Evaluation of Driving Behavior using Virtual Reality Experiment at Expressway Sag and Merging/ Diverging Sections

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ABSTRACT

This research studies driving behavior at sag and merging/ diverging sections on expressways to evaluate several operational schemes to be provided. In Japan, expressway congestion has been frequently observed at sags as well as merging sections. To alleviate the congestion, new operational schemes have been provided such as message signs at a sag to avoid deceleration, dynamic road markings at a merging/ diverging sections. In order to put these new operational schemes to practical use on actual roads efficiently, experiments that identified influences of the schemes on driving behavior were conducted by using a virtual reality experiment system.

1. INTRODUCTION

In our country, congestion in expressway has been frequently observed at sags as well as merging sections. To alleviate the congestion, new operational schemes have been provided such as message signs at a sag to avoid deceleration, dynamic road markings at a merging/ diverging sections, and so on to forth. To evaluate the impacts of the schemes, driving behavior at the sections has to be first examined under such new operational schemes. A virtual reality experiment system, which is a driving simulator combined with a microscopic traffic simulator, is used to analyze driving behavior of testees in virtual but fully controlled environment.

2. OPERATIONAL SCHEMES TO BE EXAMINED

The operational schemes to be examined are briefly explained below:

(a) Dynamic lane Addition

<u>(a-1) Dynamic Channelization at Merging/ Diverging Sections</u>

Merging/ Diverging sections have been frequent bottlenecks especially on urban expressways. Although traffic demand such as merging/ diverging ratios may change over time during a day, the conventional geometric design cannot respond to the change with flexibility.

Fig.1 shows an example of the dynamic channelization at a merging section and similar operation could also be applied to a diverging section.

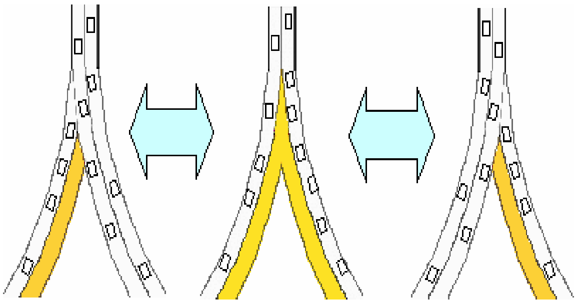


Fig.1 Dynamic Channelization at a Merging Section

(a-2) Dynamic lane Addition during Congestion

Dynamic lane addition is certainly quite effective during traffic congestion due to a sag, road works, and accidents. We propose the system as shown in Fig.2, in which one lane is added by utilizing the shoulder.

gestion

(b) Message Sign at a Sag

The uneven lane usage at high level traffic demand has been identified as a cause of the sag congestion. On a 4-lane highway, for example, when traffic demand increases to about 3000 [vehicle/hour], about 60% of the demand tends to use the passing lane and the break down always first occurs there. The immediate cause of the break down has been identified as unintentional deceleration due to slight grade change at a sag which is hardly recognized by a driver.

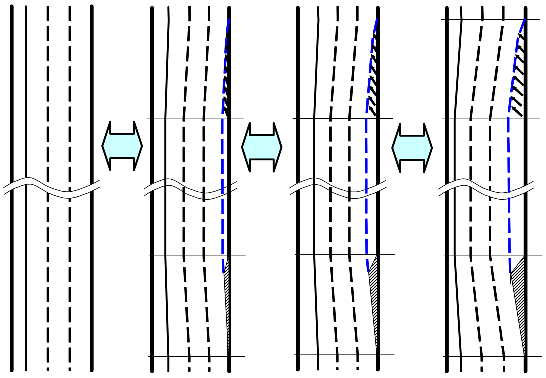


Fig.2 Dynamic Lane Addition

To avoid such unintentional deceleration, the message sign to encourage a driver to maintain the current driving speed has been proposed; however, it has never been systematically evaluated.

3. VIRTUAL REALITY EXPERIMENT SYSTEM

The virtual reality experiment system, which is a driving simulator combined with a microscopic traffic simulator, has been developed in Sustainable ITS Project at CCR, University of Tokyo. Fig.3 shows the current system and the details are explained in references [1] and [2]. The system is specially characterized by the realistic interaction among a driven vehicle by a testee, surrounding vehicles, and road infrastructure such as road signs and road markings. The system makes it possible to observe driving behavior in several scenarios under fully controlled environment.

