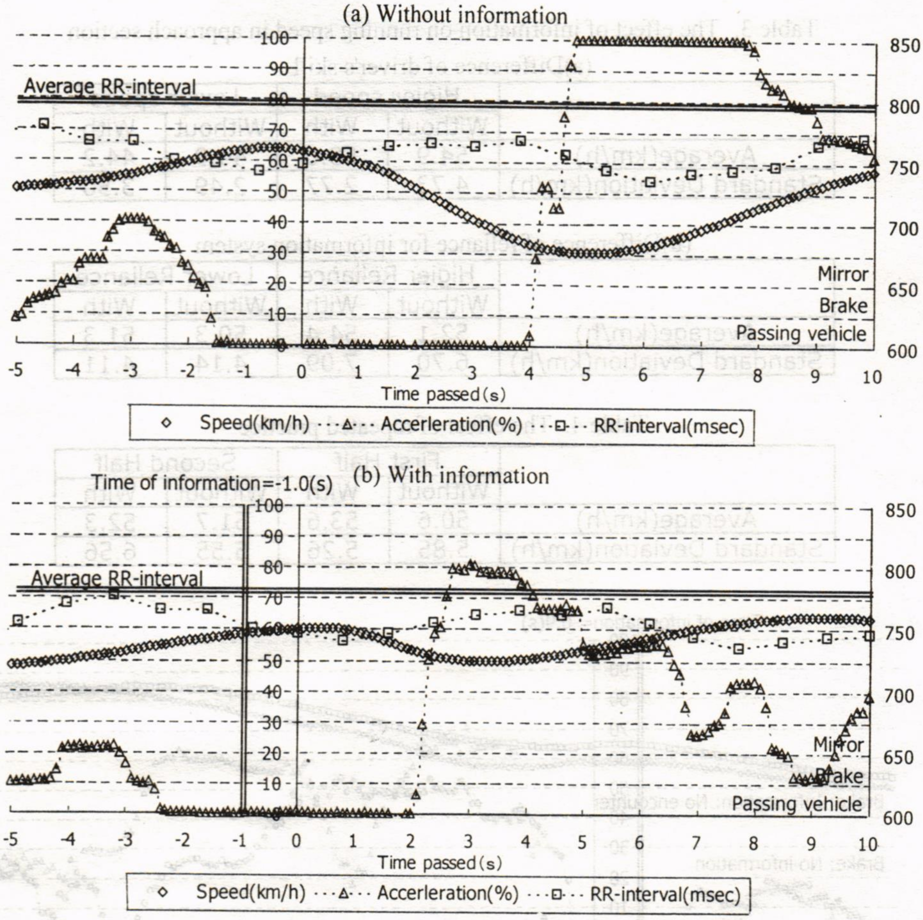

Figure8. Relationship of driving operation, vehicle movement and heart beat (passing merging)

Table 5. Total braking time in merging section

	Independent		Passing	
	Without	With	Without	With
Average (sec)	2.71	1.83	4.61	4.11
Standard Deviation (sec)	0.863	1.11	2.23	2.03

Table 6. Total time to watch mirror in merging section

	Independent		Passing	
	Without	With	Without	With
Average (sec)	2.40	2.08	4.23	3.41
Standard Deviation (sec)	0.551	0.681	1.81	1.70

Table 7. Time to stop braking from time 0

	Independent		Passing	
	Without	With	Without	With
Average (sec)	1.34	0.594	4.44	4.94
Standard Deviation (sec)	0.888	0.725	2.59	7.86

Table 8. Time to start accelerating from time 0

	Independent		Passing	
	Without	With	Without	With
Average (sec)	1.63	0.948	4.00	3.56
Standard Deviation (sec)	0.969	0.749	1.32	1.66

