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DEVELOPMENT OF PRO-BEAM ROAD LIGHT

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Abstract

The present study proposes a road lighting system that uses pro-beam light distribution. The visibility of a pedestrian who is crossing the road and is illuminated by a conventional road light is known to depend on the relationship between the driver's position and the pedestrian's position. Pro-beam road lights are a fundamental solution to the problem of enhancing the visibility of pedestrians crossing the road. Based on the author's previous studies, the present study presents two novel types of pro-beam luminaires that incorporate LED lamps to show a slightly different light distribution and reveals the effects of these pro-beam road lights on the visibility of pedestrians crossing the road at night. The study conducted a field experiment to evaluate the visibility performance of these pro-beam road lights at a test track. The two types of pro-beam road lights were found to afford considerably greater visibility performance in the driving lane than conventional road lights provided.

Keywords: Pro-beam road lights, Visibility performance, Crossing pedestrian

1 Introduction

The Cabinet Office of the Japanese Government has set a target for reducing the annual number of traffic fatalities in which the death occurs within 24 hours after the accident to less than 2,500 by the year 2020 (1). Annual fatal accidents in Japan numbered 4,028 in 2015 (2). Fatal pedestrian-vehicle accidents numbered 1,474 in 2015. Of these fatal pedestrian-vehicle accidents, 548 occurred at mid-block locations, and 408 of those 548 occurred at night. To achieve the abovementioned target in Japan, it is required to reduce night time pedestrian-vehicle accidents at mid-block locations. Most pedestrian fatalities at mid-block locations result from the failure of the driver to detect the pedestrian at night (3). The visibility of pedestrians who cross highways at night should be improved. Japan has taken various measures to mitigate pedestrian fatalities. However, the number of pedestrian fatalities at night is falling more slowly than the numbers of other types of fatalities.

The pro-beam road light is oriented toward a traffic flow. The luminance under the pro-beam road light was constantly higher for targets on the road than for the background. Hagiwara (4) proposed a pro-beam road lighting system that allows pedestrians and obstacles on the road to be constantly seen as brighter than the background. The vertical illuminance exceeded 20 lx, which is sufficiently close to providing favorable detectability on the road. Hasson (5) indicated that pedestrians are more visible in positive contrast than in negative contrast. Pro-beam road lighting might have the potential to improve the positive visibility of pedestrians on the road. Hagiwara et al. (6) proposed a prototype pro-beam road light, and his group reported it to be effective at increasing the visibility performance on the road. However, the group's prototype pro-beam road light did not provide enough vertical illuminance in the opposing driving lane. Based on the results of subjective visibility assessments on a test track, they then proposed the following two types of pro-beam road lights to improve vertical illuminance in the opposing driving lane while minimizing the glare.

1) Type-A pro-beam road light: It is designed to provide high visibility performance by covering both the driving lane and the opposing driving lane, with the glare remaining below the maximum acceptable level.
2) Type-B pro-beam road light: It is designed to balance low glare and high visibility performance. It maintains high and stable vertical illuminance in the driving lane and the opposing driving lane while maintaining low glare.

In the present study, we developed luminaires incorporating LED lamps to achieve a light distribution that would achieve the lighting performance of pro-beam road lights of types A and B. Thus, the present study reveals the effects of the two types of pro-beam road lights on the visibility of pedestrians crossing the road at night. The study conducted a field experiment to evaluate the visibility performances of the type-A and the type-B pro-beam road lights on the test track. This experiment was under static conditions, with a stationary dummy pedestrian in front of the driver and the vehicle stopped at a predetermined position on the test track. The subjective visibility of the dummy pedestrian was evaluated by the participants on a test track.

2 Research Method

2.1 Road Alignment and Locations of Luminaires on the Test Track

The experiment location was the test track of Iwasaki Electric Co., Ltd. in Tsukuba, Japan. This test track was selected mainly because it is installed with full-scale instruments for road lighting. Figure 1 shows the road alignment of the test track. The test track consists of a highway with one lane in each direction. The width of each lane is 3.5 m, and the width of the sidewalk is 4.0 m. There were three lamp posts on each side of the road. The height of the luminaire was 8.0 m, the luminaire spacing between P1 and P2 was 30 m, and the luminaire spacing between P2 and P3 was 35 m. The same three lamp posts were installed at the same positions on the road. The road surface was conventional asphalt pavement from the left-end side of the road to a longitudinal point 5.0 m short of the P3-P6 line and high-performance asphalt from a point 5.0 m short of the P3-P6 line longitudinally to the right-end side.

