TECHBRIEF

Pedestrian and Bicycle Safety

Investigating Improvements to Pedestrian Crossings with an Emphasis on the Rectangular Rapid-Flashing Beacon

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FHWA Contact: Ann Do, HRDS-30, (202) 493-3319, ann.do@dot.gov

This document is a technical summary of the Federal Highway Administration report *Investigating Improvements to Pedestrian Crossings with an Emphasis on the Rectangular Rapid-Flashing Beacon* (FHWA-HRT-15-043).

OBJECTIVE

The goal of this research effort was to improve pedestrian safety at urban and suburban crossing locations by identifying and evaluating low- to medium-cost pedestrian treatments. The treatments were to have the potential to reduce pedestrian crashes at both midblock and intersection locations. While several treatments were considered during early efforts of this project, later tasks focused on the rectangular rapid-flashing beacon (RRFB). The RRFB has received extensive national attention because of high yielding rates observed at multiple installations, and several studies have found increased driver yielding after installing this device.

The key research effort for this study included a closed-course study and an open-road study. The objectives of the closed-course study were as follows:

- Determine whether the shape, size, and placement of flashing beacons/light-emitting diodes (LEDs) affect sign legibility distances and object detection.
- Determine driver ratings of disability glare for 8-inch circular beacons and LED-embedded signs using a rapid flash pattern.

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

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- Identify up to two assemblies for field evaluation to be conducted following the conclusion of the closed-course tasks.

The objectives of the open-road study were as follows:

- Determine whether drivers yielded differently to circular or rectangular beacons when used with a rapid-flashing pattern.
- Determine to what extent, if any, a driver is more likely to yield to a pedestrian when the rapid-flashing beacon is activated than when it is not activated.
- Determine whether vehicle traffic volume affects driver yielding.

INTRODUCTION

Several methods have been used to emphasize the presence of a pedestrian in a crossing, including methods with beacons or embedded LEDs. A device that has received national attention is the rectangular rapid-flashing beacon. On July 16, 2008, the Federal Highway Administration (FHWA) provided interim approval (IA-11) for the optional use of the RRFB.[1] FHWA approved the use of this device at pedestrian and school crosswalks across uncontrolled approaches. As defined in IA-11, "An RRFB shall consist of two rapidly and alternately flashing rectangular yellow indications having LED-array based pulsing light sources, and shall be designed, located, and operated in accordance with the detailed requirements specified [within the interim approval]."[1]

The Signals Technical Committee of the National Committee on Uniform Traffic Control Devices (NCUTCD) makes recommendations to FHWA regarding the provisions of Part 4 of the *Manual on Uniform Traffic Control Devices* (MUTCD). They are interested in research and/or assistance in developing material on the RRFB for inclusion in future editions of the MUTCD. Earlier research studies did not address certain issues that the Signals Technical Committee believes to be important to crafting language suitable for creating a uniform standard. The Signals Technical Committee sought advice on several issues, including the following:

- Do the housings have to be rectangular?
- Will circular-shaped housings achieve the same effect?

As a result of FHWA providing interim approval (IA-11) for the optional use of RRFBs and the NCUTCD's interest in addressing issues such as beacon shape, this research focused on RRFBs and circular rapid-flashing beacons (CRFB).

METHODOLOGY

Early Tasks

Efforts within the initial phase of this project included a comprehensive literature review of pedestrian treatments being used at unsignalized intersections. A review of pedestrian crash datasets was conducted to document the characteristics, circumstances, and contributing factors for crashes at midblock pedestrian crossings and to assess the suitability of these databases for any safety evaluations to be conducted in the research.

Pedestrian crash data from a variety of sources were reviewed—including data from the National Highway Traffic Safety Administration, Fatality Analysis Reporting System (FARS), and General Estimates

System, and from the State datasets of California, Minnesota, North Carolina, Ohio, Texas, and Washington—to document the characteristics, circumstances, and contributing factors for crashes at midblock pedestrian crossings. The FARS data included only pedestrian fatalities; the other datasets included pedestrian crashes of all severity levels. Key findings from the datasets include the following:

- The proportion of total pedestrian crashes that occurred at midblock locations ranged from 29 to 73 percent.
- Of the midblock crashes, 0.7 to 5.0 percent occurred at midblock crosswalks.
- FARS data indicate that nearly one-third of the midblock pedestrian fatalities that do not occur at midblock pedestrian crosswalks occurred near midblock pedestrian crosswalks. (None of the other datasets included a category for pedestrian crashes near, but not at, a pedestrian crosswalk.)