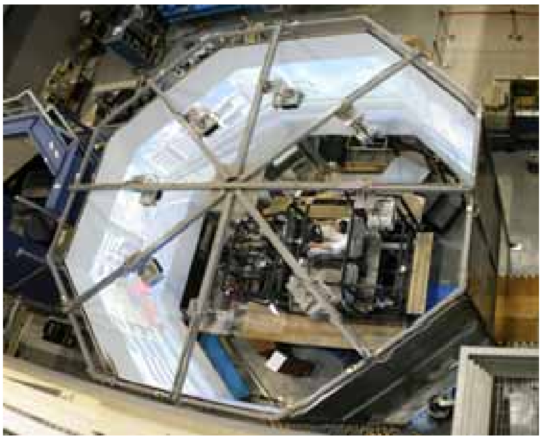


Fig.3 Virtual Reality Experiment System

The virtual reality experiment system that controls these operational schemes is introduced as follows

(a) Dynamic Lane Addition at a Simple Section

Figures 4 and 5 shows the display image of the dynamic lane addition. In Fig.4, the zebra marking is automatically widened or shrunk so as to eliminate or add a shoulder lane. Responses to drivers running on the section are examined.

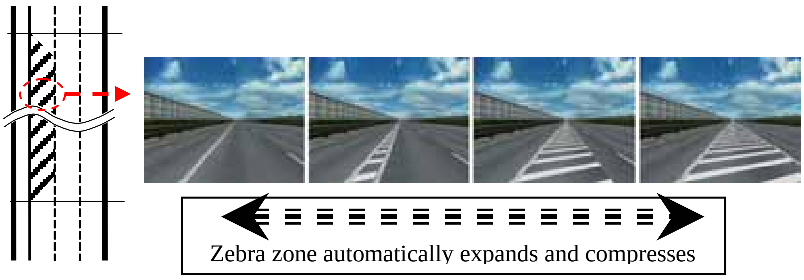


Fig. 4 Display Image of Dynamic Lane Addition

In Fig.5, the road marking automatically shifts its lateral position to increase/decrease the number of lanes.

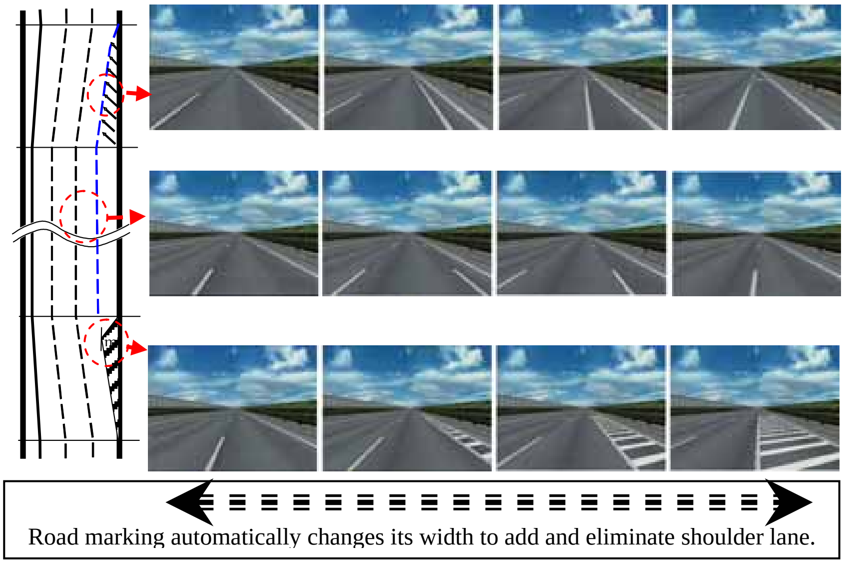


Fig.5 Display Image of Dynamic Lane

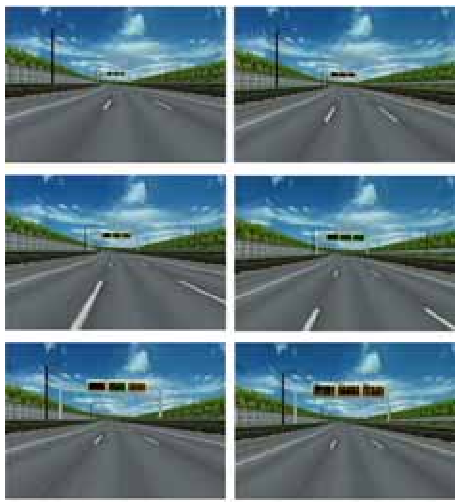


Fig.6 Message Board at Yamato Sag (Sizes of the message boards are 1.5 (left) and 2 (right) times enlarged on the display.)

