RESEARCH ON THE SAFE DRIVING SUPPORT SYSTEM FOR WINTER ROADS

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1. Introduction

The driving environment in winter is very severe in cold, snowy regions, due to slippery roads covered with snow and ice and poor visibility caused by adverse weather conditions including snowstorm. Single-vehicle accidents often develop into multi-vehicle collisions under reduced visibility since other drivers will probably recognize traffic accidents more slowly. Multi-vehicle collisions obstruct road traffic for a long time, which in turn greatly affects daily activities. Although facility-based measures, such as snow fences and snow break forests, have been implemented, development of a new system employing ITS technologies is imperative to prevent traffic accidents more effectively. Since around 1994, the Civil Engineering Research Institute (CERI) has been developing cold-region-specific sensors (e.g., a millimeter-wave radar) that detect obstructions and visual guidance systems that are effective during snowstorm.

At the national level, five ITS-related ministries and agencies (Ministry of Post and Telecommunications, National Police Agency, Ministry of Transport, Ministry of International Trade and Industry, and Ministry of Construction) built ITS-based system architecture in November 1999 toward advancing ITS development and early diffusion. In April 2000, the Ministry of Construction (the current Ministry of Land, Transport and Infrastructure) jointly with the Hokkaido Development Bureau and other organizations, formulated guidelines to diffuse nine services according to the ITS-based system architecture. This effort aims to promote ITS projects on a regional level and to efficiently develop and construct systems for provision of ITS-related services. CERI prepared a draft proposal for the Advanced cruise-assist Highway System for cold regions (Cold-Region AHS), one of those nine services. This draft proposal was prepared with the assistance of the Public Works Research Institute of the Ministry of Construction (the current National Institute for Land and Infrastructure Management of the Ministry of Land, Transport and Infrastructure).

Cold-Region AHS integrates five sub-services defined in the system architecture built by the five central government ministries and agencies in charge of ITS, based on the viewpoints of situations where services are provided and the necessity of functions. The five sub-services are these: 1) Provision of weather information, 2) Provision of information on road surface conditions, 3) Provision of information on obstacles ahead and behind, 4) Danger warning to nearby vehicles, and 5) Notification to nearby vehicles when an accident occurs. Development of Cold-Region AHS is fostered such that it will be compatible with the Road Communication Standard of the former Ministry of Construction. In poor visibility situations, such as snowstorms, these services allow detection of slippery road surface conditions and obstacles, including parked cars, by various types of sensors, and the gathered information is provided to drivers through on-board equipment of vehicles and roadside facilities. In addition, a service to provide regional road weather information and forecasts, on which route selection is based, is included. Therefore, the Cold-Region AHS is characterized by a range of support wider than ordinary cruise-assist road driving systems on a temporal and spatial basis. Figure 1 is a conceptual diagram of the Cold-Region AHS.

The challenges for realization of services based on the Cold-Region AHS are as follows:

1) Examination of cold-region-specific sensing technologies, such as obstruction detection sensors, including a millimeter-wave radar that can detect hazardous phenomena ahead even under reduced visibility, and sensors capable of detecting extremely slippery, icy surfaces
2) Development of information provision facilities that can issue continuous danger warnings, and examination of methods and the specifications for facilities to properly issue danger warning

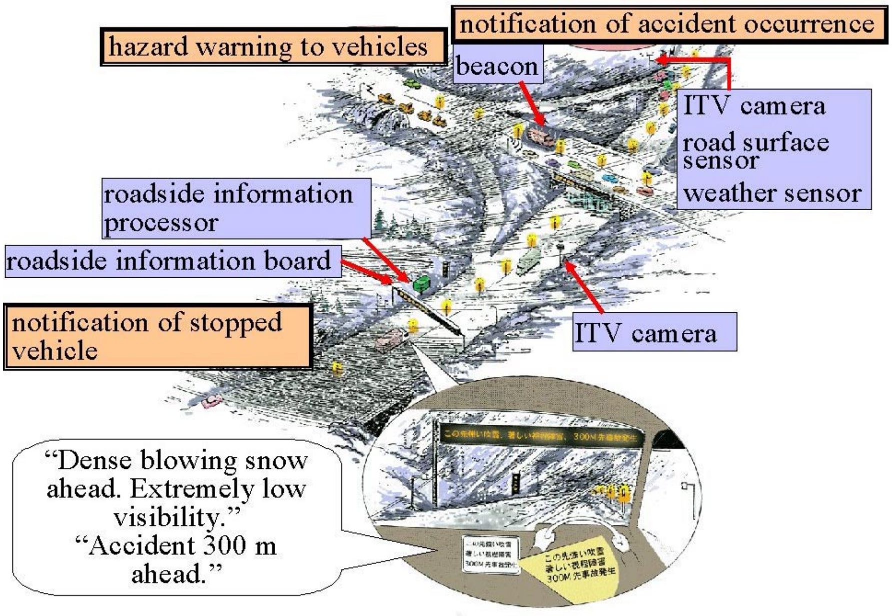

Figure 1 Conceptual Diagram of the Cold-Region AHS

To examine the above, CERI and the Public Works Research Institute, which has been researching and developing a non-Cold-Region AHS, jointly conducted research and development of a cruise-assist system for winter roads. In this joint research, the Public Works Research Institute was tasked with the development of a cold-region-specific sensor, and the Civil Engineering Research Institute with the development of a pilot system and a danger-warning system with a high level of user acceptability.

