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Improving the nighttime visibility of signs and workers in road work zones in Japan

Submitted by

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ABSTRACT

In Japan, work-related accidents at construction sites resulted in 487 fatalities and 27,193 injuries in 2005. The Ministry of Land, Infrastructure and Transport began devising more stringent safety measures to address those accidents in 2001, but standards for construction safety facilities vary from one construction site to another, and work zone safety improvement has been insufficiently studied. In previous studies, the authors surveyed traffic safety contractors and road users on their satisfaction with road work traffic safety measures. Both traffic safety contractors and road users reported the greatest dissatisfaction with the understandability of road work signs, followed by the nighttime visibility of traffic control personnel.

The present study aims to improve the understandability of information displayed on road work signs and to examine measures to improve the nighttime visibility of traffic control personnel. This study suggests that clear signage that is not text heavy is the most effective at prompting drivers to change lanes. Also, in some cases it may be more effective to light traffic control personnel with aimed floodlights than with additional light-emitting devices.

INTRODUCTION

Work-related accidents at construction sites in Japan resulted in more than 1,000 worker fatalities a year until 1996 (1). In light of this, the Ministry of Land, Infrastructure and Transport identified the most common types of construction accidents and in 2001 began devising more stringent safety measures to address those accidents. Regional development bureaus and other road work administrators implemented those measures (2, 3), which by 2005 had halved annual fatalities to 500. It should be noted, however, that fatalities at construction sites still account for one third of all work-related fatalities, and that traffic accidents rank as the third most frequent cause of fatalities at construction sites (4).

In the United States, the Federal Highway Administration (FHWA) publishes the *Manual on Uniform Traffic Control Signs (MUTCD)*, specifying national standards for road work signs and traffic control personnel deployment. Based on the *MUTCD*, many studies have been conducted to improve road work zone safety (5-8). In Japan, standards for construction safety facilities vary from one road administrator to another, and work zone safety improvement has been insufficiently studied. It is essential to discuss and propose effective measures for reducing traffic accidents and ensuring the safety of road construction personnel.

In previous studies, the authors surveyed contractors and road users (trucking companies) on their satisfaction with road work traffic safety measures (9). The survey showed that both traffic safety contractors and road users reported the greatest dissatisfaction with the understandability of road work signs, followed by the nighttime visibility of traffic control personnel (Table 1).

In light of this, the present study aims to improve the understandability of information displayed on road work signs and to examine measures to improve the nighttime visibility of road work zones, especially of the traffic control personnel in such zones. Toward the first goal, the study investigates the information that road users need from road work signs, the understandability of the information displayed by various types of road work signs, and the effect of sign type on driving behavior. Toward the second goal, the study examines light-emitting devices used at road work zones surveys the satisfaction of road users with such signs, and conducts experiments to examine the types and numbers of light-emitting devices at road work zones and to improve the nighttime visibility of traffic control personnel by using floodlights aimed at such personnel.

**TABLE 1 Road Work Traffic Safety Measures with the Lowest Satisfaction Rankings
(i.e., those necessitating priority improvement)**

	Traffic Safety Contractors	Road Users (Trucking Association)
1	Understandability of roadworks signs	Understandability of roadworks signs
2	Nighttime visibility of crash cushions	Nighttime visibility of traffic control personnel
3	Nighttime visibility of traffic control personnel	Nighttime visibility of roadworks signs
4	Nighttime visibility of roadworks signs	Understandability of internally illuminated roadworks signs
5	Number of roadworks signs	Daytime visibility of traffic control personnel