Closed-Course Study

The closed-course study was designed to investigate the ability of a driver to detect an object (box, trash can, or pedestrian) placed about 3 ft beyond a beacon assembly for different combinations of beacon shape (circular or rectangular), size (8 or 12 inches in diameter for the circular), and placement (above or below sign). Participants drove two laps, and the signs and objects were changed between laps.

One of the objectives of the closed-course research effort was to identify assemblies for open-road evaluation. It should be emphasized that the variables measured in the closed-course study are not surrogates for driver yielding, which was measured in the open-road study. Legibility distance, detection distance, and discomfort glare were used to help the research team determine which assemblies had the best potential for study in an open-road environment.

The study included 71 participants approximately evenly distributed among males over 55 years, females over 55 years, males under 55 years, and females under 55 years. Within each of those demographic groups, researchers sought an even distribution between those who drove during the day and those who drove at night and between those who drove Lap A first and those who drove Lap B first. Each participant drove the course twice, with a pause between laps for the field crew to switch the signs and objects. After the participants completed the driving portion of the study, they were directed to the discomfort glare portion of the study.

The tasks for the participants while driving the route were to indicate when they could first perform the following actions:

- See warning lights.
- See road signs.
- Read the words or identify the symbol on the road signs.
- See objects (box, trash can, or pedestrian).

As soon as the driver said "lights," "sign," or "object," or read the words/numbers/symbol on a road sign, the experimenter pressed a key on the laptop computer, which placed a mark in the file to indicate an event.

At the beginning of the discomfort glare study, researchers asked the participants to park 250 ft away from the first sign. After the participant parked the vehicle, researchers turned on the beacon and asked the participant to indicate whether the brightness (more formally known as luminous intensity) of the light is comfortable, irritating, or unbearable, defined as follows:

- Comfortable—the glare is not annoying and the device is easy to look at.
- Irritating—the glare is uncomfortable; however, the participant is still able to look at it without the urge to look away.
- Unbearable—the glare is so intense that the participant wants to avoid looking at it.

After the participant rated the first level, a technician increased the brightness. This process continued until the participant indicated that the brightness was unbearable or the technician reached level 6 on the controller, which was the highest setting for the device. This process was then repeated at 150 ft for sign 1, 250 ft for sign 2, and 150 ft for sign 2.

Open-Road Study

Because of the common use of the RRFB below the pedestrian crossing sign, it was considered the baseline device and was selected for inclusion in the open-road study. The suggested alternative was the 12-inch circular beacons located below the sign. During the closed-course study, the circular treatment had longer sign legibility distances during the night and longer object detection distances during both day and night as compared with other assembles. The open-road study was designed to investigate (a) whether drivers yield differently to circular or rectangular beacons when used with a rapid-flashing pattern, (b) whether a driver is more likely to yield to a pedestrian when the rapid-flashing beacon is activated than when it is not activated, and (c) whether vehicle traffic volume affects driver yielding. Table 1 lists the characteristics of the 12 sites located in four

Table 1. Open-road study site characteristics.

Site	Posted Speed Limit (mi/h)	Total Crossing Distance (ft)	Crossing Distance to Refuge (ft)	Calculated Daily Traffic (veh/day)	Advance Yield Lines?	Number of Lanes	Presence of Median
AU-01	35	44	44	17,732	No	4	None
AU-02	30	56	22	9,096	No	3	Raised
CS-01	30	48	48	2,130	No	2	None
CS-02	40	60	60	16,496	Yes	4	TWLTL
FG-01	35	84	31.5	23,008	No	4	Raised
FG-02	30	55	21	19,297	No	2	Raised
FG-03	35	76	28.5	14,590	No	4	Raised
MK-04	30	39	39	7,238	No	2	None
MK-05	30	40	40	6,883	No	4	None
MK-06	30	80	31	13,312	No	4	Raised
MK-07	30	98	42	11,401	No	6	Raised
MK-08	30	49	49	10,117	No	4	None

TWLTL = Two-way left-turn lane.

cities (Milwaukee, WI; Flagstaff, AZ; Austin, TX; and College Station, TX) included in the study. Figure 1 shows an example of one of the CRFBs included in the open-road study, while figure 2 shows one of the RRFBs.