This study reports the survey results of specifications for the danger-warning system created by the Civil Engineering Research Institute.

2. Examination of Danger Warning Effects by the Light-emitting Delineator on Driving Behavior

The road information board is a common means of disseminating information to drivers. However, in cold regions, it is inadequate for warning drivers of hazards; possible reasons include factors causing reduced visibility such as snowstorms will make it unrecognizable. Research was conducted on a danger-warning system that uses a light-emitting delineator capable of continuous operation, suitable for times of reduced visibility. Past research results have thus far clarified the following:

1) Danger warning by light emission is effective in supporting safe driving.

2) Short-cycle (rapid) flashing gives drivers a sense of caution.

3) Delineators whose danger-warning lamp and visual-guidance lamp are (vertically) separated from each other are effective for hazard warning.

The optimum specifications have not been fully clarified for such delineators (installation position, vertical offset of the lamps, etc.). Through a moving-image CG experiment with subjects and a driving experiment on the test road, the optimum specification for the delineator with a danger-warning function was examined.

3. Moving-image CG Survey

3.1 Examination items

(1) Installation position

Installation positions of the light-emitting delineator were examined to determine whether the roadside or the center strip is more effective. This research used a road with two lanes on each side of a center strip. Comparisons were made according to the following four configurations (note: driving lane is left in Japan):

- DELINEATOR position: roadside; Driving in the left lane (passenger side lane)
- Delineator position: roadside; Driving in the right lane: (passing lane)
- Delineator position: center strip; Driving in the left lane (passenger side lane)
- Delineator position: center strip; Driving in the right lane (passing lane)

(2) Height of the lamps of light-emitting delineator

The light-emitting delineator of the Cold-Region AHS has a visual guidance function for poor visibility and other situations, as well as a danger-warning function to notify moving vehicles of obstacles and other dangers ahead. One lamp for each function is installed on the same pole. The heights of these two lamps must be easy for drivers to see and recognize.

In this research, examination was carried out for combinations of the heights of the visual-guidance lamp and the vertical offsets between the visual-guidance lamp and the danger-warning lamp (hereinafter, “lamp-distance”). The heights of the visual-guidance lamp were in the range of 1.0-3.0 m, and the lamp-distance in the range of 0-1.5 m. Each was varied in increments of 0.5 m.