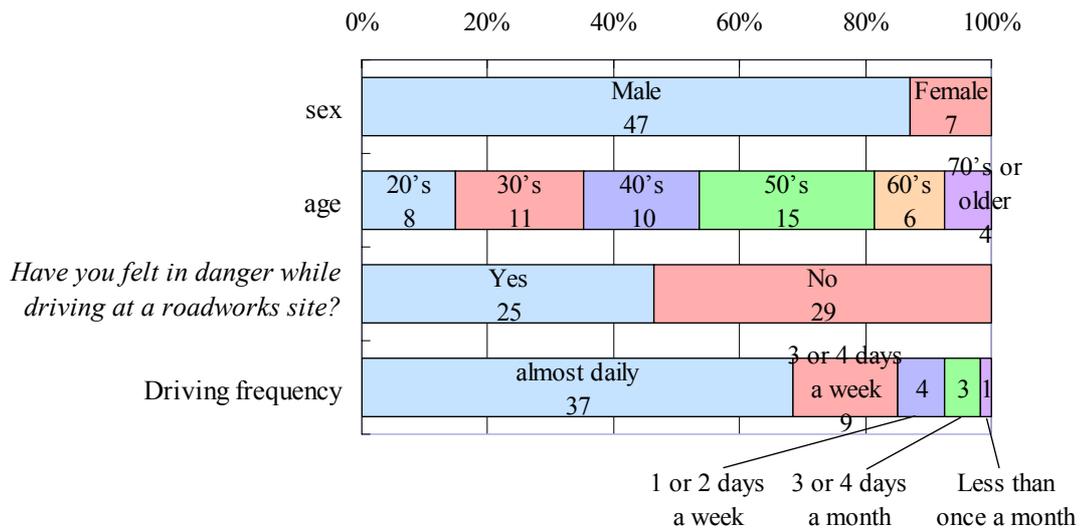
UNDERSTANDABILITY OF THE INFORMATION DISPLAYED ON ROAD WORK SIGNS

Survey of Information Needed from Road Work Signs

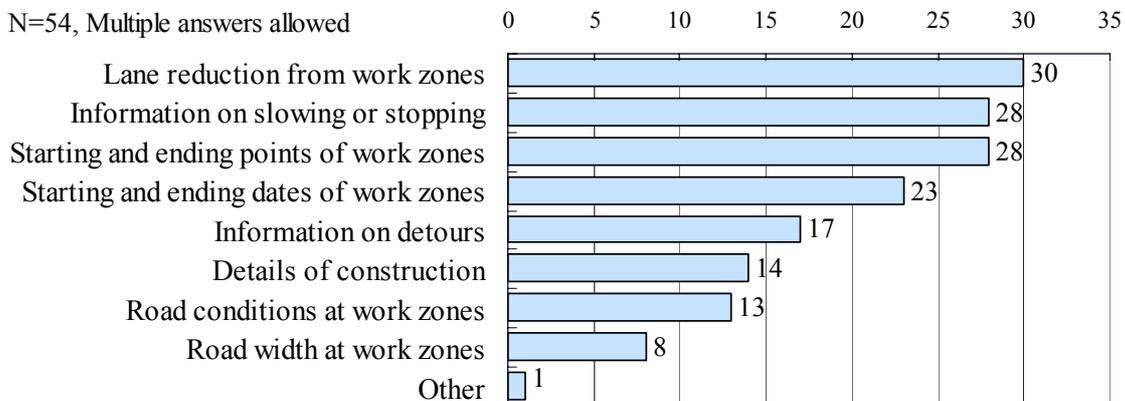
To determine what information road users want from road work signs, the authors surveyed drivers at the Road Information Center on National Route 230 in the suburbs of Sapporo on December 18, 2006. A questionnaire was handed to drivers at the Center and collected immediately after completion. Fifty-four drivers responded.

The majority of respondents are men. Respondents in their 50's make up the largest age group (Figure 1a). Seventy percent of respondents reported driving "almost daily," and 46% reported having felt in danger while driving at road work zones.

Figure 1b shows the responses to the question, *What information do you need from road work signs?* The most common response (30 out of the 54 respondents) is "lane reduction from road work," followed by "information on slowing or stopping" (28 out of 54), and "starting and ending points of road work" (28 out of 54). This demonstrates that the most needed information is on where to change lanes and at what speed to drive.



(a) Respondents' attributes



(b) *What information do you need from road work signs?*

FIGURE 1 Results of questionnaire

Effects of Sign Information Type on Driving Behavior

Outline

Drivers first recognize that road work is being conducted ahead from road work signs. Such signs that are easy to understand leave drivers extra time to think about their reactions and to allow them a sense of security in passing through road work zones. The survey above determined that information on where to change lanes before a road work zone is the most needed information for display on road work signs. Based on these results, an experiment was conducted on the effect of sign information type on driving behavior. It was done at the Tomakomai Winter Test Track on December 23, 2006.

Signs each with one of three displays were used. Sign 1 displays the text “LANE ENDS.” Sign 2 displays the text “LANE ENDS” and a pictograph of merging lanes. Sign 3 displays the text “MERGE 100 M AHEAD” and shows a pictograph of merging lanes.

The test roadway was designed to resemble a rural national highway with two lanes in each direction. In reference to the *Guidelines on Road Design* of the Hokkaido Regional Development Bureau, three consecutive zones were set up on the roadway: a “proceed with caution” zone, a lane-changing zone and a construction zone (Figure 2). Three sets of those zones were set up on the test track, with one of the three types of road work signs placed 100-m before the start of the lane-changing zone.

In the experiment, 28 subjects were asked to drive at 50 km/h on a 250-m test track from the starting point to the end of the construction zone. While the subject was driving, a data recorder and a video camera recorded driving speed, longitudinal acceleration, lateral acceleration, and the location of the start of lane change. Data were analyzed to examine where the test subject started to change lanes after seeing the road work sign, the minimum speed in the construction zone, and the speed reduction in the construction zone (i.e., normal speed minus minimum speed).

Results

Sign 1 (“LANE ENDS”) prompted the subjects to change lanes the most quickly, followed by Sign 2 (“LANE ENDS” plus a pictograph of merging lanes). Sign 2 prompted the slowest driving in the construction zone and the greatest speed reduction (Table 2). Sign 2 is regarded as prompting the safest driving.

After the experiment, the subjects were surveyed by questionnaire in order to determine the most understandable display of information from the three types of sign displays generally used in Japan: short text, short text and pictograph, and longer text and pictograph. The subjects reported the short text sign as the easiest to understand, followed by the short text and pictograph sign. Only 14% of the respondents answered that the sign with longer text and pictograph is easy to understand (Figure 3). This indicates that the road work signs that are easy to understand are simple ones with short text, rather than over-polite ones with long text.