(b) Message Sign at Yamato Sag on the Tomei Expressway

The testee experiment on message sign and dynamic lane addition is organized at Yamato sag on the Tomei expressway. The highway geometry, traffic demand, and display image data are prepared to implement the experiment. Fig.6 shows the display for the experiment on the message sign. On each lane, several messages are displayed to encourage drivers to maintain their speed at the sag section.

4. EXPERIMENT

A driver repeatedly controls speed and lateral position of the vehicle coping with continuous psychological stress in driving environment [3]. Among various driving stresses, change of road markings may be one of the most influential factors. Normally, a driver would recognize the change in road markings in his/her front view and feels stress from the gradual view transition as the vehicle moves forward. Similarly, dynamic road markings (DRM) might bring even more stress and affect driving manipulation, since DRM itself changes the form. We conduct experiment to analyze impacts of DRM on the driving behavior through the preliminary virtual experiment.

Additionally we perform a supplemental experiment in order to define differences between normal and urgent steering wheel operation. This experiment is supposed to indicate urgent steering wheel operation.

(1) Outline of the Experiment

We examine impacts on driving behavior in the following three scenarios of DRM: (i) road markings instantaneously change from previous to current configurations, which seems most stressful to a driver without any advance notification in the front view, (ii) road markings are gradually shifting laterally from previous to current configuration, and (iii) road markings are gradually disappearing and appearing so that a driver can recognize the configuration change.

The followings are the summary of DRM of zebra marking. The test section is a 3-km straight motorway section with three lanes, in which the three types of DRM (i), (ii), and (iii) above are installed. A testee drives the driving simulator at the speed of about 100 [km/h] while experiencing three DRM patterns sequentially as shown in Fig.7. During the test driving, the vehicle position, travel speed, angle of the steering wheel are recorded and the testee is interviewed on the psychological risk after the test driving.

1) When the test vehicle arrives at 500m point [point a] from the beginning of measuring area, the zebra zone starts appearing laterally from the most left hand side of the shoulder lane and it completely covers the shoulder lane (3.5 m width) in 10 seconds. During this transition, the testee is asked to shift gradually from the shoulder to the middle lane (Fig 7 a-b section).

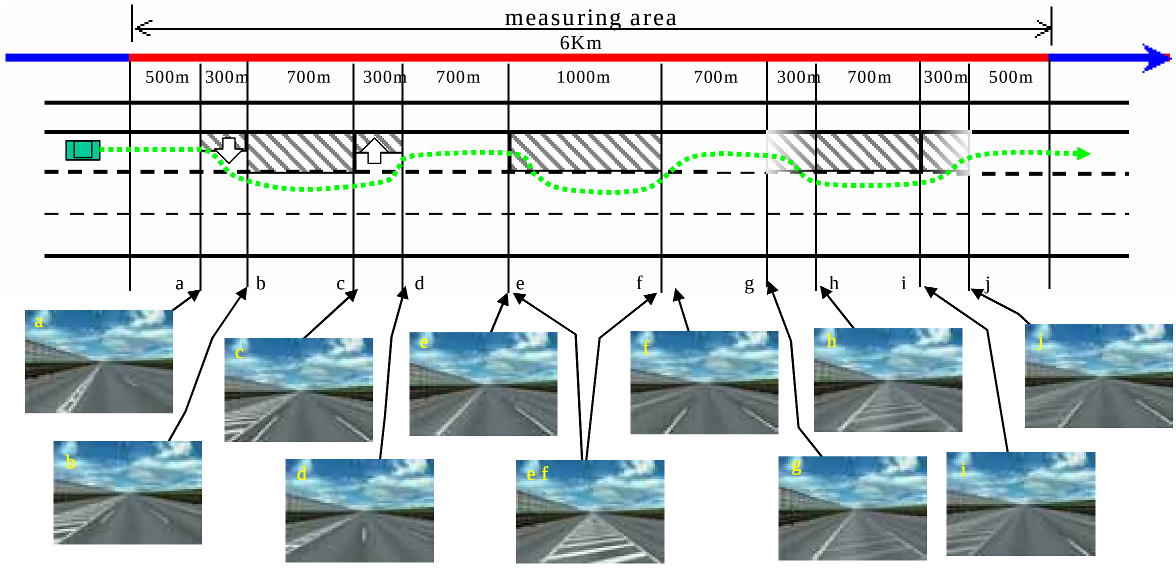
2) When the test vehicle reaches 1.5 km point [point c] of the measuring area, the zebra marking starts shrinking laterally to the left and disappears completely in 10 seconds. During this period, the testee keeps observing the width of zebra zone and returns to shoulder lane when he/she judges that the zebra has shrunk sufficiently and he/she is able to drive on the shoulder lane (c-d section).