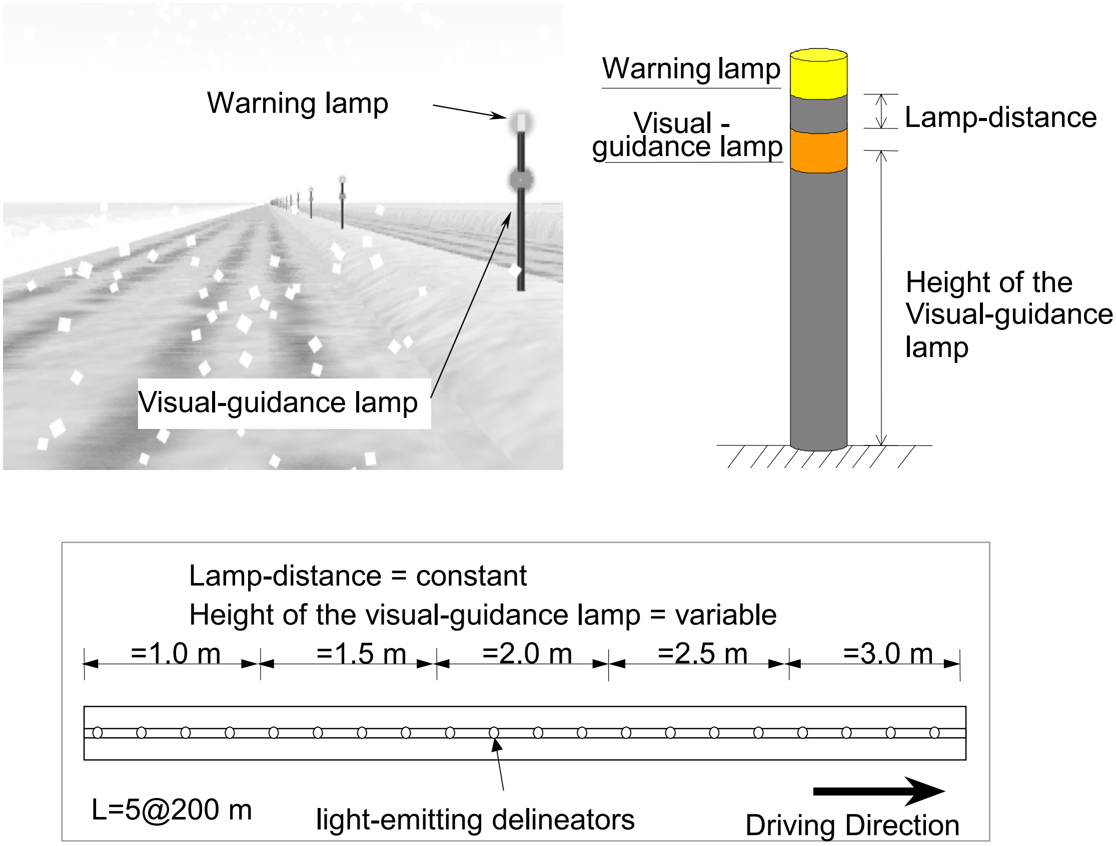

Figure 2 Example of CG (top left), Structure of the Delineator (top right), and CG Structure for Height Comparison of the Visual-guidance Lamp (bottom)

3.2 Survey outline

(1) Creation of moving-image CG

Moving-image CGs were created under the combination conditions described in 3.1. Common conditions, such as road and weather conditions (Figure 2) are as follows:

- Time of day: daytime
- Weather: snow
- Road surface: compacted snow
- Travelling speed: 50 km/h
- Number of other vehicles: zero
- Height of line of sight: assumes ordinary passenger car (1.2 m height)
- Interval between delineators: 20 m

(2) Subjects

In total 58 subjects were joined the experiment. The subjects were selected so that their sex, age and driving history were well distributed.

(3) Survey method

Moving-image CG files stored on the hard disk were projected onto screen. The projection took into account the height of drivers' line of sight (1.2 m) and the vanishing points (15 degrees to the right and left).

(4) Questionnaire Items

The three items below formed the basis of the evaluation. The subjects were provided with a questionnaire answer sheet in advance and were instructed to fill it out while watching the CG movie.

1) Sense of caution: Is the warning lamp effective?
2) Guidance capability: Is the visual-guidance lamp effective?
3) Level of comfort: Is level of driving discomfort low? Is it annoying?

Two evaluation methods of the delineator position were carried out from these three aspects: 1) pair comparisons for the four aforementioned patterns of installation position, which is a method whereby two patterns at a time are shown for comparison; and 2) a five-level scale evaluation of respective four patterns.

The five-level evaluation was made on the height of light-emitting lamp. In the evaluation, the subjects made a comprehensive evaluation of sense of caution, guidance capability, and level of comfort by watching the CG where the lamp-distance was constant and the height of visual-guidance lamp was varied. The CG and example images are shown in Figure 2.

3.3 Survey results

(1) Installation position

The experimental results of comparison of installation position of delineators are summarized.

The results of the pair comparison demonstrate that a high sense of caution tends to be felt when the driver is travelling on the lane adjacent to delineators (Figure 3). This tendency can be observed whether installation is at the center strip or on the left side of the driving lanes. The guidance capability is almost constant with regard to combination of driving lanes and installation positions. The level of comfort is prone to be low when the driver is travelling on the lane adjacent to delineator. This tendency can be seen when delineators are installed either at the center strip or on the left side of the driving lanes.

The five-level evaluation of each pattern shows the points to be roughly equal with respect to guidance capability and level of comfort (Figure 4). The result for sense of caution are the lowest when delineators are installed on the left side of the road and the vehicle is running in the right lane (the pattern of roadside installation position and driving in the passing lane). Since the pattern with small differences in evaluation of the driving lanes is desirable for installation position, installation on the right side (center strip) would be more appropriate for multi-lane roads.

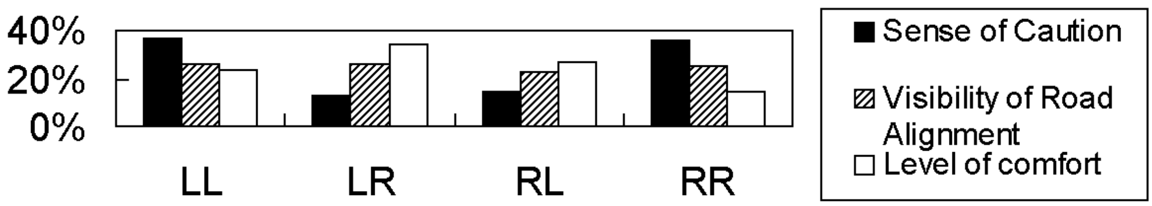

Figure 3 Pair Comparison. LL: Traveling in the left lane with delineators installed at the roadside, LR: Traveling in the left lane with delineators installed at the center strip, RL: Traveling on the passing lane with delineators installed at the roadside, RR: Traveling in the passing lane with delineators installed at the center strip.