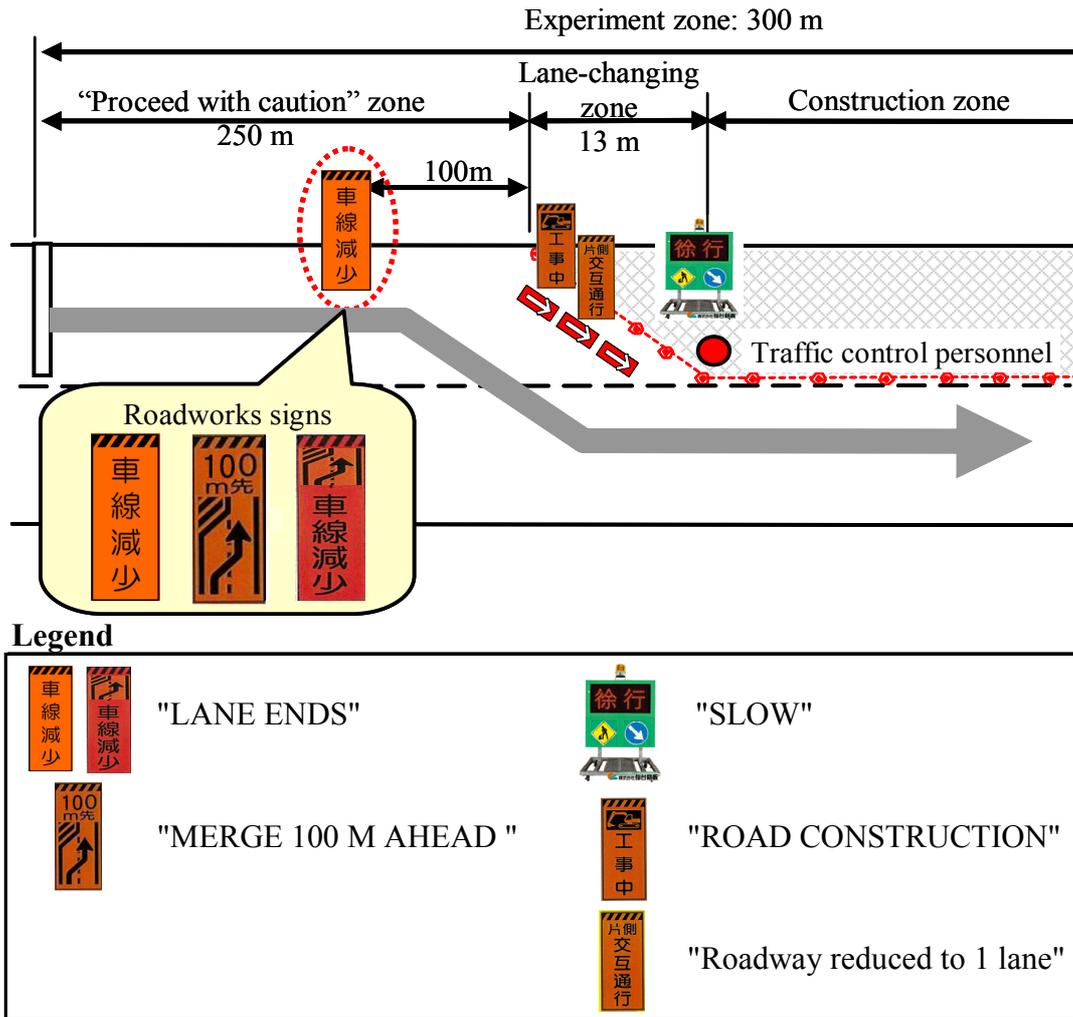
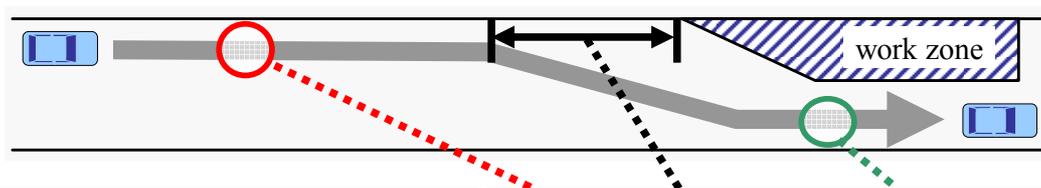


FIGURE 2 Experiment setup for effect of sign information type on driving behavior

TABLE 2 Experiment Results for Effect of Sign Information Type on Driving Behavior



	Sign display	Normal speed (a) (km/h)	Location of lane change start (m)	Min. speed at construction zone (b) (km/h)	Speed reduction (a - b) (km/h)
N=28	LANE ENDS	47.7	176.5	43.1	4.6
	LANE ENDS + pictograph	47.2	163.7	39.5	7.7
	MERGE 100 M AHEAD + pictograph	45.2	124.7	41.6	3.6

Notes: All numbers are mean values.

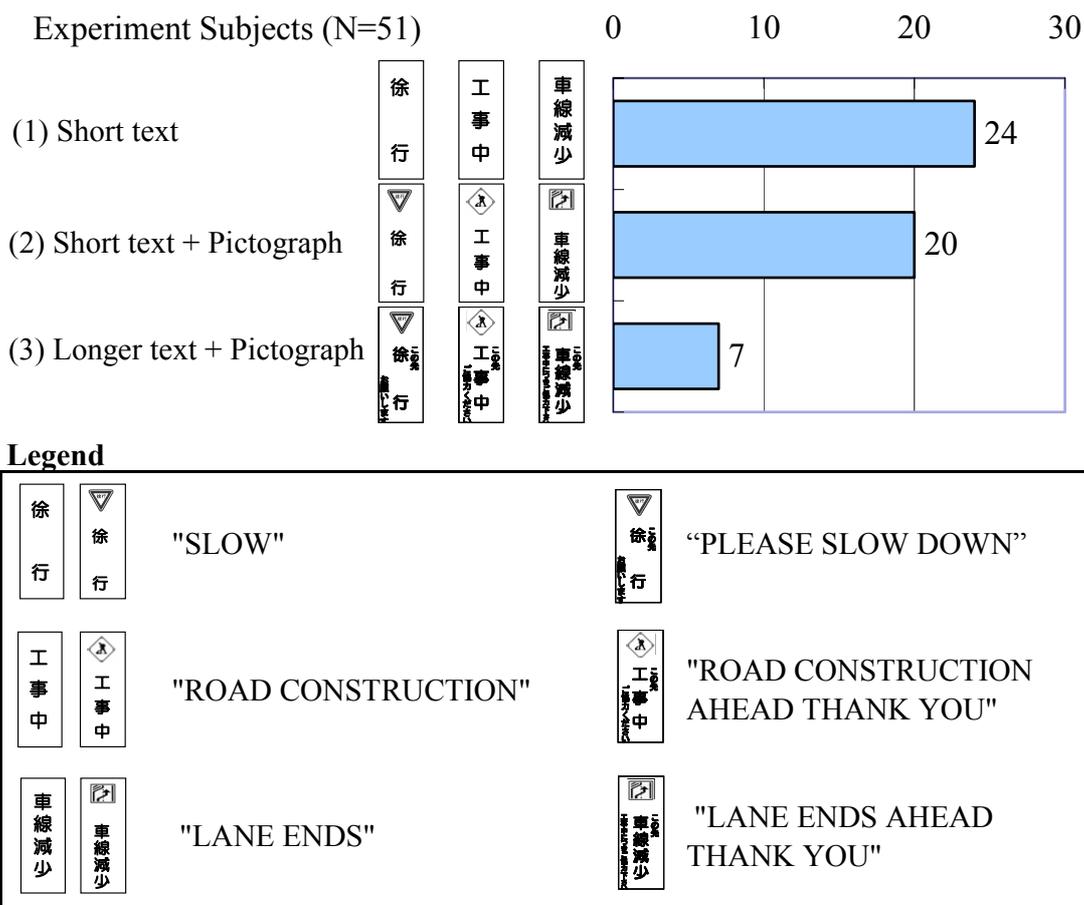


FIGURE 3 Which sign is the easiest to understand?