RESULTS

Closed-Course Study

The evaluation of the driving portion of the study focused on the legibility distance for the study assemblies (i.e., the distance away from the sign when the participant could correctly state the words or symbol on the sign), the detection distance to objects, and the accuracy of detecting the objects. The discomfort glare evaluation focused on participants' ratings of discomfort for an LED-embedded sign assembly and two circular 8-inch beacons, each with six different levels of intensity.

Figure 1. A CRFB included in the open-road study.

Source: Texas A&M Transportation Institute.

Figure 2. An RRFB included in the open-road study.

Source: Texas A&M Transportation Institute.

Key Findings Regarding Legibility Distance

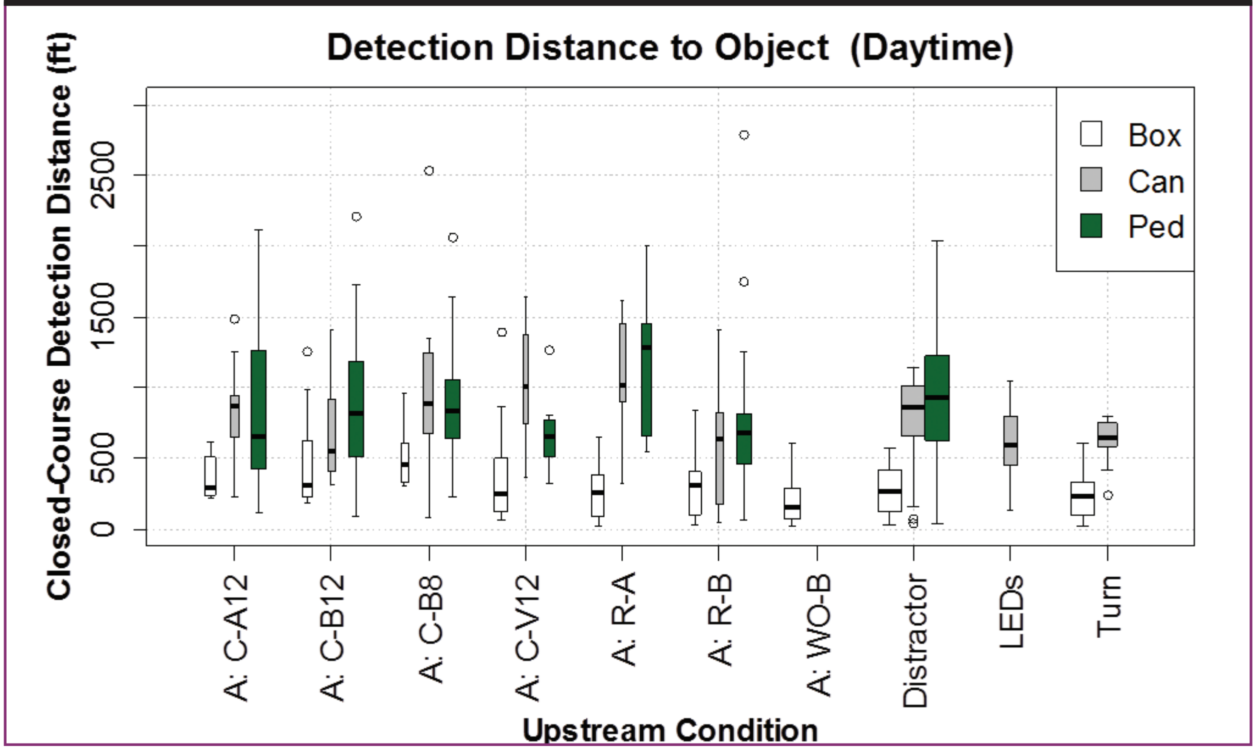
For the analysis that focused on the legibility distance, which is the distance between the sign and the participant when the participant reads the message on the sign, results were generally as expected and indicate the following:

- The legibility distance for signs during the day is greater than the legibility distance for signs at night.
- Younger driver legibility distance is greater than older driver legibility distance, indicating that future studies will also need to consider older participants.
- The type of assembly was significant at night and nearly significant during the day, suggesting that the effects of the beacons/LEDs on reading the message on the sign are more influential during nighttime conditions.