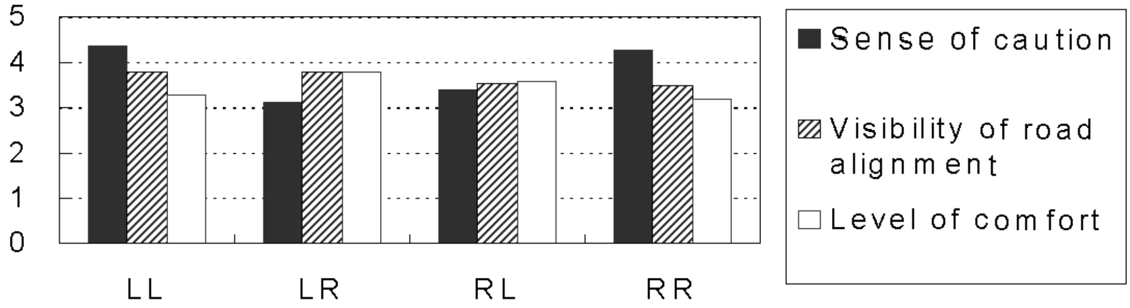

Figure 4 valuation of Each Item (Five-level Scale)

(2) Height of the light-emitting lamps

The five-level evaluation of height of the light-emitting lamp was conducted with subjects while maintaining the lamp-distance and changing the height of the visual guiding lamp. The evaluation clarified the following (Figure 5):

- The light-emitting delineator, whose visual-guidance lamp is 1.5 m in height, ranked highest. Among such delineators, those with the lamp-distance ranging from 0 – 1.0 m ranked highest. The second-highest ranking of such type was achieved by the light-emitting delineator whose visual-guidance lamp at 2.0m height and whose lamp-distance ranges from 0 – 0.5 m.

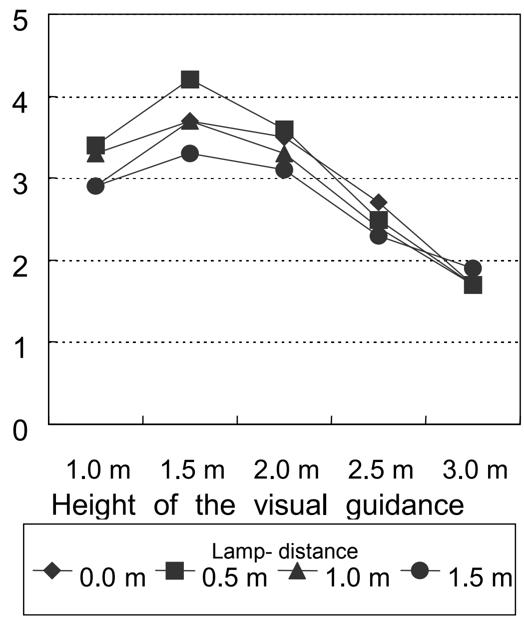

Figure 5 Evaluation of Each Item (Five-level scale) for Height of the Visual-guidance Lamp (when distances from the danger-warning lamp are 0 m, 0.5 m, 1.0 m, and 1.5 m)

4. Driving Experiment

4.1 Outline of the experiment

At the test road at Ishikari Snowstorm Experimental Site of CERI, there is a pilot system installed for developing driving support systems in cold regions that can adjust the space between delineators and the lamp-distance. A driving experiment was conducted with test drivers using this pilot system. Equipment installed in the test vehicles recorded driving behavior: speed, force of accelerator application, force of brake application, steering angle, and acceleration vector (forward/backward/rightward/leftward). This experiment addressed the fundamental specifications optimal for light-emitting delineators according to data on these items.

4.2 Experimental methods

The test drivers were requested to drive the test vehicles on the test road. During the test, the drivers' behavior was observed under two conditions: 1) warning by light-emitting delineator prior to the appearance of the obstacle and 2) absence of such warning. The obstacle was a panel simulating a small vehicle, and appeared from behind a snow mound on the roadside. The obstacle was set to appear 80 m ahead of the test vehicle. Multiple locations were designated for appearance of the obstacle, and the location was randomized, in order to reduce the learning effect of the test drivers. The setup is shown in Figure 6.

On the straight sections of road, an obstacle was assumed to appear suddenly in front of the vehicle in a snowstorm situation where the range of visibility is 100 m. On the curved sections, the obstacle used is assumed the type that appears in a curved section which is slippery and whose sight distance is short. The test drivers received an explanation of the purpose of the flashing of the danger-warning lamps in advance.