IMPROVING THE NIGHTTIME VISIBILITY OF ROAD WORK ZONES

Survey on Installation of Light-Emitting Devices at Road Work Zones

The next sections discuss measures for improving the nighttime visibility of road work zones, because drivers' satisfaction with nighttime visibility at such zones was low in past surveys and it was considered that nighttime visibility needed priority improvement. In light of this, types and numbers of light-emitting devices used at road work zones were surveyed at nine road work zones on national highways in Hokkaido (Table 3).

The *Guidelines on Road Design* of the Hokkaido Regional Development Bureau specifies internally illuminated road work signs as the standard road work sign. These are signs in which an enclosed light source shines through a semi-transparent film (Figure 4a). It was found that all of the surveyed work zones were installed with LED road work signs that were brighter than internally illuminated road work signs (Figure 4b), and that in rural areas, revolving lights were used in combination with the LED road work signs. At a work zone on Route 453, a traffic control personnel was illuminated by a floodlight aimed at him to improve his visibility (Figure 4c).

TABLE 3 Survey Location

Location	Description		Light-Emitting Devices		
	Number of lanes	Area	Roadworks Signs		Other Devices
			Types	Numbers	
1. Natl. Rte. 12 (Azuma Bridge)	4	Urban area	LED	1	None
2. Natl. Rte. 230 (Kawazoe)	6	Urban area	LED	1	None
3. Natl. Rte. 275 (Higashi-kariki)	4	Urban area	LED	1	None
4. Natl. Rte. 274 (N33E1)	5	Urban area	LED	1	Revolving light
5. Natl. Rte. 235 (Aza-seppu, Niikappu, Niikappu-gun)	2	Rural area	LED	2	LED roadworks sign
6. Natl. Rte. 235 (Aza-seppu, Niikappu, Niikappu-gun to Hokusei-cho, Niikappu)	2	Rural area	LED	2	400 m in front of the construction zone
7. Natl. Rte. 453 (Tokiwa)	2	Rural area	LED	1	Revolving light
8. Natl. Rte. 276 (Maruyama, Tomakomai)	2	Rural area	LED	1	Revolving light
9. Natl. Rte. 453 (Shikotsu lakeside)	2	Rural area	LED	1	Revolving light, Spotlight aimed at personnel



(a) Internally illuminated road work sign



(b) LED road work sign



(c) Example of lighting traffic control personnel by aimed floodlight

FIGURE 4 Light-emitting devices at road work zones

Questionnaire Survey on Nighttime Visibility at Road Work Zones with Light-Emitting Devices

An earlier opinion survey at the Road Information Center on the information displayed by road work signs addressed nighttime visibility at work zones with light-emitting devices, and problems related to such work zones. Drivers were asked, *Have you had any problems with light-emitting road work signs or revolving lights at road work zones?* Eighty percent answered “yes.” To the follow-up question, *What problems?*, the respondents were asked to choose problems that they had experienced from those listed in Figure 5 (multiple responses allowed.) The most common response was, “The light-emitting devices were too bright” (55%), followed by “The positioning of light-emitting devices made it hard to see the traffic control personnel” (45%), “Too many light-emitting devices make it hard for me to see the information I needed” (40%), “The LED road works signs were so noticeable that they distracted from the traffic control personnel and from the starting and ending points of road work zones” (40%) (Figure 5). The onsite survey found that LED road work signs tend to be brighter than the design specification and that they tend to be used in combination with revolving lighting. The survey indicates that such configurations do not necessarily improve nighttime visibility.