Key Findings Regarding Object Detection Distance

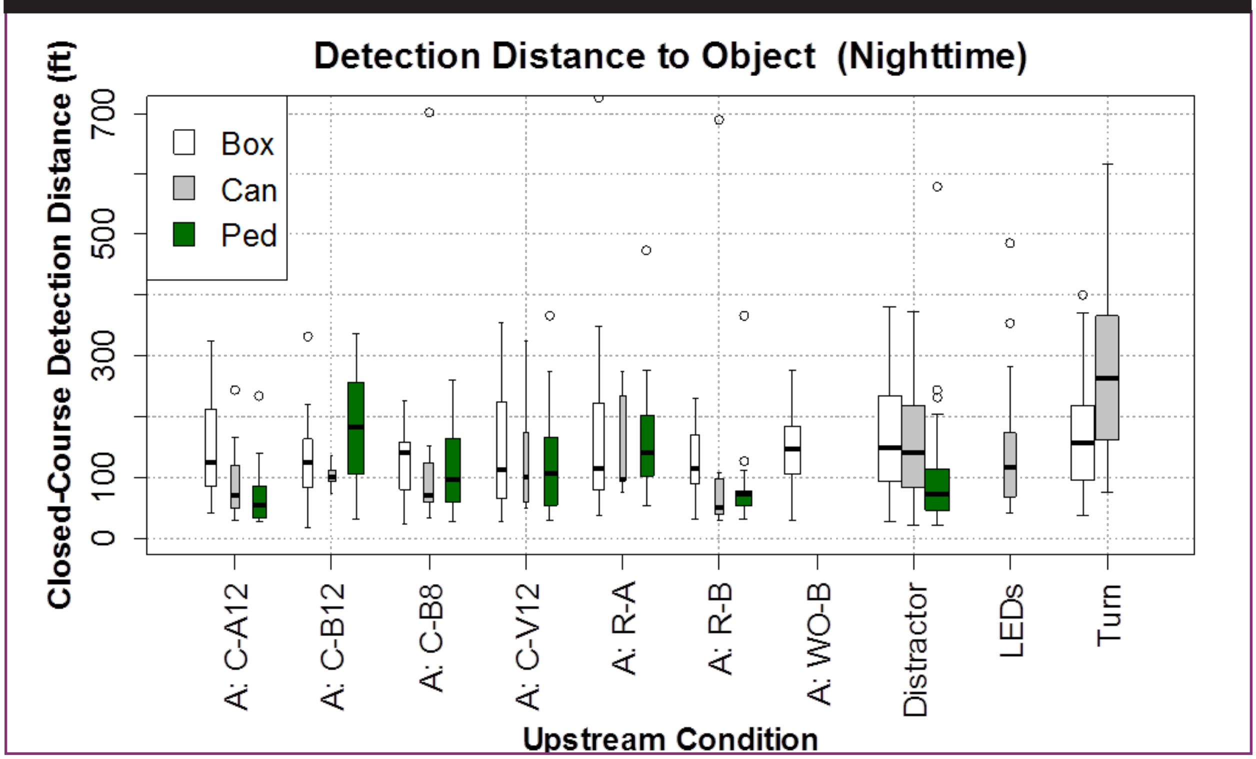
Box plots were generated to show the range of distances at which participants detected various objects. Figure 3 shows box plots for the daytime data, while figure 4 shows the nighttime data box plots. The limits of the box plots are at the 25th and 75th percentiles. The whiskers were drawn at 1.5 × the interquartile range, and the widths were drawn proportional to square root (number of observations). For

Figure 3. Box plot of daytime object detection distance by upstream condition.



Source: Texas A&M Transportation Institute.

Figure 4. Box plot of nighttime object detection distance by upstream condition.



Source: Texas A&M Transportation Institute.

the analysis focusing on object detection distance, results indicated the following:

- As expected, there is a significant difference between day and night object detection distances. For example, the day detection distance to a pedestrian was, on average, 911 ft with a standard deviation of 539 ft. At night, the pedestrian detection distance was quite different, with a mean distance of 116 ft and standard deviation of 93 ft. For comparison, stopping sight distance for 35 mi/h is 250 ft and for 45 mi/h is 360 ft.
- Similar to legibility distance, there was a statistically significant difference because of age during the daytime, although the same finding did not occur at night. The nighttime condition seems to impede detection to a point that the effects of several variables were too small to detect in the experiment.
- Certain assemblies were associated with shorter object detection distances. For daytime conditions, the detection distance to an object was shorter for RRFB below the sign than with 8- or 12-inch circular beacons below the sign or with RRFB above the sign (statistically significant). During the nighttime, the detection distance to an object was shorter with the RRFB than with the 12-inch circular beacon (statistically significant). These findings indicate that characteristics of the RRFB, such as the light intensity or the location of the beacon beneath the sign, might negatively affect the driver's ability to see an object.