Figure 6 Driving Experiment: At left is a panel simulating the obstacle; at right is the experimental light emitting delineator.

4.3 Experimental conditions

The experiment on the optimum specifications for the light-emitting delineator was conducted under the following conditions, which were determined according to the results of the CG experiment:

1) Light-emitting pattern: comparison between flashing once and flashing multiple times, and comparison with regard to flashes per minute
2) Lamp-distance: comparison between 0.25 m and 0.5 m
3) Height of the visual-guidance lamp: comparison between 1.5 m and 2.0 m
4) Installation position of light-emitting delineators: comparison between right and left sides of the driving lanes

4.4 Experimental results

(1) Comparison by flashing pattern

Figure 7 shows the comparison results of vehicle speed 80 m ahead of the obstacle by flashing pattern of danger warning. The four flashing patterns are shown below. The flashing frequency was 60 flashes per minute for each flashing pattern. The lighting duration ratio is the rate of lighting duration to the whole duration of a certain period of time (Figure 8). The flashing patterns are denoted as follows:

- Flashing once and a lighting duration ratio of 0.3 (denoted as “1A”)
- Flashing once and a lighting duration ratio of 0.4 (denoted as “1B”)
- Flashing three times and a lighting duration ratio of 0.3 (denoted as “3A”)
- Flashing four times and a lighting duration ratio of 0.4 (denoted as “4B”)

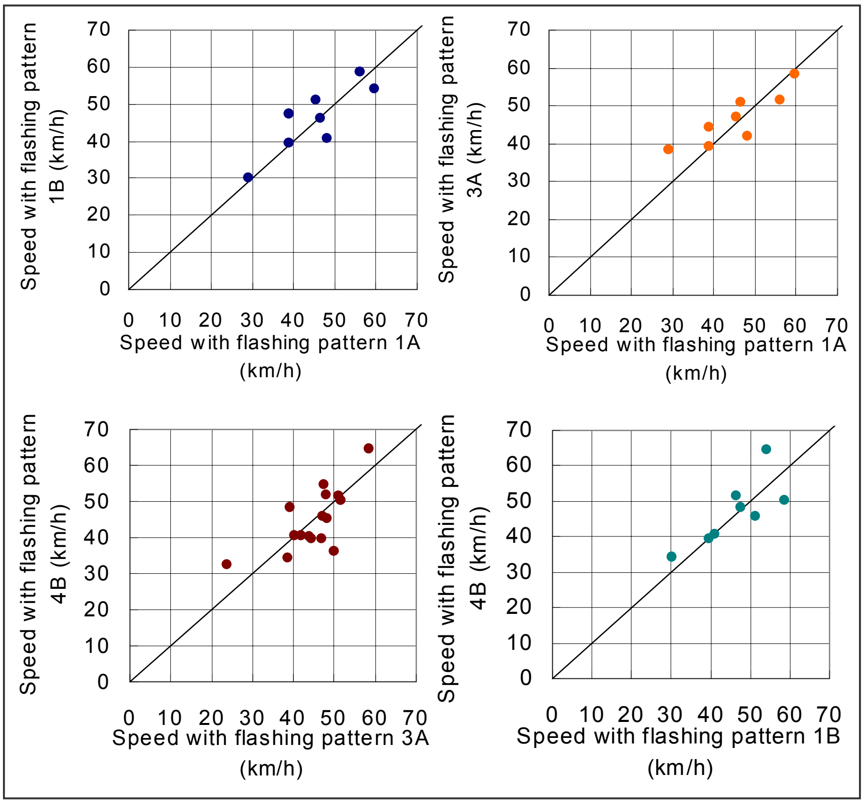

Figure 7 Comparison of Vehicle Speed 80 m Ahead of the Obstacle by Flashing Pattern

