DETERMING THE MOST EFFECTIVE LOCATIONS OF ILLUMINATED DELINEATORS FOR IMPROVING VISIBILITY ON EXPRESSWAYS UNDER SNOWSTORM CONDITIONS USING A DRIVING SIMULATOR

T. Hagiwara
Hokkaido University, Japan
hagiwara@eng.hokudai.ac.jp

A. Kawamura
Kitami Institute of Technology, Japan
kawamuak@mail.kitami-it.ac.jp

K. Tomiyama
Kitami Institute of Technology, Japan
tomiyama@vortex.civil.kitami-it.ac.jp

S. Tozuka
Nexco-Engineering Hokkaido Co. Ltd., Japan
s.tozuka.sa@e-nexco.co.jp

T. Ohiro
Nexco-Engineering Hokkaido Co. Ltd., Japan
t.ohiro.sa@e-nexco.co.jp

ABSTRACT
This study investigated how the location of illuminated delineators affected the driver's subjective mental workload (SMWL) and subjective visibility assessment items for drivers running under snowstorm conditions. The experiment was conducted on a driving simulator. Thirty-six participants, aged 22 to 77 years, participated. The participants were exposed to four delineation conditions as the main independent variables: (1) no illuminated delineators (no delineation), (2) illuminated delineators at the shoulder (left-side delineation), (3) illuminated delineators at the median strip (right-side delineation), and (4) illuminated delineators on the left and right sides (both-sides delineation). The subjects drove in the simulator on a 4-km section of a four-lane expressway under snow-induced low-visibility for each run. SMWL was lower for "both-sides delineation" than for "left-side delineation" or "right-side delineation." Also, the subjective visibility assessment values for "both-sides delineation" were the highest among the four delineation conditions.

KEYWORDS
ILLUMINATED DELINIATOR /LOCATIONS /SNOWSTORM /EXPRESSWAY /VISIBILITY /DRIVING SIMULATOR

1. INTRODUCTION

As driving during snowstorms cannot be avoided, expressways should have adequate cues about the road geometry even under snowstorm conditions. Expressway administrators in Hokkaido, Japan, have installed illuminated delineators at the median strip (right-side delineation) of expressways, mainly to improve visibility. Allen et al. reported drivers' visibility requirements for roadway delineation [1]. Under adverse visibility conditions of fog, steering performance can be improved by increasing delineation contrast to achieve a longer visual range and by improving the quality of the delineation configuration by increasing the segment-to-gap ratio and decreasing the segment cycle length. Schumman found that a combination of lane makings and post-mounted delineators might be optimal for night guidance, and that post-mounted delineators assisted long-range guidance [2]. Hagiwara, et al. found that the illuminated delineator in winter should be of high intensity against the background luminance during snowstorms in the daytime [3]. However, there have been few investigations on whether the right side is the most effective delineator locations.

This study investigated how the location of illuminated delineators affected the driver subjective mental workload (SMWL) and subjective visibility assessment items for drivers running under snowstorm conditions. SMWL was evaluated using a questionnaire based on the National Aeronautics and Space Administration Task Load Index (NASA-TLX). The experiment was conducted on a driving simulator, mainly because it enabled measurement of driver subjective assessments under the same conditions as a function of the four delineators. Also, the driving under the poor visibility conditions would be too dangerous on actual roads. The participants were exposed to four delineation conditions as the main independent variables: (1) no illuminated delineators (no delineation), (2) illuminated delineators at the shoulder (left-side delineation), (3) illuminated delineators at the median strip (right-side delineation), and (4) illuminated delineators at the left and right sides (both-sides delineation). Installation of illuminated delineators was at 50-m intervals on the simulated expressway.

2. METHODS

2.1. Experiment Dates and the Driving Simulator

The experiment was carried out from December 1 to 6, 2008 at the Driving Simulator Research Laboratory at Kitami Institute of Technology in Kitami City, Japan. Table 1 indicates the specifications of this driving simulator which gives both visual feedback and motion feedback. Each participant was seated in the cabin shown in Figure 1, which is on a motion base with 6 degrees of freedom. The participants watched a radial screen (field of view = 138 degrees horizontally, 35 degrees vertically) on which the road and the traffic environment were projected. The sounds of the simulated vehicle and of the traffic in the environment were also generated. The experimenter was seated on the opposite side of a partition (Figure 1) but could see the cabin and communicate with the participant directly.