Key Findings Regarding Object Detection Accuracy

For the analysis focusing on the accuracy of detecting objects, which considered the number of objects missed by the participants, results indicate the following:

- There is a significant difference in the probability of missing objects between daytime and nighttime conditions. What was not expected was the magnitude of the difference. Overall, during the day, participants missed pedestrians/trash cans 1 time out of 23, while the miss rate at night was more frequent, with participants missing 1 in 5 pedestrians/trash cans.
- For both daytime and nighttime conditions, the shape of the beacon did not matter; a similar probability of missing the object was present whether the beacons were circular or rectangular.
- The location of the beacons (above or below the sign) was significant during the day but not at night. During the day, participants were less likely to miss an object when the beacons were above the sign.

Key Findings for Discomfort Glare Study

The data show that for all devices at all distances, the percentage of participants indicating that the brightness of the lights from the beacons/LEDs is comfortable goes down as brightness increases, and the percentage of participants indicating that the discomfort glare is unbearable increases as brightness increases. These findings indicate that agencies should focus on meeting minimum intensity and place less emphasis on obtaining the brightest devices possible.

Direction for Open-Road Study

Based on the findings from the closed-course study and primarily on the object detection distance results, two assemblies were selected for testing on the open road: rectangular beacons located below the sign and the 12-inch circular beacons located below the sign.

Open-Road Study

Both rectangular beacons and circular beacons were installed at the 12 sites. In half of the sites, the circular beacons were installed first, while the rectangular beacons were installed first in the other half of the sites. The same flash pattern was used regardless of whether the beacons were circular or rectangular. The research team used a staged pedestrian protocol to collect driver yielding data to ensure that oncoming drivers receive a consistent presentation of approaching pedestrians.

Shape

Because a previous study that included RRFBs found that posted speed limit, crossing distance, and city influenced driver yielding, the initial analyses were conducted with those variables along with ADT, treatment rotation order, and beacon shape.[2,3] An indicator variable for nighttime conditions was included in the final model to determine whether nighttime results were significantly different from daytime results. Average daytime yielding was 63 percent for CRFBs and 59 percent for RRFBs, suggesting that there are only minor, if any, differences between the two beacon shapes. The results from the generalized linear mixed model also indicate that there are no significant differences between the two beacon shapes.

Brightness

For a subset of the sites, the brightness of the beacons was measured. For those sites, there is evidence of an increasing yielding rate with increasing intensity at night. The trend is in the same direction during the day but with a smaller magnitude that the analysis found statistically insignificant.

Activation of Beacon

An analysis was also conducted to determine the extent to which the presence of a flashing beacon influences driver yielding. Driver yielding rates were compared between pedestrian crossings when a beacon was and was not activated. The analysis included RRFBs and CRFBs, staged pedestrians and non-staged pedestrians, and daytime study periods. The results of the analysis concluded that a driver is 3.7 times more likely to yield when the beacon is activated than when the beacon is not activated.

Traffic Volume

Based on observations of driver behavior during the data collection, the research team conducted an analysis to determine whether driver yielding was influenced by other vehicles in the traffic stream. The objective of the analysis was to evaluate the relationship between traffic volume and driver yielding rate. The results of the analysis concluded that traffic volume was not significant, suggesting that driver yielding behavior was not influenced by traffic volume present at the sites.

CONCLUSIONS/DISCUSSION

In conclusion, the results of the study show that the shape of a yellow rapid-flashing beacon does not have an impact on whether a driver yields to a pedestrian. The study also revealed that a driver is nearly four times as likely to yield when a beacon has been activated as when it has not been activated. Other variables that had an impact on driver yielding include beacon intensity (for nighttime) and city. (Yielding was higher in Flagstaff compared with the other cities included in the study.) Several studies have found increased driver yielding after installing CRFBs/RRFBs, as summarized in table 2 and table 3. The findings from this FHWA study are also included in table 2.

Table 2. Overview of driver yielding results from several RRFB studies.