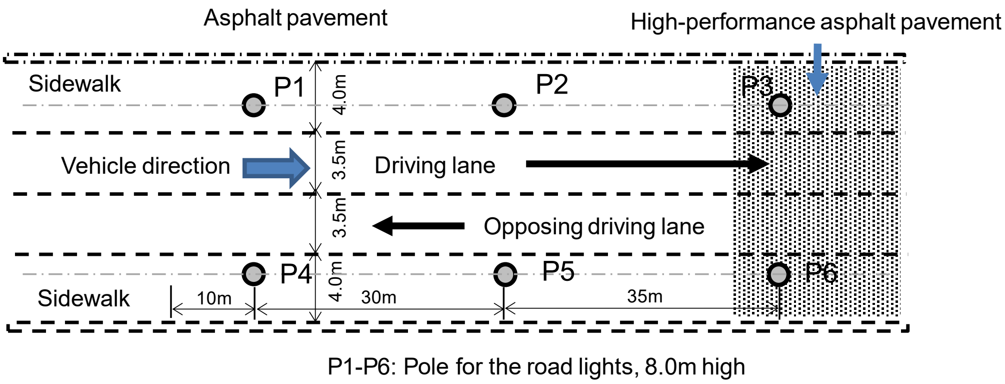


Figure 1 – The road alignment of the test track and the configurations of the six lamp posts

2.2 Lighting Distribution of the Two Types of Pro-beam Road Lights

In the present study, we designed and produced luminaires equipped with an LED module with a lens to achieve the performances of the type-A and type-B pro-beam road lights. Figure 2 shows the appearance of the luminaire that was produced in the present study, which is able to provide light distributions for both type-A and type-B pro-beam road lights. There are 12 units per case, with each unit containing the same four LED modules, each with a lens. There are three different types of units, each containing different LED modules with a lens: narrow-angle beam (8 deg.), middle-angle beam (16 deg.) and wide-angle beam (28 deg.) (Figure 2). Each unit has a different irradiation angle to satisfy the light distribution of the type-A and type-B pro-beam road lights.

Table 1 shows the optical properties of the two types of pro-beam road lights produced in the present study, which are designed to fulfill the criteria defined in “Road Lighting Installation Standards 2007” of Japan (7). Figure 3 shows the results of averaged measured vertical illuminance at the height of 0.8 m without low beams for each of the two types of pro-beam road lights as a function of the lanes. These measurements were made on the section between P2 and P3 over the illuminated area in Figure 1. There were small differences in average vertical luminance between type-A and type-B for the driving lane. In contrast, the average vertical luminance of type-A was much higher than that of the type-B for the opposing driving lane. This is consistent with the concept of each of the two types of pro-beam road lights.