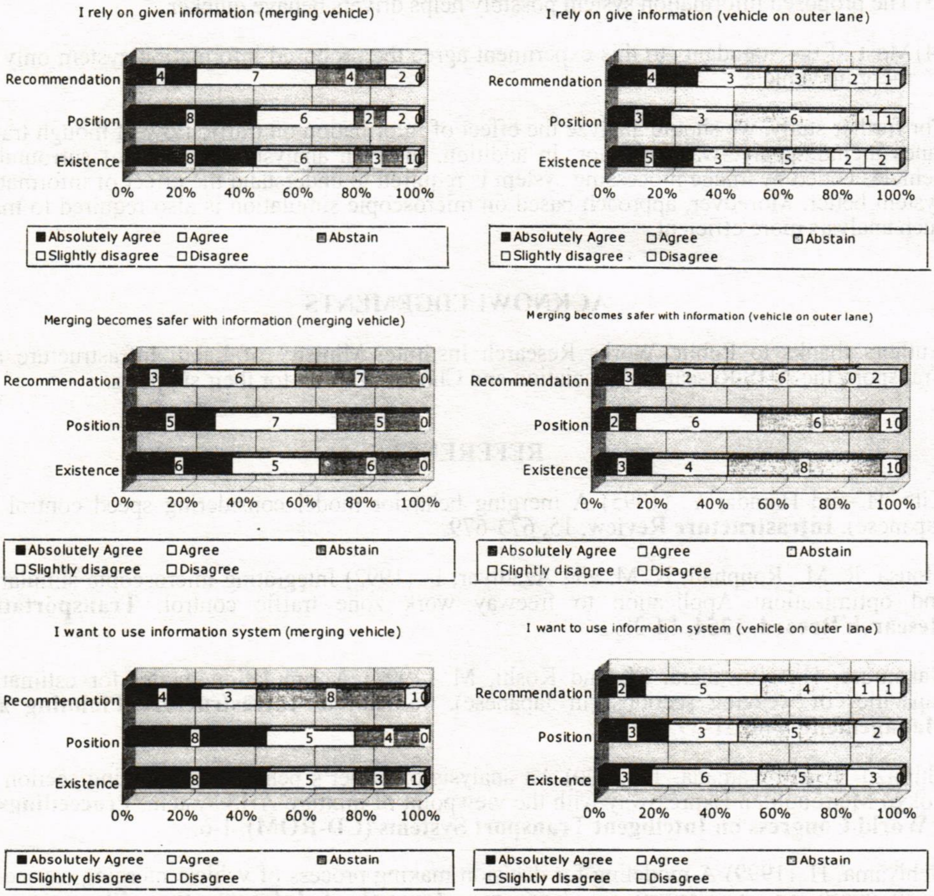

Figure 9. Attendant's acceptance of experimental information system

is useful and reliable after the experiment. Figure 9 shows the acceptance of the information system examined in the experiment. Information system for merging vehicle is more acceptable for driver than that for vehicle on outer lane. This reason is considered that vehicle on outer lane has priority to pass though merging section basically and there is little initiative to react to given information. We also understand that "Recommendation" information is not accepted because driver never wants to entrust his/her decision to the system.

5. CONCLUSIONS

This study focuses on the effect of information system at merging section of urban expressway in order to achieve safer, more efficient and more comfortable driving condition. We propose the primitive algorithm of information system at merging section. A field experiment of proposed information system is conducted at several merging sections by manual operation using cellar phone.

Through the experiment, we obtain several considerations as follows:

(1) The driver with better driving skill will use information given effectively, and will merge into a gap in better condition.

(2) The proposed information system possibly helps drivers drive smoother and reduces the stress for merging behavior.

(3) The proposed information system possibly helps drivers behave quicker.

(4) Most of the attendants to this experiment agree the proposed information system only for merging vehicle.

For further study, we should analyze the effect of information on traffic flow of though traffic lanes including give-way behavior. In addition, in-depth analysis with data of surrounding vehicles coded by image processing system is required to understand the effect of information system better. Moreover, approach based on microscopic simulation is also required to make such analysis more efficient.

ACKNOWLEDGEMENTS

Authors thanks to Public Works Research Institute, Ministry of Land, Infrastructure and Transport, the AHS Research Association and Chodai Co. Ltd. for their supports.

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