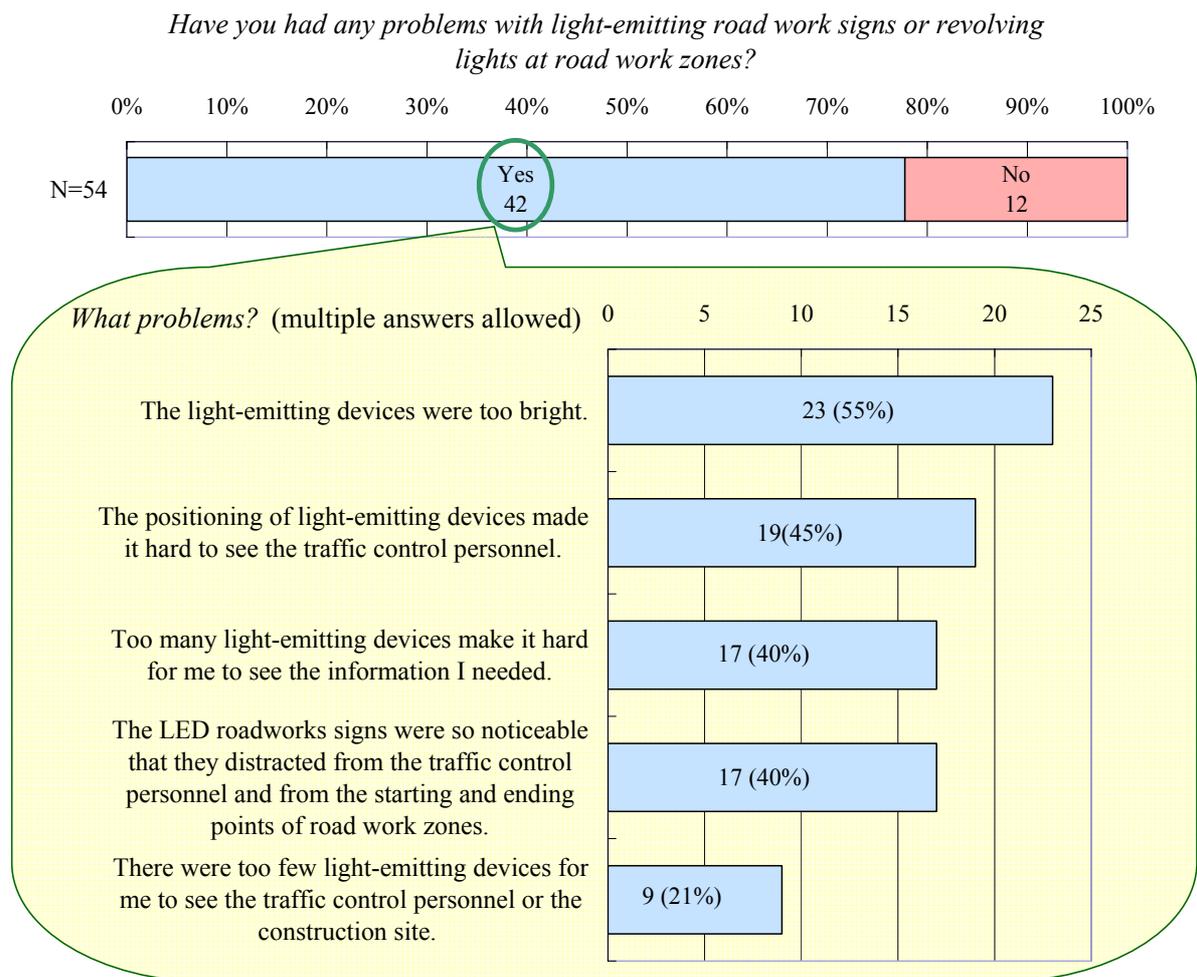


FIGURE 5 Problems with light-emitting devices at road work zones

Experiments at the Test Roadway

Outline

It is important for drivers to visually understand from road work signs that roadwork is ahead and from traffic control personnel that certain driving actions are required. In light of this, the following sections examine proper installation of light-emitting devices and visibility of traffic control personnel.

Based on the foregoing survey results, two experiments were conducted at the Tomakomai Winter Test Track on December 23, 2006. These experiments aimed to examine the proper installation configuration of light-emitting road work signs and the effect of a floodlight aimed at traffic control personnel on the visibility of such personnel. The method is described here.

The test roadway was designed to resemble a rural national highway with two lanes in each direction. In accordance with the *Guidelines on Road Design* of the Hokkaido Regional Development Bureau, three consecutive zones were set up on the roadway: a “proceed with caution” zone, a lane-changing zone, and a construction zone (Figure 6). Four sets of those zones were set up on the test roadway, with one of the four types of light-emitting road work signs for each setup. A traffic control personnel was positioned at the starting point of the construction zones in a pose indicating to drivers that they should stop.

Fifty-one subjects – 10 each in their 20’s, 30’s, 40’s and 50’s, and 11 in their 60’s – were recruited from the public. Twenty-five of the subjects participated in an experiment on light-emitting road work signs, and the remaining 26 in an experiment on floodlights aimed at traffic control personnel. After driving on the experimental roadway, the subjects were surveyed by questionnaire on the nighttime visibility of traffic control personnel and the sense of safety when driving in the road work zone.

Proper Installation of Light-Emitting Road Work Signs

To determine which installation configuration of light-emitting road work signs afforded the greatest visibility of traffic control personnel and the greatest sense of driving safety, four lighting configurations were set (Table 4): Configuration A uses an internally illuminated road work sign, based on the *Guidelines on Road Design*; Configuration B uses an LED road work sign; Configuration C uses an LED road work sign plus a revolving light, a combination that was often found in the onsite survey; and Configuration D uses two LED road work signs with different messages plus a revolving light. To eliminate the influence of driving order, 13 of the 25 test drivers were asked to drive in order of Configuration A, B, C, and D, and the remaining 12 test drivers were asked to drive in order of Configurations C, D, A, and B. And to eliminate the influence of lights from other vehicles, test drivers started driving after the experimenter confirmed that there were no other test vehicles ahead.

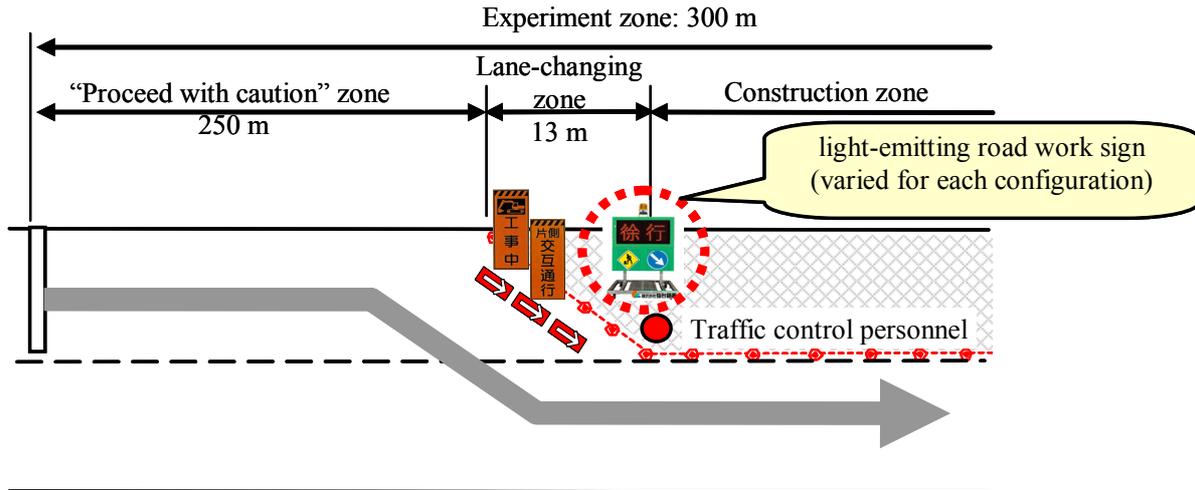
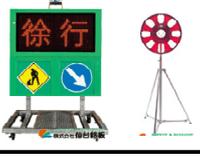