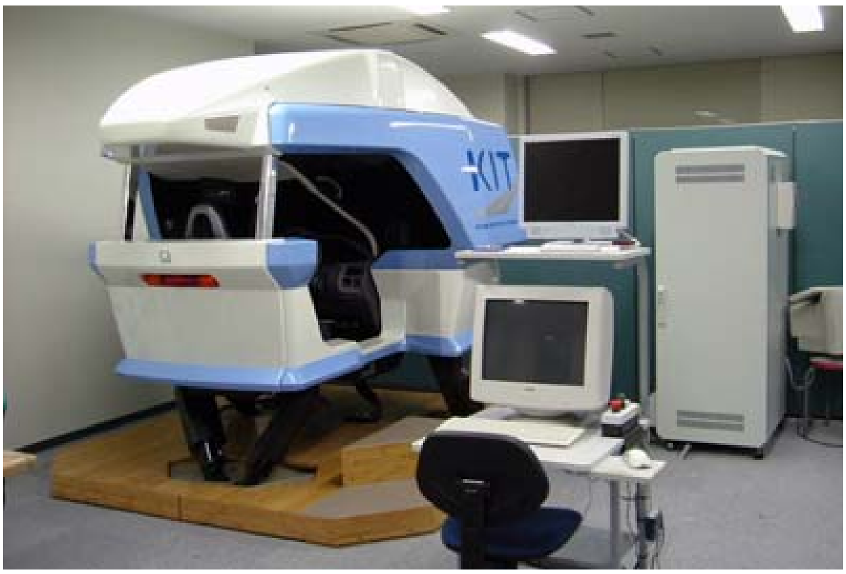

Figure 1 - The driving simulator

Table 1 - Driving simulator specifications

Type	Stationary automobile-cabin
Dashboard	Automobile dashboard where all indicators, lamps and displays are operative, provision has been made to select emergency/failure conditions
View angles and picture size	Forward view: Horizontally 138°, Picture resolution: 1024 x 768 pixels, Transport delay time: 16.7 ms
Projection and refreshing frequency	DPL projector, 30 to 60 Hz
Vehicle motion system	6-axsis motion platform, Cockpit with 6 cylinders activate by electric motors Pitch angle: ± 6°, Roll angle: ± 10°, Yaw angle: ± 8°, Lateral motion: ± 100 mm, Vertical motion: ± 100 mm, Longitudinal motion: ± 100 mm, Maximum acceleration: 0.5 g
Sound	Three-dimensional stereo sound, Body sonic sound
Dimension	Length 2.440 m, Width 4.000 m, Height 1.855m, Weight 600kgf
Electric power	200 V, three phase current (cockpit), 100V (control panel)
Data processing	IBM-compatible PC under MS Windows 2000 (host PC)
Operating conditions	Use indoors, fixed position, Temperature under operation: 10-30 °C

2.2. Participants

A total of 36 drivers (15 female, 21 male) divided into three age groups participated. Fifteen (7 female, 8 male) were aged 20 to 39 years, with an average driving experience of 12.7 years and an average driving distance of 9,800 km/year. Another fifteen (7 female, 8 male) were aged 40 to 59 years, with an average driving experience of 27.5 years and an average driving distance of 7,600 km/year. The remaining 6 (1 female, 5 male) were over age 60, with an average driving experience of 35.8 years and an average driving distance of 7,200 km/year. None of participants had experience in a driving simulator, each had normal color vision, and all were compensated for their participation.

2.3. Road alignments and illuminated delineators

We simulated a mountainous 4-km section of the Douou Expressway (kiloposts (KP) 99 to 103). The average annual traffic volume per 12 hours of this section is about 10,000 vehicles/12hours, and the section is near Asahikawa, the second largest city in Hokkaido. The section has a horizontal alignment in which there are large curves whose radii range from 700 m to 1,500 m. The grade ranges from 1.5% to 3.7%. The speed limit is 80 km/h under normal conditions, and 50 km/h under hazardous conditions. The section is a fully divided four-lane highway with a lane width of 3.5 m and a shoulder width of 3.0 m.

The participants drove through the test section without any leading vehicles, following vehicles or overtaking vehicles. Figure 2 shows the driving scene created by the visual system of the driving simulator. The scene simulates the hazardous visibility condition of falling snow. The second delineator ahead is slightly visible under this visibility condition. We also simulated snow conditions on the road. The height of snow embankments at the shoulder is 1.5 m, and the road surface is covered with snow. The center line and edge line are not visible.