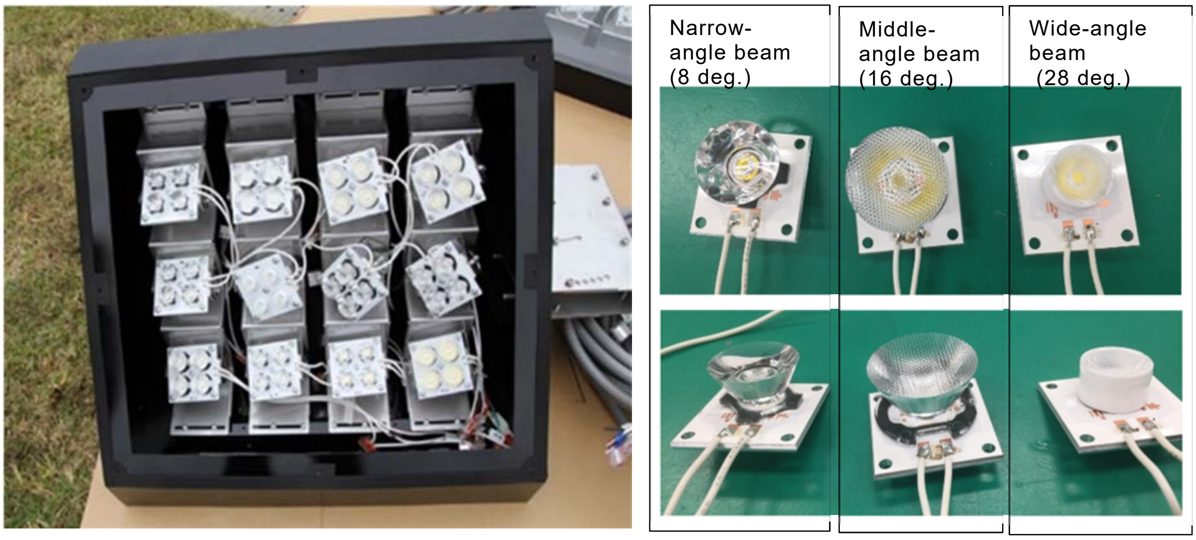


Figure 2 – Appearance of the luminaire for the two types of pro-beam road lights developed for the present study

Table 1 – Optical properties of the two types of pro-beam road lights

	Type-A	Type-B
Rated luminus flux (lm)	4385	4385
Color rendering index	82	82
Light-source color(K)	4000	4000
Measured luminance		
Average luminance (cd/m^2)	1.82	1.56
Overall luminance uniformity on the road	0.45	0.42
Longitudinal luminance uniformity within the driving lane	0.56	0.49
TI value (%)	11.4	6.0
Measured vertical illuminance at 0.8m high		
Average illuminance on the driving lane (lx)	22.3	20.3
Average illuminance on the opposing driving lane (lx)	25.8	16.6

(A) Type-A pro-beam road light (B) Type-B pro-beam road light

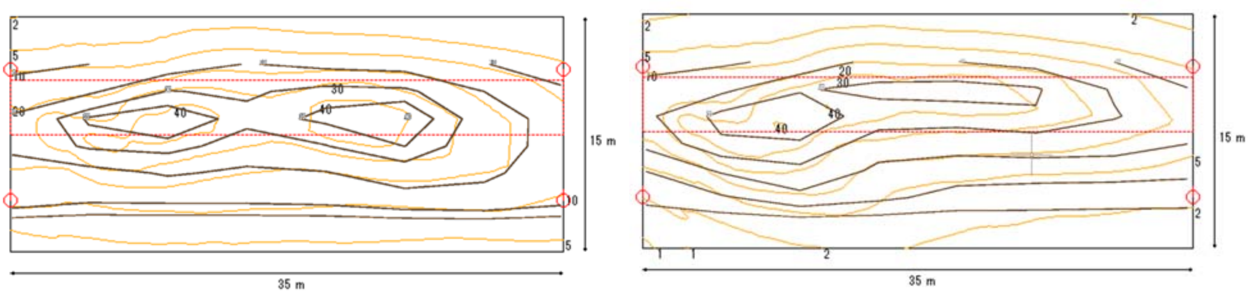


Figure 3 – Distribution of vertical illuminance at the height of 0.8 m for the two types of pro-beam road lights

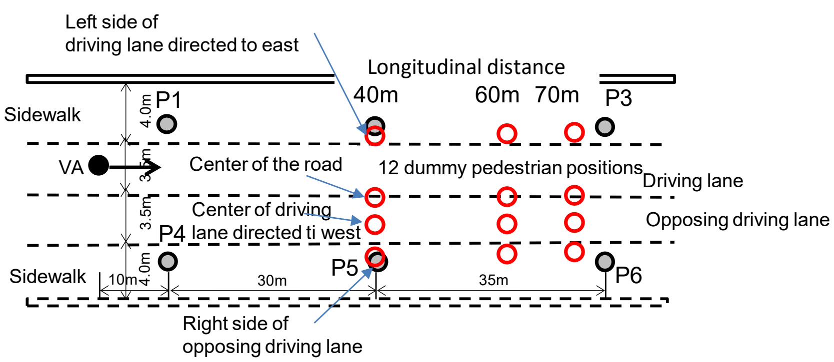
2.3 Experimental Date and Participants

The experiment was carried out in October 2017. The weather was completely clear, and the road surface was completely dry during the experiment. The 16 drivers who participated were in their early 20s and were students at Utsunomiya University. They were screened to ensure that they were active drivers with a valid Japanese driver's license and normal vision. At the beginning of the experiment, the experimenters spent 30 minutes explaining the schedule, the experimental overview and the visibility evaluation tasks to be performed during the experiment, the risks of the experiment, the cancellation policy and emergency procedures. When the explanation was complete, the participants gave written informed consent of participation. No individual declined to participate. The research methodology was approved by the Ethical Review Committee for Research with Human Subjects in the Engineering Course of Hokkaido University, Japan.