3) At 2.5 km point [point e], the running shoulder lane is suddenly changed to zebra zone. Then, the testee quickly makes lane changing to the middle lane as soon as the zebra zone is recognized.

4) At 3.5 km point [point f], the zebra zone on the shoulder lane instantaneously disappears. The testee returns to shoulder lane after confirming the availability of the shoulder lane.

5) At 4.2 km point [point g], the zebra zone starts gradually appearing on the shoulder lane; that is, the color of the zebra marking gradually changes from transparent to white in 5 seconds. When the testee judges that the shoulder lane completely shifts to the zebra zone, he/she makes lane changing to the middle lane (g-h section).

6) Finally at 5.2 km point [point i], the zebra zone starts gradually disappearing by changing the color from white to transparent in 5 seconds. Then, the testee returns to the shoulder lane (i-j section).



ab : zebra gradually shifts from the left
cd : zebra gradually shrinks to the right
e : zebra instantaneously appears
f : zebra instantaneously disappears
gh : zebra gradually appears by changing color
ij : zebra gradually disappears by changing color

Fig 7 Configuration of the Straight Test Section

Next, to evaluate if the driving behavior under DRM is different from one under the normal condition, the supplementary experiment is conducted. In the first run, the testee is asked to drive individually as usual avoiding a parked vehicle located in the middle of the course. In the second run, the testee is asked to follow the leading vehicle which runs almost the same trajectory of the first run. But, after passing a parked vehicle, the leader stops suddenly without any advance notice (see top of Fig.9).

(2) Experimental Results

Fig.8 shows one of the results recorded during the test driving. At the bottom of Fig.8, shapes of the zebra zone are shown as the shaded area. In section a-b, the testee was pushed from the shoulder to the middle lane as the zebra zone was widened. At point e, the testee could not immediately respond to the zebra zone instantaneously appearance. The testee therefore kept running on the zebra for a few seconds and shifts to the middle lane. In section g-h, the similar lane changing was made when the color of the zebra zone got sufficiently close to white.

For the steering manipulation, slightly larger angles of steering wheel were observed at point e and section g-h, in which the zebra transitions were relatively fast. The rotation speed of the steering wheel at the beginning of the lane changing, 20 degree/second, was also a bit larger than 10 degree/second at other sections. However, these differences were smaller than the differences among individual testees. The angle of the steering wheel at a moment when the vehicle returns to the original shoulder lane due to the zebra disappearance was about 3 degrees smaller than one when the zebra zone appeared. Nevertheless, in the questionnaire after the experiment, all testees felt risk to some degree especially when the zebra zone instantaneously appeared as shown in Table 1.