Illuminated delineators are installed at 50-m intervals. There are four delineation conditions as the main independent variables: (1) no illuminated delineators (no delineation), (2) illuminated delineators at the shoulder (left-side delineation), (3) illuminated delineators at the median strip (right-side delineation), and (4) illuminated delineators at the left and right sides (both-sides delineation). The delineator height is 2 m, the diameter is 0.1 m, and the height of the illuminated part is 0.2 m. The illuminated delineator at the shoulder is green; that at the median is orange. These colors are standard in Japan. Their luminance is maximized on the screen.

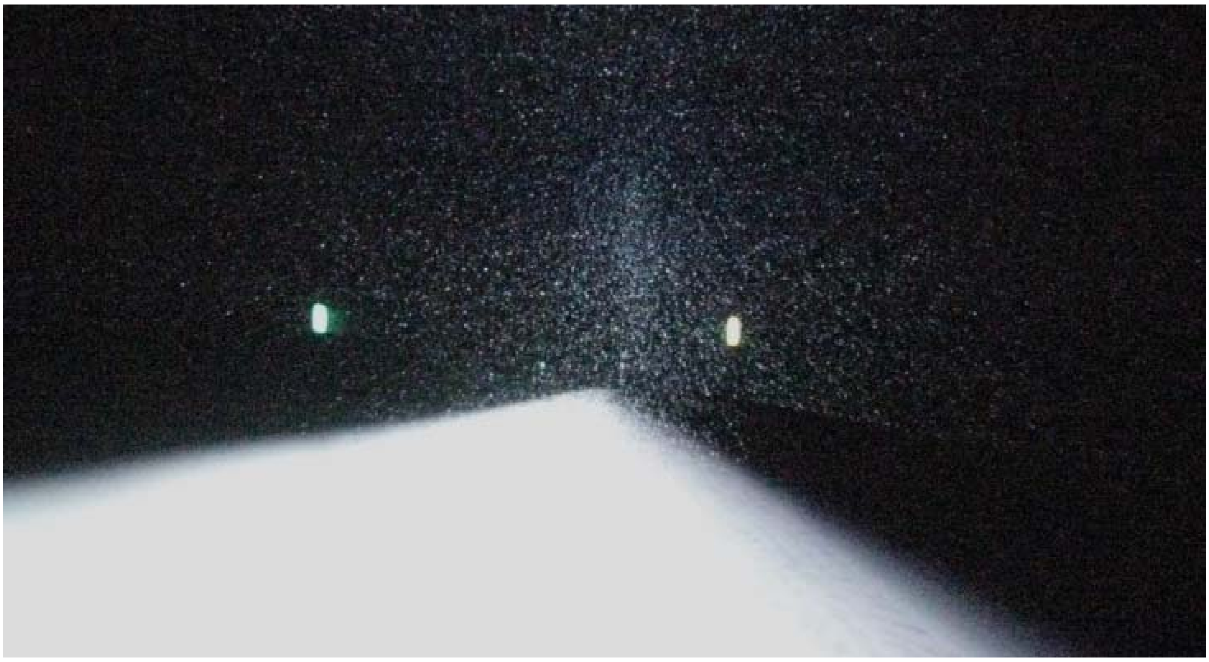

Figure 2 - Driving simulation

2.4. Subjective Mental Work Load

The National Aeronautics and Space Administration Task Load Index (NASA-TLX) was used to estimate driver SMWL [4]. NASA-TLX is a multi-dimensional rating procedure that provides an overall workload score based on the weighted average of ratings of six factors: mental demand (MD), physical demand (PD), time pressure (TP), effort (EF), performance (OP), and frustration (FR). The subjects are asked to rate each of these factors. Overall workload (SMWL) was computed by multiplying each rating by the ranking number given to that factor by the subject.

2.5. Five subjective visibility assessment items

There were five subjective visibility assessment items: visibility of road direction, shoulder position, median position, position of the vehicle in the lane, and driving comfort. The last item was to evaluate whether the participants could drive comfortably despite the low visibility conditions. These subjective visibility assessment items were evaluated on a scale of one to ten (Figure 3).

Q1. While you were driving the test section, how clearly could you see where the road was going?

Clealy ——————————————— Not clearly

Q2. While you were driving the test section, how easy was it to recognize your position relative to the shoulder?

Easy ——————————————— Hard

Q3. While you were driving the test section, how easy was it to recognize your position relative to the median

Easy ——————————————— Hard

Q4. While you were driving the test section, how easy was it to recognize the position of the vehicle in the lane?