2.4 Dummy Pedestrian and Vehicle Position

A dummy pedestrian was used as a target on the road to simulate a pedestrian crossing the road as seen by a driver. The shape of the dummy pedestrian imitates the profile body silhouette of a person crossing the road (165 cm high). The dummy pedestrian was covered in light gray paper with a reflectivity of 23%. Figure 4 shows the vehicle position and the dummy pedestrian's position on the test track. There are two driver positions: the two vehicle positions of VA and VB. There are 12 dummy pedestrian positions for each of the two vehicle positions (Figure 4(A) and 4(B)). There are three longitudinal distances between the vehicle and the dummy pedestrian. There are four lateral positions at each longitudinal distance: the left side of the driving lane, the center of the road, the center of the opposing driving lane and the right side of the opposing driving lane.

(A) Vehicle position of VA



(B) Vehicle position of VB

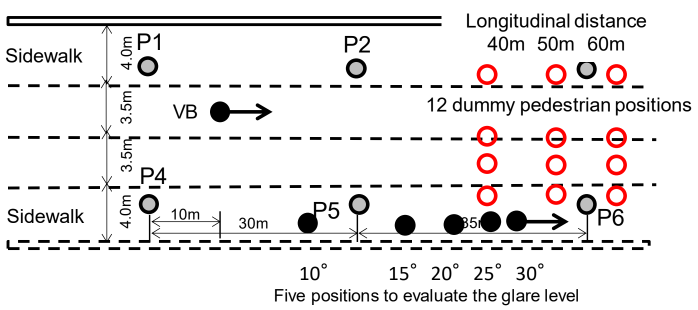


Figure 4 – The two vehicle positions of VA and VB and the positions of the 12 dummy pedestrians for each vehicle position (VA or VB) on the test track

2.5 Subjective Visibility Assessments

There were two subjective assessment items as the dependent variables: a visibility assessment of the dummy pedestrian and a severity assessment of the road light glare. The participants evaluated the visibility on a scale from 1 ("low") to 7 ("high"). The participants evaluated the glare of the road lights on a scale from 1 ("not severe") to 9 ("extremely severe") . The five positions from which the subject evaluated the glare level corresponded to the angles of attack of 10 degrees, 15 degrees, 20 degrees, 25 degrees and 30 degrees (Figure 4).

2.6 Experimental Design

The study employed a repeated-measures design as the experimental design. The independent variables were the two types of pro-beam lights, and the two vehicle positions. There were 12 positions for the dummy pedestrian (Figure 4). Combinations of the 12 positions for the dummy pedestrian at each of two vehicle positions were randomly assigned to a sequence of treatments for each participant.

2.7 Experimental Procedure

The participants were instructed on how to assess the visibility level of the dummy pedestrian. Before starting the visibility evaluation, one of the participants sat in the driver's seat and another in the assistant driver's seat. To replicate driving conditions, a black curtain was suspended in front of the vehicle. The experimenter lowered the black curtain in order to allow the participants to see the pedestrian ahead. The exposure time was approximately 3 sec. Once the curtain was raised again, the participants had to answer a questionnaire about the visibility of the standing pedestrian. After finishing all 12 visibility assessments, the participants assessed the glare at each of the two vehicle positions. While viewing the dummy pedestrian located at the center of the road 60 m ahead of the vehicle, the participants evaluated the glare. During the visibility assessment, the participants stood still at the five positions on the right sidewalk shown in Figure 4 and evaluated the glare for each of the two types of pro-beam road lights.

3 Results

3.1 Results of Measured Vertical illuminance

Table 2 shows the results of measured luminance and vertical illuminance with the low beams under the proposed pro-beam road lights and conventional road light. The values of vertical illuminance under both pro-beam road lights were approximately 10(lx) or over. However, when the distance was 40m for vehicle position VA, the values of vertical illuminance with the conventional road lighting were less than 5(lx). The pro-beam road lights could indicate high vertical luminance and also provide uniform distribution of vertical luminance rather than those by the conventional road lights.