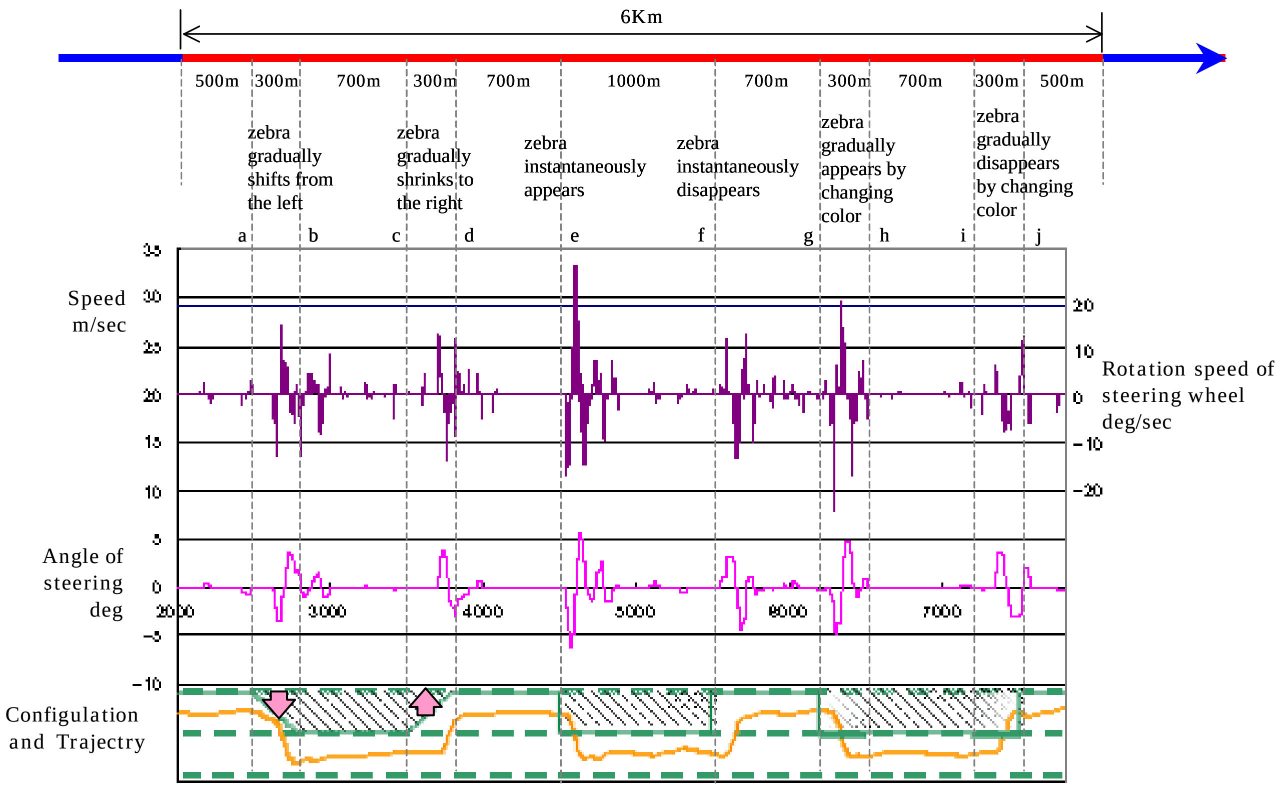


Fig 8 Measurement of Dynamic Zebra Experiment

Table 1 Subjective Evaluation in Questionnaire

section	a-b	c-d	e	f	g-h	i-j
DRM	Zebra shifts from the left	Zebra shrinks to the right	Zebra instantaneously appears	Zebra instantaneously disappears	Zebra gradually appears	Zebra gradually disappears
Feel risk			5			
Feel unusual	2	1		2	3	1

On the other hand, according to the supplementary experiment, the steering wheel manipulation above was different from one under the urgent condition such as avoiding the collision for the sudden stop (see Fig.9). The angle of the steering wheel and the rotation speed in the first run of supplementary experiment were within 5 degrees and 20 degrees/second respectively. However, those in the second run at the sudden stop were more than 15 degrees and over 50 degrees/second.

As comparison between the result of DRM experiment and this result of the supplementary experiment, the manipulation of the steering wheel when the zebra zone appeared and disappeared seem similar to one under the normal condition without any risk. Therefore this indicates that he/she would get some stress from the quick search of available gaps for lane changing since the testee was forced to change lane due to the zebra zone. And the stress seems larger as the zebra transition gets faster.