Easy ——————————————— Hard

Q5. How comfortable was it to drive the test section?

Comfort ——————————————— Uncomfort

Figure 3 The five questions asked of the participants after each run.

2.6. Experimental Design

The study employed a repeated-measures design as the experimental design. The four delineator conditions are randomly assigned to a sequence of treatments for each participant. The dependent variables are the SMWL of the participants, and the five subjective visibility assessment items. Major independent variables are the following four delineation conditions: (1) no illuminated delineators (no delineation), (2) illuminated delineators at the shoulder (left-side delineation), (3) illuminated delineators at the median strip (right-side delineation), and (4) illuminated delineators at the left and right sides (both-sides delineation).

2.7. Experimental procedure

Three participants attended each experimental session. There were two sessions per day, with the morning session performed from 9:00 to 12:00 and the afternoon session from 13:15 to 16:15. The 36 participants were randomly assigned to the sessions. The experimenters briefly explained the schedule and aims of the experiment. Each participant drove through a training section a few times. This training section was not the same as the experimental section. During each test run, the participants were instructed on how to operate the car of the driving simulator and how to familiarize themselves with driving. Also, the participants were instructed to drive the experimental section at a constant 50 km/h.

The experiment was organized such that each participant had one experimental run under each of the four delineation conditions. The four delineation conditions were randomly assigned to a sequence of runs. After each experimental run, the participant had to fill out a questionnaire concerning workload and subjective visibility assessments. They took turns at driving in the simulator: While one was driving, the other two completed questionnaires and rested. After finishing the experiment, the participants received a contrast sensitivity test and filled out a questionnaire on the level of motion sickness from the simulator, their understanding of the given task and comments about the experiments. Also the participants filled out a questionnaire sheet on their attributes.

3. RESULTS

3.1. Mental Work Load

Table 2(A) shows the average scores and standard deviations for the four delineation conditions. The average overall SMWL for both-sides delineation was 5.02 (n=36). It was the best score among the four delineation conditions. The second best score was for left-side delineation, the third was for right-side delineation, and the worst was for no delineation. One-Factor Repeated Measures ANOVA (α=0.05) was performed to compare the delineations conditions shown in Table 2(B). Post hoc tests showed significant differences in overall SMWL among all pairs of the four delineation conditions. The overall SMWL for both-sides delineation was significantly lower than for any of the other three conditions, that for the left-side delineation was significantly lower than for the right-side delineation and no delineation, and that for the right-side delineation was significantly lower than for no delineation.

Table 2 - Effects of the four delineation conditions on subjective evaluations

(A) The average scores and standard deviations of five subjective visibility assessment items

Four delieation conditions		Oveall SMWL	Road direction	Shoulder position	Median position	Position in lane	Driving comfort
None	Average	7.34	7.00	6.89	8.28	7.11	7.75
	Std.	1.75	2.46	2.49	1.85	2.28	2.10
	n	36	36	36	36	36	36
Right-side	Average	6.76	5.36	6.25	4.78	5.81	6.72
	Std.	1.69	2.35	2.25	2.66	2.18	2.04
	n	36	36	36	36	36	36
Left-side	Average	6.09	4.81	4.25	7.44	4.78	5.86
	Std.	1.79	2.54	2.59	1.89	2.36	2.29
	n	36	36	36	36	36	36
Both sides	Average	5.02	3.36	3.31	3.64	3.53	4.53
	Std.	1.89	2.24	2.26	2.50	2.07	2.61
	n	36	36	36	36	36	36

(B) Rresults of One-Factor Repeated Measures ANOVA (α=0.05) for five items

	Oveall SMWL	Road direction	Shoulder position	Median position	Position in lane	Driving comfort
Effect of four delineation conditions	**	**	**	**	**	**

(C) Results of the post hoc test (α=0.05) among all pairs of four delineation conditions for five questions.

Four delieation conditions		Oveall SMWL	Road direction	Shoulder position	Median position	Position in lane	Driving comfort
None	Right-side	*	**	*	**	**	**
	Left-side	**	**	**	**	**	**
	Both	**	**	**	**	**	**
Right-side	None	*	**	*	**	**	**
	Left-side	*		**	**	**	**
	Both	**	**	**	**	**	**
Left-side	None	**	**	**	**	**	**
	Right-side	*		**	**	**	**
	Both	**	**	**	**	**	**
Both sides	None	**	**	**	**	**	**
	Right-side	**	**	**	**	**	**
	Left-side	**	**	**	**	**	**

Note: * means α=0.05. ** means α=0.01.