FIGURE 6 Experiment setup for experiments on proper installation of light-emitting road work signs

TABLE 4 Facilities Used in the Experiments on Proper Installation of Light-Emitting Road Work Signs

Configuration	Facilities varied between configurations	Facilities not varied between configurations	Number of subjects
A		roadworks signs  	25
B			25
C			25
D			25

Legend

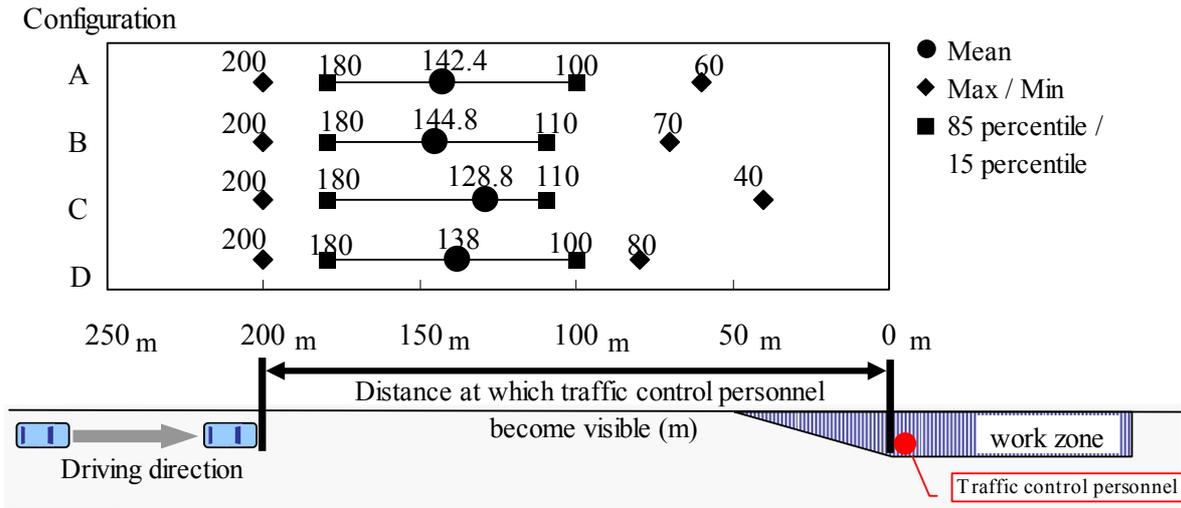
	"SLOW"		"ROAD CONSTRUCTION"
	"ROAD CONSTRUCTION"		"Roadway reduced to 1 lane"

Quantitative Evaluation of the Visibility of Traffic Control Personnel For each lighting configuration, the distance at which a subject recognized the traffic control personnel was measured. The subjects were asked to drive at 50 km/h and to vocally indicate when they recognized the personnel. A researcher sitting in the rear seat recorded the distance of the car from the traffic control personnel, using marks installed at the road shoulder at 10-m intervals.

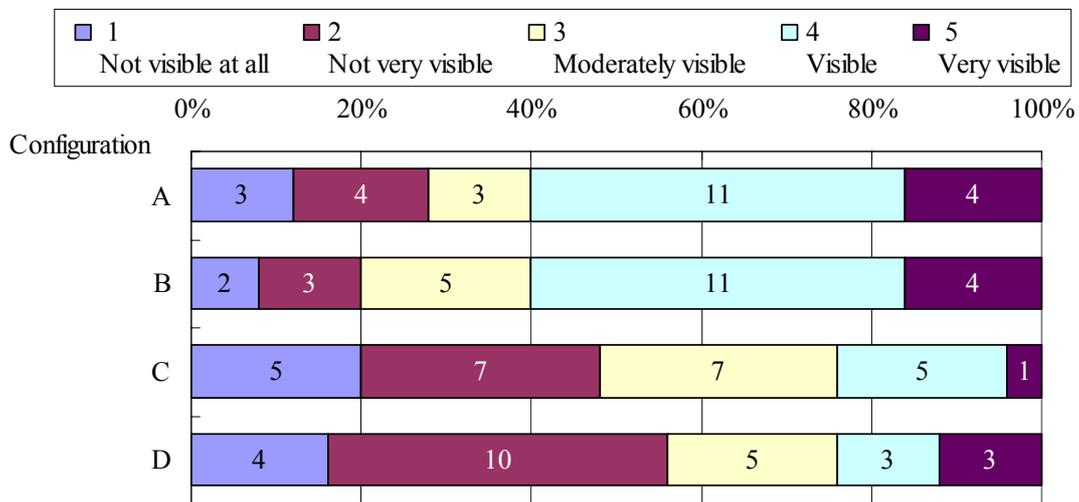
Configuration B afforded the greatest recognition distance between test driver and traffic control personnel (Figure 7a). However, difference in recognition distance among all configurations did not differ greatly. This confirms that when LED road work signs are used, adding additional lights of other types does not necessarily improve the visibility of traffic control personnel.

Post-Experiment Questionnaire Results After driving, the subjects were asked, *How visible was the traffic control personnel?* and *How safe did you feel to drive in the road work zone?* They were asked to answer on a 5-point scale, from “not visible at all” or “not safe at all” (1) to “very visible” or “very safe” (5).