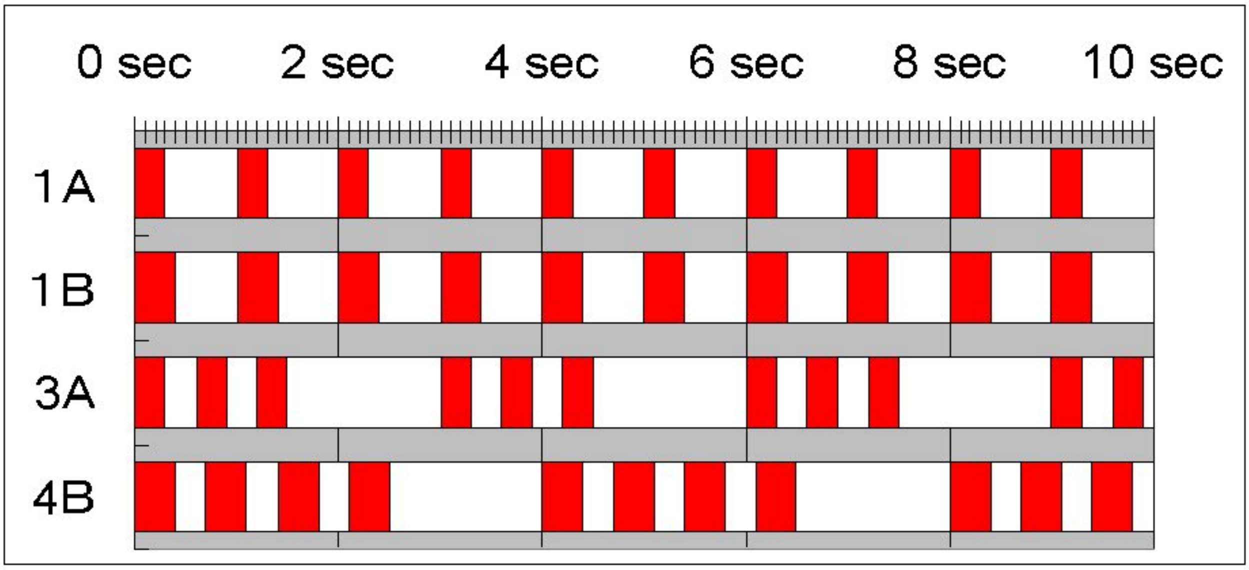

Figure 8 Flashing Patterns: Black Indicates Flashing

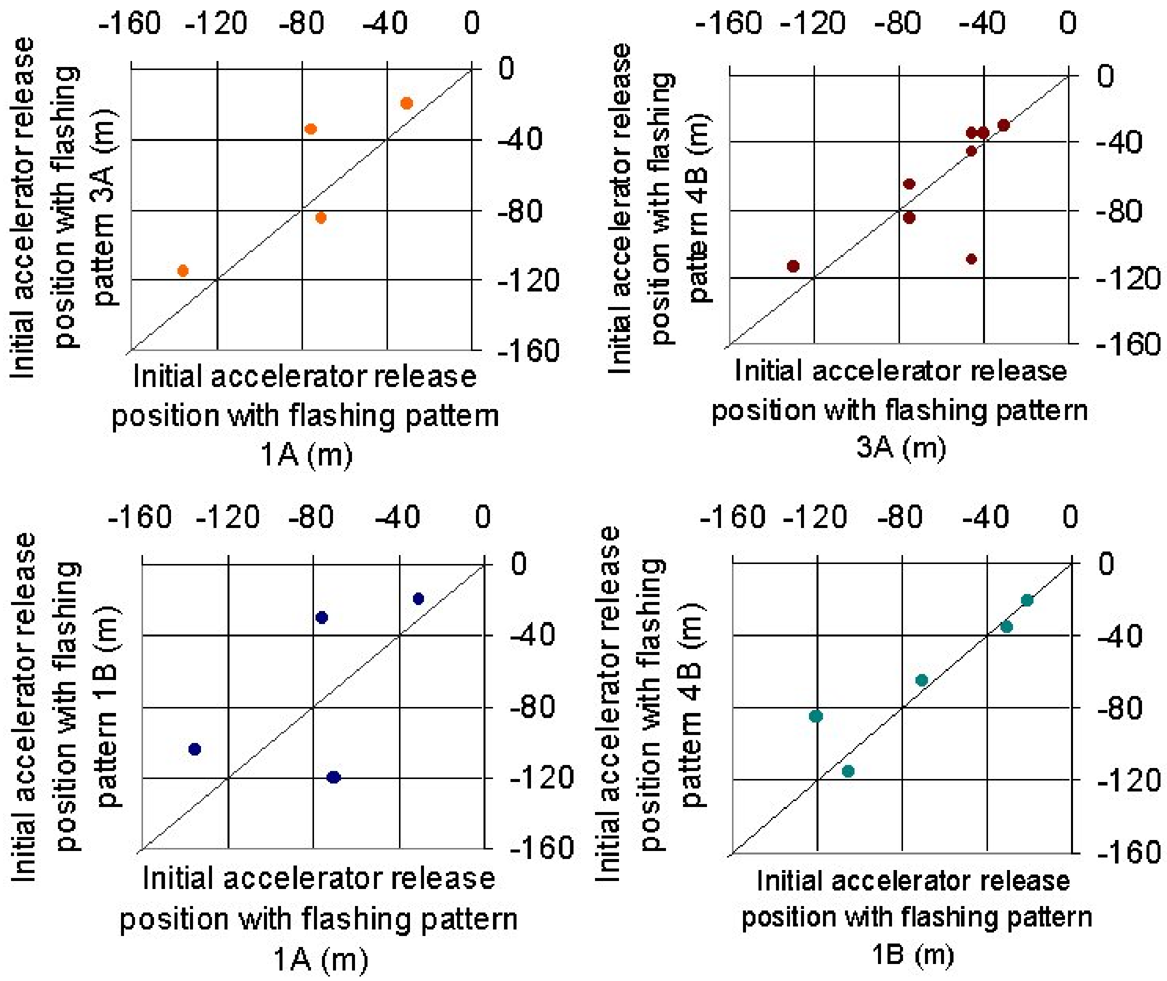

Figure 9 Comparison of Initial Accelerator Release Distances by Flashing Pattern (shown by the distance from the obstacle (the distance of the obstacle is 0 m))