3.2. Subjective visibility assessment items

In addition, Table 2(A) shows the average scores and standard deviations of five subjective visibility assessment items: road direction, shoulder position, median position, position in lane, and driving comfort. The score for these five items for both-sides delineation was the highest among the four delineation conditions. Table 2(B) shows the results of One-Factor Repeated Measures ANOVA (α=0.05) for the five items. Table 2(C) shows the results of the post hoc test (α=0.05) among all pairs of the four delineation conditions for the five questions. Scores for the five items for both-sides delineation are significantly lower than those for the three other delineation conditions. The scores for the five items for both-sides delineation are significantly lower than those for the three other conditions. In the case of median position, the score for right-side delineation is better than that for left-side delineation.

3.3. Effects of participant attributes on overall SMWL and on the five subjective visibility assessment values

Multiple-regression analysis was applied to clarify the effects of explanatory variables on overall SMWL and on the five subjective visibility assessment values. The four delineation conditions, sex, three age groups, driving distance per year and contrast sensitivity were selected as the explanatory variables. Delineation conditions, sex and age group are categorical variables. We considered interaction effects between sex and age group, between sex and driving distance per year, and between age group and driving distance per year. The parameters of the multiple regression model shown in Table 3 were estimated by the least-squars method using JMP 7.0 (SAS). We removed the explanatory variables whose t statistics were below the level of significance (α=0.05).

Table 3 - Results of parameter estimation for multiple regression model to estimate subjective assessment values

Item	Determination Coefficient	Main Effect								Interaction Effect
		Position of the illuminated delineators				Sex Male	Age *3	Driving Distance	Contrast Sensitivity	
		Both sides	Left side	Right side	None					
Overall SMWL	0.53	-1.28	-0.21	0.454	1.04	-0.89	0.850 0.691	-4.07 e-5	-3.23 e-3	*1
Road direction	0.36	-1.77	-0.33	0.229	1.87	-1.20				
Shoulder position	0.40	-1.87	-0.92	1.076	1.72	-0.87				
Median position	0.56	-2.40	1.41	-1.26	2.24	-1.24				*2
Position in Lane	0.43	-1.78	-0.53	0.500	1.81	-1.11				*2
Driving Comfort	0.51	-1.69	-0.35	0.507	1.54	-1.19	0.826 1.279			

Note 1: Interaction between age and driving distance per year

Note 2: Interaction between age and sex.

Note 3: Upper number is a coefficient for 20 to 39 years, and lower number is a coefficient for 40 to 59 years

The coefficient of determination for the overall SMWL is 0.53, and those for the five of the dependent variables. For the overall SMWL, all of the independent variables show significant effects on the dependent variable. Both-sides delineation shows the largest effect in decreasing the overall SMWL, and left-side delineation shows the second large decreasing effect. The “no delineation” condition shows the largest effect in increasing the overall SMWL, and right-side delineation shows the second large increasing effect. The sex of male shows an effect of decreasing the overall SMWL. The overall SMWL decreases with increases in driving distance per year and contrast sensitivity. The overall SMWL increases with increases in age group. In the case of overall SMWL, there is a significant interaction effect between age and driving distance per year. Overall SMWL of the over 60 age group increases with increases in driving distance per year.

4. SUMMARY

In this study, using the driving simulator, we found that both-sides delineation improved driver’s subjective mental workload and driver subjective visibility assessment. Of the two types of one-side delineation, the left-side delineation was found to be better than the right-side delineation. The no delineation condition had the highest values for driver’s mental workload and driver’s subjective visibility assessment among the four delineation conditions. Elderly driver and drivers who do not drive far each year had a higher mental work load than young drivers and drivers who drive far each year. The results suggest that both-side delineation can assist elderly driver and drivers who do not drive far each year on expressways under low visibility conditions. Expressways in Hokkaido tend to employ right-side delineation, because the cost of right-side delineation is the cheapest among the both-sides, left-side and right-side delineation conditions. However, the present study indicates that that both-sides delineation is the most desirable in terms of driver mental work road. Previous papers studied the effect of visual guidance on drivers [1],[2]. Those studies found that driving performance and subjective assessments increased with increases in visual guidance. The results of this study found the same tendency by measuring mental work load variables using the driving simulator. It should be noted that the results are based on simulation conditions and that driving under actual visibility conditions may produce different results. Thus, we should confirm the results of this study under field conditions.

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