Study	Number of Sites	Driver Yielding[1]	Unique Characteristics of Study
2010 FHWA(4)	22 (most in St. Petersburg, FL)	72 to 96 percent (staged[2])	Original study that included data for multiple years
2009 FHWA(5)	2 (Miami, FL)	55 to 60 percent daily (staged) 66 to 70 percent (staged)	Day and night
2009 Florida(6)	1 (St. Petersburg, FL)	35 percent overall 54 percent activated[3]	Trail crossing
2011 Texas(7)	1 (Garland, TX)	80 percent (staged)	School, overhead
2011 Oregon(8)	3 (Bend, OR)	74 to 83 percent (staged)	2 sites had 45-mi/h posted speed limit
2013 California(9)	2 (Santa Monica, CA)	See table 3.	2 sites where the RRFB and CRFB were rotated (data available for a third rotation where back plates were changed)
2013 Calgary(10)	6 (Calgary, AB, Canada)	98 percent (staged)	Before installing RRFBs, the yielding was 83 percent (type of before treatment not provided)
2014 Michigan(11)	1 (South Lyon Township, MI)	69 percent (staged)	Comparison with no signs (20 percent), gateway in-street signs (80 percent), combination of gateway and RRFBs (85 percent)
2014 Texas(2,3)	22 (most in Garland, TX)	34 to 92 percent (staged)	Significant variables: city, posted speed limit, crossing distance, one/two way
2014 FHWA (this study)	12 daytime and 4 nighttime (Austin and College Station, TX; Flagstaff, AZ; Milwaukee, WI)	Daytime (staged): RRFG: 22 to 98 percent CRFB: 36 to 95 percent Nighttime (staged): RRFB: 53 to 95 percent CRFB: 52 to 89 percent	Study compared yielding to beacon with circular and rectangular shapes. Data were collected at night.

[1]Range provided shows the average driver yielding for the sites included in the study as reported by the authors. See study references for details regarding study methodology and whether the findings are significant.
[2]Staged pedestrian was used to collect the data.
[3]Finding reported for when the device was activated (i.e., pedestrian pushed the pushbutton).
FHWA = Federal Highway Administration.
RRFB = Rectangular rapid-flashing beacon.
CRFB = Circular rapid-flashing beacon.

Table 3. Overview of driver yielding results from 2013 California study.(9)

Shape	Light	Range when activated[1,2]	Range when not activated[1]
RRFB	Day	80–85 percent	58–73 percent
CRFB	Day	63–92 percent	57–83 percent
RRFB	Night	80–95 percent	35–60 percent
CRFB	Night	65–90 percent	35–80 percent
RRFB	Dusk	80–85 percent	65–85 percent
CRFB	Dusk	55–100 percent	20–75 percent

[1]Staged pedestrian was used to collect the data.
[2]Findings reported for when the device was activated (i.e., pedestrian pushed the pushbutton).
RRFB = Rectangular rapid-flashing beacon.
CRFB = Circular rapid-flashing beacon.

The brightness of the beacons can help draw a driver's attention to a device and the area around the device. It can also result in drivers looking away from the device because the brightness is irritating or unbearable. As the brightness of the beacons on a traffic control device increases, the probability of a driver indicating that the discomfort glare is unbearable increases. When the discomfort glare is unbearable, drivers are more likely to divert their eyes away from the discomfort, which might result in drivers missing the identification of conflicts or hazards located near the glare source. Further research is needed to identify appropriate/maximum brightness for RRFBs. Guidance is also needed on whether to dim these devices during low light conditions and, if so, by how much.

The closed-course study demonstrated that fewer objects were missed when the beacons were located above the sign. It also found that both the daytime and nighttime detection distance was shorter, which is less desirable, to objects beyond an assembly with two rectangular beacons below the sign as compared with other selected assemblies. Therefore, based on these findings, having the rectangular beacons located above the sign rather than below the sign should be studied in an open-road setting.

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Researchers—This study was performed by Kay Fitzpatrick, Raul Avelar, Ingrid Potts, Marcus Brewer, James Robertson, Chris Fees, Jessica Hutton, Lindsay Lucas, and Karin Bauer. For more information about this research, contact the Principal Investigator of the study, Dr. Kay Fitzpatrick, Texas A&M Transportation Institute, 2935 Research Parkway, College Station, TX 77845-3135, k-fitzpatrick@tamu.edu.

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