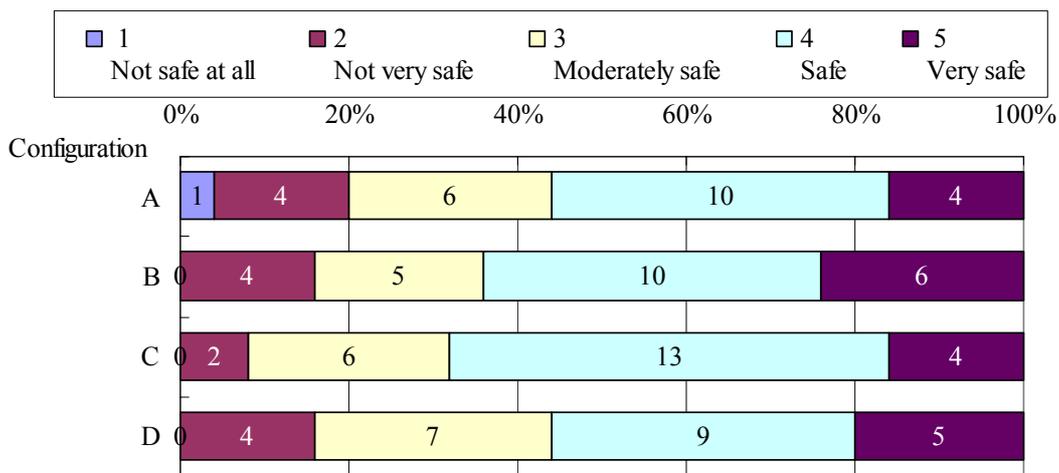
To the question, *How visible was the traffic control personnel?*, the numbers of respondents who answered “very visible” and “visible” for Configurations A and B, which had only one light-emitting road work sign, were much greater than those for Configurations C and D, which had more than two light-emitting road work signs. (Figure 7b). To the question, *How safe did you feel to drive in the road work zone?*, 1 subject responded “not safe at all” for Configuration A (Figure 7c). This indicates that one internally illuminated road work sign is not enough to make drivers feel safe, even though such a sign fulfills the specifications in the *Guidelines on Road Design*. But Configurations A and B did not differ greatly in terms of visibility of traffic control personnel, and internally illuminated road work signs are more economical to procure than LED road work signs. It is preferable to set up a minimum number of light-emitting road work signs and to choose that type of sign for road work zones in areas with low traffic volume or in rural areas.



(a) Distance at which traffic control personnel become visible



(b) How visible was the traffic control personnel?



(c) How safe did you feel to drive in the road work zone?

FIGURE 7 Results of experiments on proper installation of light-emitting road work signs

Using a Floodlight Aimed at Traffic Control Personnel to Improve Their Visibility

The survey examined the visibility of traffic control personnel under different lighting configurations, including one in which a floodlight was aimed at the traffic control personnel. (Figure 4c). And the questionnaire survey at the Road Information Center found that improper positioning of light-emitting road work signs made it hard to see the traffic control personnel.

In consideration of the finding that increasing the number of light-emitting road work signs does not always improve the visibility of traffic control personnel and the sense of driving safety, another survey was conducted to assess the visibility of traffic control personnel and the sense of driving safety in a work zone when the traffic control personnel are lit up by floodlight.

The experimental setup has four configurations: (I) floodlight, (II) floodlight plus floodlight aimed at traffic control personnel, (III) balloon light, and (IV) balloon light plus floodlight aimed at traffic control personnel (Table 5). The floodlight (Figure 8a) and balloon light (Figure 8b) cover the entire work zone; the floodlight aimed at the traffic control personnel (Figure 8c) focuses on the traffic control personnel. After driving, the subjects were asked to answer on a 5-point scale, from “not visible at all” or “not safe at all” (1) to “very visible” or “very safe” (5). Thirteen test drivers were asked, *How visible was the traffic control personnel?* and *How safe did you feel to drive in the road work zone?* for Configurations I and II, 26 test drivers were asked these questions for Configuration III, and 23 were asked for Configuration IV.

Configurations II afforded earlier recognition of traffic control personnel than Configuration I, and Configuration IV afforded earlier recognition of traffic control personnel than Configuration III. Configurations II and IV each used a floodlight aimed at the traffic control personnel (Figure 9a). Without a floodlight aimed at the traffic control personnel, some subjects failed to recognize the traffic control personnel until they had almost reached the personnel. But with a floodlight aimed at the traffic control personnel, all subjects recognized the traffic control personnel well before reaching the personnel. To the question, *How visible was the traffic control personnel?*, in which the respondents were asked to answer on a 5-point scale, fewer subjects responded “not visible at all” for Configurations II than for Configurations I, and for Configurations IV than for Configurations III (Figure 9b). To the question, *How safe did you feel to drive in the road work zone?*, more subjects responded that they felt “very safe” for Configurations II than for Configurations I, and for Configurations IV than for Configurations III (Figure 9c).

The experimental setup was designed to simulate a rural road work zone, with no surrounding buildings and no surrounding lights. The survey found that a floodlight aimed at the traffic control personnel improve the visibility of such personnel for a given work zone condition.

TABLE 5 Facilities Used in the Experiment on Using a Floodlight Aimed at Traffic Control Personnel

Configuration	Facilities varied between configurations		Facilities not varied between configurations	Number of subjects
	floodlight aimed at traffic control personnel	Light type		
I	no	floodlight	LED roadworks sign 	13
II	yes	floodlight	roadworks sign 	13
III	no	balloon light	traffic control personnel 	26
IV	yes	balloon light		23

Legend

	"SLOW"		"ROAD CONSTRUCTION"		"Roadway reduced to 1 lane"
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(a) Floodlight