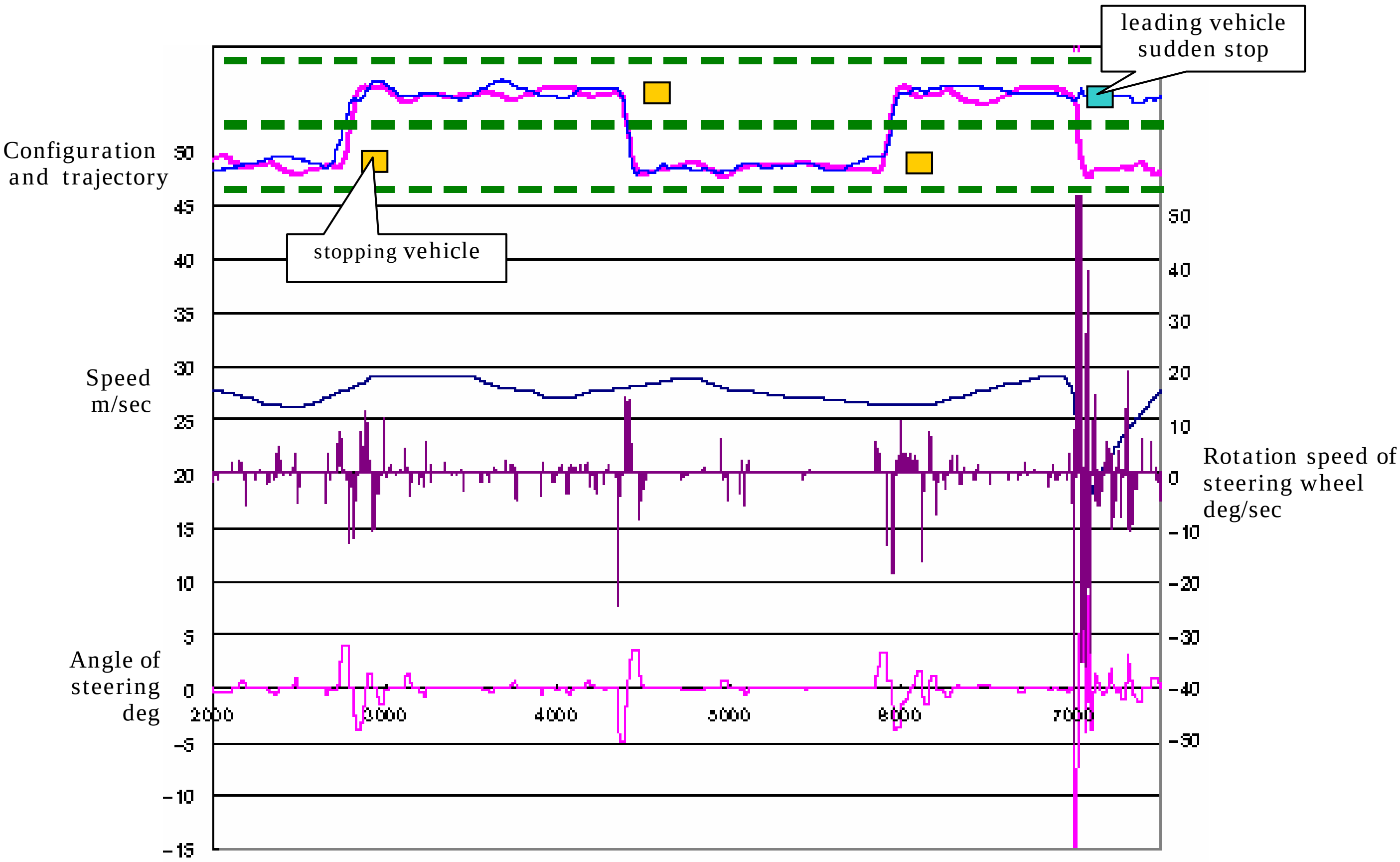


Fig 9 Normal and Abnormal Manipulation of Steering

5. CONCLUSION

In this study, we examine driving behavior only during individual run and hence stresses from surrounding vehicles are not explicitly generated. As the result, the measured steering wheel manipulation due to the dynamic road marking is almost the same level as in the ordinary driving environment. However, since a driver is almost always receiving stress watching adjacent vehicles, we also learn that quick transition of road marking might significantly grows driving stress under the existence of surrounding vehicles. For the future research, we plan to observe driving behaviors of more number of testees in the virtual reality environment with surrounding vehicles.

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