As shown in Figure 7, significant difference in vehicle speed 80 m ahead of the obstacle was not confirmed with respect to flashing pattern. No significant difference was found by statistical tests. Since differences in speeds 80 m ahead of the obstacle affected by presence/absence of danger warning have been confirmed by statistical tests differences are small in the effects of danger warning by the four experimental flashing patterns employed in the experiment.

Also, Figure 9 shows the comparison results of differences in positions of the initial accelerator release by flashing pattern. Although the amount of data is small, differences are considered to be small with respect to flashing pattern.

(2) Comparison by lamp-distance

Figure 10 compares vehicle speed 80 m ahead of the obstacle using delineators of whose lamp-distances are 0.25 m and 0.5 m. Differences in speed were not observed with respect to the lamp-distance, according to the figure. Figure 11 compares positions of initial accelerator release, but differences in speed cannot be confirmed with respect to the lamp-distance.

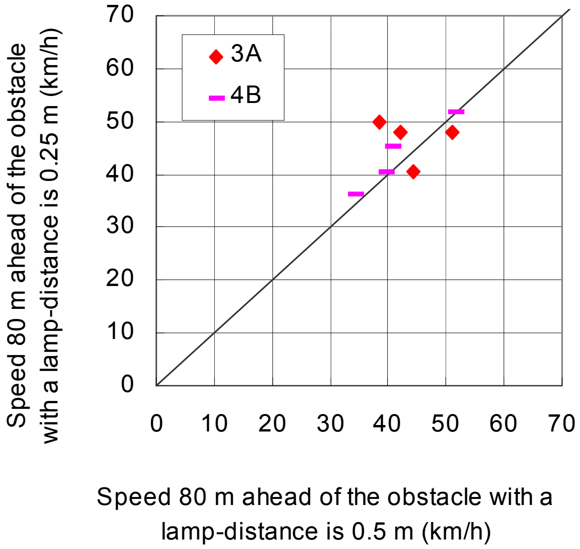

Figure 10 Comparison of Speeds 80 m Ahead of the Obstacle when Distances from the Danger-warning Lamp are 0.25 m and 0.5 m (3A and 4B are flashing patterns of the danger-warning lamp)

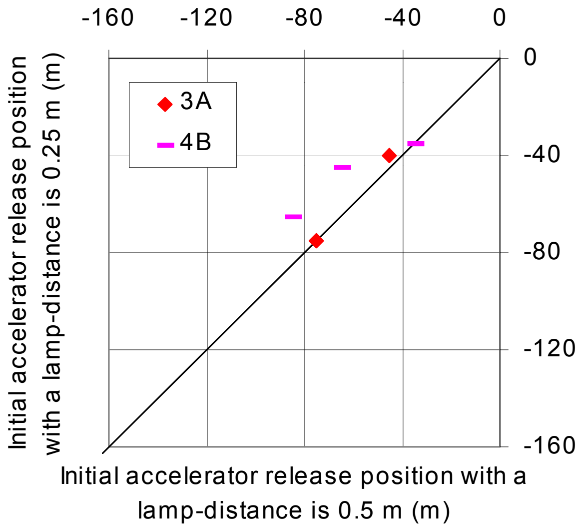

Figure 11 Comparison of Initial Accelerator Release Positions when Distances from the Danger-warning Lamp are 0.25 m and 0.5 m (3A and 4B are flashing patterns of the danger-warning lamp)

(3) Comparison by height of the visual-guidance lamp

Figure 12 shows the comparison results of vehicle speed 80 m ahead of the obstacle using delineators of whose visual-guidance lamps are 1.5 m and 2.0 m in height. Differences in speed cannot be recognized with respect to height of the visual-guidance lamp, according to the figure. Figure 13 compares positions of initial accelerator release, but differences in speed is not confirmed with respect to height of the visual-guidance lamp.