Table 2 – Results of measured vertical illuminance with the low beams under the proposed pro-beam road lights and the conventional road light

(A) VA: Position of the vehicle					
Type of road light	Distance (m)	Left side of the driving lane	Center of the road	Center of the opposing driving lane	Right side of the opposing lane
Conventional	40	1.94	1.68	1.63	NA
Type A		6.9	21	20.8	18.3
Type B		6.02	17.2	11.2	4.93
Conventional	60	7.56	10	9.19	NA
Type A		17.5	36.2	29.8	19.4
Type B		20.1	25.1	12.9	6.43
(B) VB: Position of the vehicle					
Type of road light	Distance (m)	Left side of the driving lane	Center of the road	Center of the opposing driving lane	Right side of the opposing lane
Conventional	40	10	12.6	11.3	NA
Type A		17.5	36.2	29.8	19.4
Type B		20.1	25.1	12.9	6.43
Conventional	60	26.9	43	35.1	NA
Type A		10.4	31.9	34.4	18.6
Type B		9.2	29.7	29	13.3

3.2 Results of Subjective Visibility Assessments

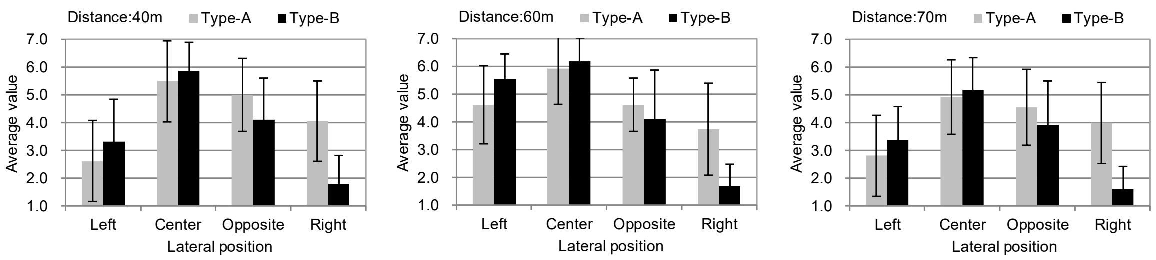
3.2.1 VA position

Figure 6(A) shows the average and the standard deviation of subjective visibility from the VA vehicle position to each of the 12 dummy pedestrian positions (n: 16) for each of the pro-beam road light types. Most of the average values of subjective visibility as evaluated at the 12 dummy positions exceed 4 for each of the pro-beam road light types, except when the dummy pedestrian is at the left or the right roadside. The average subjective visibility values at the right side of the opposing driving lane are higher for the type-A pro-beam road light than for the type-B pro-beam road light. The average values of subjective visibility are particularly reduced when the dummy pedestrian is at the right roadside for the type-B pro-beam road light.

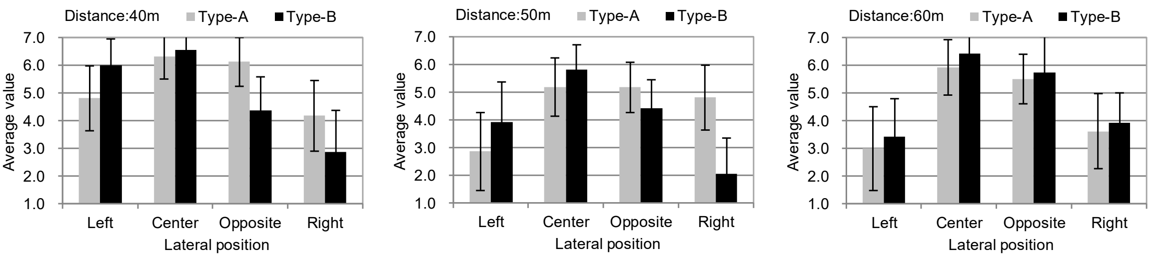
3.2.2 VB position

Figure 5(B) shows the average and the standard deviation of subjective visibility from the VB vehicle position to each of the 12 dummy pedestrian positions (n: 16) for each of the pro-beam road light types. Similarly, most of the average values of subjective visibility evaluated at the 12 dummy positions exceed 4 for each of the pro-beam road light types, except when the dummy pedestrian is at the left or right roadside. The average subjective visibility values at the right side of the opposing driving lane are higher for the type-A pro-beam road light than for the type-B pro-beam road light.