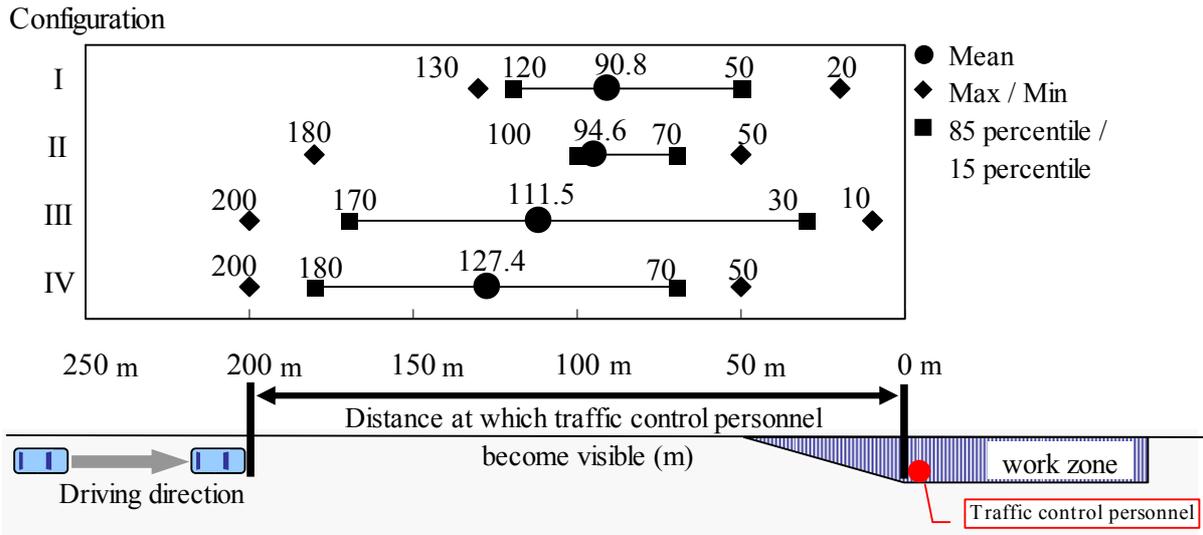


(b) Balloon light

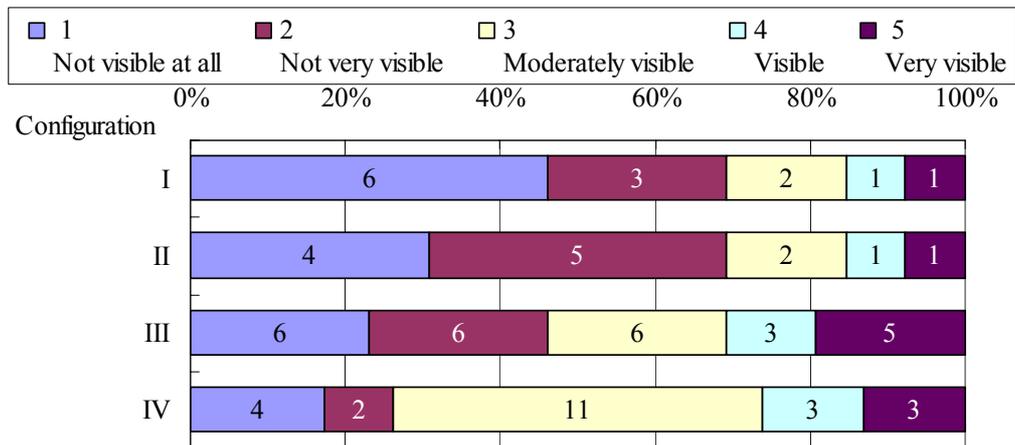


(c) Floodlight aimed at traffic control personnel

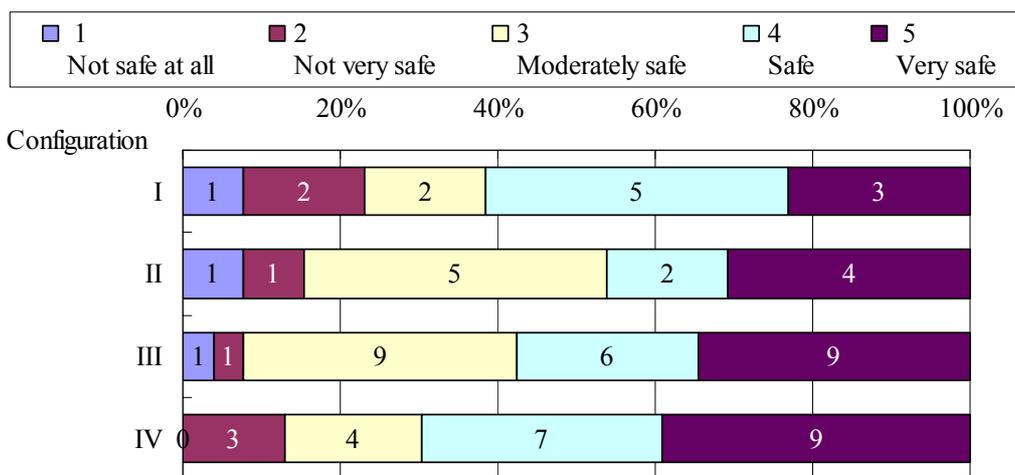
FIGURE 8 The three types of light used



(a) Distance at which traffic control personnel become visible



(b) How visible was the traffic control personnel?



(c) How safe did you feel to drive in the road work zone?

FIGURE 9 Results of experiment on using a floodlight aimed at traffic control personnel to improve the visibility of such personnel

CONCLUSIONS

This study suggests that clear signage that is not text heavy (e.g.: “LANE ENDS”) is the most effective at prompting drivers to change lanes. A questionnaire survey on types of information displayed showed that simple text with pictograph provides the greatest understandability. Clear, simple road work signs are more desirable than over-polite, over-detailed signs.

The survey on installation of light-emitting devices at road work zones and the questionnaire survey on visibility achieved by those devices found that the use of LED road work signs which are more luminous than the standard of the *Guidelines on Road Design* and the use of revolving lights in combination with light-emitting road work signs do not necessarily improve nighttime visibility at road work zones. And an experiment on proper installation of light-emitting road work signs confirmed that when LED road work signs are used, adding additional lights of other types does not necessarily improve the visibility of traffic control personnel. In addition, an experiment on improving the visibility of traffic control personnel demonstrated that a floodlight aimed at traffic control personnel can improve the visibility of such personnel at road work zones.

The experimental setup was designed to simulate a rural road work zone, with no surrounding buildings and no surrounding lights. Consequently, in some cases for a given work zone condition it may be more effective to light traffic control personnel with aimed a floodlight than with additional light-emitting devices. It is important to select the configuration that best suits each road work zone after consideration of economic efficiency.

The authors will further analyze these findings toward improving the safety of road work zones by examining safety measures that go beyond improvements to understandability of road work signs and to the nighttime visibility of traffic control personnel.

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