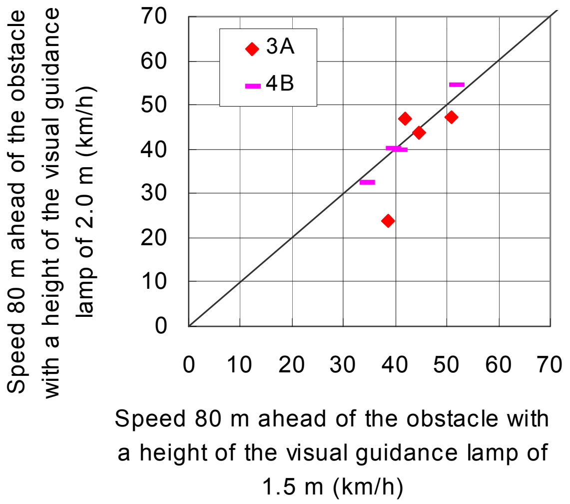

Figure 12 Comparison of Speeds 80 m Ahead of the Obstacle when Heights of the Visual Guidance Lamp are 1.5 m and 2.0 m (3A and 4B are flashing patterns of the danger-warning lamp)

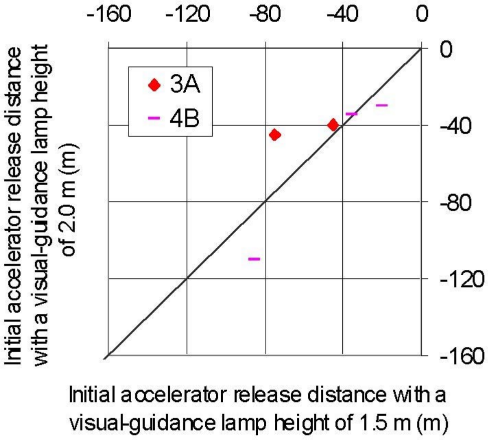

Figure 13 Comparison of Initial Accelerator Release Distances when Heights of the Visual Guidance Lamp are 1.5 m and 2.0 m (3A and 4B are flashing patterns of the danger-warning lamp)

(4) Comparison by installation position of delineators

Figure 14 shows the comparison results of speed of the vehicle 80 m ahead of the obstacle when delineators are installed on the left and right sides of the driving lanes. When they are installed on the right side, there are two cases of speed increase 80 m ahead of the obstacle. However, statistical tests did not indicate significant differences.

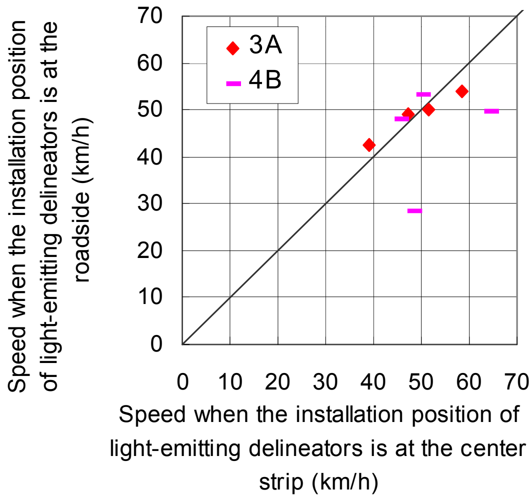

Figure 14 Comparison of Speeds 80 m Ahead of the Obstacle when Installation Positions of Light-emitting Delineators are on the Right and Left Sides of the Driving Lanes (3A and 4B are flashing patterns of the danger-warning lamp)

5. Conclusions

CERI and the Public Works Research Institute jointly studied the safe driving support system for winter roads. To develop specifications for the danger-warning lamp light-emitting delineator (installation position, height of the light-emitting lamp, etc.), CERI conducted an moving-image CG experiment and a driving experiment with test drivers to survey user acceptability.

In the CG experiment with subjects, the right side of the driving lanes (center strip) was evaluated rated relatively highly as an installation position. Also, delineators with a guidance lamp at heights of 1.5-2.0 m were rated highly, as were delineators with distances from the danger-warning lamp of 0-0.5 m.

Next, test drivers participated in an experiment on the test road, to survey operation behavior with respect to flashing pattern, structure, and installation position of the light-emitting delineator. The experimental patterns were selected according to the results of the aforementioned CG experiment with subjects. Consequently, differences in driving behavior were not found with respect to flashing pattern, lamp-distance, height of the visual-guidance lamp, and installation position of light-emitting delineators. The possible reason is that because the experimental conditions with a high level of user acceptability were chosen based on the CG experiment and for other reasons, differences were not conspicuous enough to be reflected in operation behavior. In other words, the conditions set in this actual driving experiment are considered to provide a sufficient level of user acceptability.

This series of experiments did not include survey on visibility of danger warning by light emission at the time of poor visibility and operation behavior of test drivers in the absence of prior explanation on the purpose of such danger warning. In the future, experimental data on these will be collected to find light-emitting methods, color of the light-emitting lamp, installation position, interval, and other factors of delineators that are highly acceptable to users, in order to develop fundamental specifications for the driving support system for cold regions.

Acknowledgements

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