(A) VA position



(B) VB position



Note: Left means the left side of the driving lane, Center means the center of the road, Opposite means the center of opposing driving lane, and Right means the right side of the opposing driving lane.

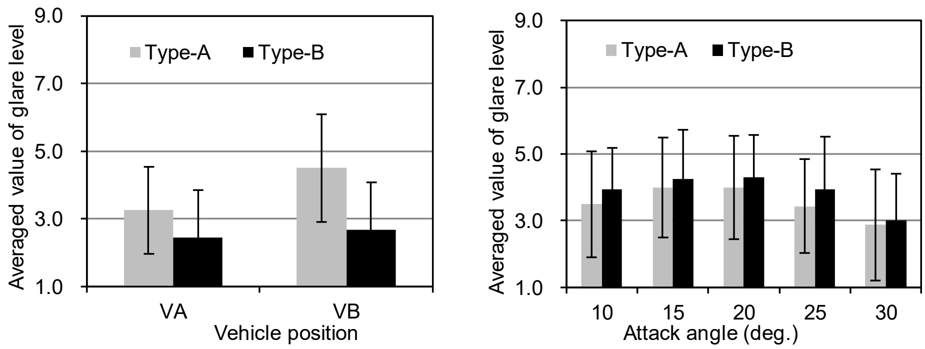
Figure 5 – Average subjective visibility values from the two vehicle positions to each of the 12 dummy pedestrian positions (n: 16) for each of the two road lighting systems

3.3 Results of Glare Assessments

Figure 6(A) shows the average subjective ratings of glare at the VA and VB vehicle positions for each of the pro-beam road light types. The measured glare increases with increase in the subjective glare rating. The average values of glare at the VA and the VB vehicle positions for the type-A pro-beam road light are significantly greater than those for the type-B pro-beam road light. The glare for the type-A pro-beam road light is close to 5 (severe) at the VB vehicle position. It should be noted that the TI value of the type-A pro-beam road light is around 6% at the VA and VB vehicle positions, and that of the type-B pro-beam road light is around 3%. The percentage increment of the detection threshold caused by disability glare in road lighting is quantified by using the value of threshold increment (TI) (8). It can be calculated based on the equivalent veiling luminance and the average road luminance.

Figure 6(B) shows the average glare at each of the five positions on the sidewalk for each of the pro-beam road light types. All of the subjective glare ratings for each of the pro-beam road light types are less than 4 (midway between "somewhat severe" and "severe"). The average values of glare at the five positions for the type-B pro-beam road light are higher than those for the type-A pro-beam road light. Whereas the maximum TI value for the type-A pro-beam road light is 17% at a 15-degree angle of attack, the maximum TI value for the type-B pro-beam road light is 24% at the same angle of attack. This is because the light intensity on the sidewalk for the type-B pro-beam road light is higher than that for the type-A pro-beam road light.

(A) The two vehicle positions (B) Pedestrian on the sidewalk



4 Conclusions

The present study assessed the visibility of crossing pedestrians for two types of pro-beam road lights on a test track. Pro-beam luminaires incorporating LED lamps to provide light distributions that fulfill the lighting performance of type-A and type-B pro-beam road lights were examined. Subjective visibility assessments on the test track were conducted for the two types of pro-beam road lights. Under a static condition using the dummy pedestrian described in the previous section, subjective visibility assessments for the crossing pedestrian on the road ahead were acceptably high and were uniformly distributed for each of the two types of pro-beam road lights. The type-A pro-beam road light afforded high vertical illuminance and achieved high visibility for a pedestrian in the opposing driving lane on the test track.

Based on the results of the present study, each of the two types of pro-beam road lights was found to afford considerably stable visibility performance in the driving lane than conventional road lights afforded. The pro-beam road lights provided enough vertical illuminance in both the driving lane and the opposing driving lane, and the glare was at an acceptable level. It can be concluded that the pro-beam road light is effective at increasing the visibility performance of a pedestrian crossing the road. In the near future, we should perform a feasibility study on the pro-beam road light on a city street where collisions involving vehicles and crossing pedestrians occur in large numbers, in order to field-test the effectiveness of the pro-beam road light.

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