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

PUBLICATION NO. FHWA-HRT-15-043 JUNE 2015

U.S. Department of Transportation
Federal Highway Administration

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

Pedestrian and Bicycle Safety

FOREWORD

The overall goal of the Federal Highway Administration (FHWA) Pedestrian and Bicycle Safety Research Program is to improve safety and mobility for pedestrians, bicyclists and drivers to share roadways, through the development of safer crosswalks, sidewalks, and pedestrian technologies, and the expansion of educational and safety programs.

This report documents an FHWA project that investigated how characteristics of rapid-flashing beacons (e.g., shape, size, and brightness) affect the ability of drivers to detect people or objects along the roadway and the likelihood of drivers yielding to a pedestrian. This report should be of interest to engineers, planners, and other community authorities who share an interest in safeguarding the lives of roadway users, especially pedestrians.

Monique R. Evans
Director, Office of Safety
Research and Development

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. FHWA-HRT-15-043	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Investigating Improvements to Pedestrian Crossings With an Emphasis on the Rectangular Rapid-Flashing Beacon		5. Report Date June 2015 6. Performing Organization Code
7. Author(s) Kay Fitzpatrick, Raul Avelar, Ingrid Potts, Marcus Brewer, James Robertson, Chris Fees, Jessica Hutton, Lindsay Lucas, and Karin Bauer		8. Performing Organization Report No.
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, TX 77843-3135		10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTFH61-08-D-00032 Task Order #4
12. Sponsoring Agency Name and Address Office of Safety Research and Development Federal Highway Administration 6300 Georgetown Pike McLean, VA 22101-2296		13. Type of Report and Period Covered Technical Report: September 2010–March 2015 14. Sponsoring Agency Code
15. Supplementary Notes The Contracting Officer's Technical Representative (COTR) was Ann Do, HRDS-30.		

16. Abstract

Several methods have been used to emphasize the presence of a pedestrian crossing, including supplementing signing with beacons or embedded light-emitting diodes. A device that has received national attention is the rectangular rapid-flashing beacon, but practitioners have asked whether the shape of the beacon plays a role in the effectiveness of this device. In the first phase of this project, researchers reviewed recent literature and pedestrian crash data to identify trends in pedestrian safety and in the effectiveness of crossing treatments. Researchers also conducted limited field observations at 10 crosswalks in 5 States, as a source of ideas for evaluating crossings in the second phase of the project.

In phase II of the project, the research included a closed-course study and an open-road study to determine what characteristics of rapid-flashing beacons affected drivers' ability to detect people or objects, as well as drivers' likelihood of yielding to a pedestrian. The closed-course study included 71 participants who drove the course and viewed 8 beacon study assemblies, 9 distractor signs, and up to 11 roadside objects. The open-road study involved both rectangular beacons and circular beacons that were installed at 12 sites located in 4 cities from 3 States; both staged and nonstaged pedestrian crossings were documented. Although a slight difference was found between the average percent yielding to circular versus rectangular beacons (daytime: 67 to 59 percent; nighttime: 69 to 72 percent), the statistical evaluation determined that the shape of the beacon did not have a significant effect on drivers' responses. However, a driver is more than three 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 included beacon intensity (for nighttime) and city (yielding was higher in Flagstaff, AZ, compared with the other cities included in study), but not average daily traffic.

17. Key Words Rectangular Rapid-Flashing Beacon, Circular Rapid-Flashing Beacon, RRFB, CRFB, Pedestrian Crossing, Driver Yielding to Pedestrians	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service Springfield, VA 22161. http://www.ntis.gov/about/contact.aspx		
19. Security Classif.(of this report) Unclassified	20. Security Classif.(of this page) Unclassified	21. No. of Pages 266	22. Price

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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LIST OF ABBREVIATIONS

ADT	Average Daily Traffic (vehicles/day)
AIC	Akaike's Information Criterion
ANOVA	Analysis of Variance
ASCII	American Standard Code for Information Interchange
C-A12	For the closed-course study, two circular 12-inch beacons located above the sign
C-B12	For the closed-course study, two circular 12-inch beacons located below the sign
C-B8	For the closed-course study, two circular 8-inch beacons located below the sign
CDT	Calculated Daily Traffic (vehicles per day) (determined using 1-hour count and national hourly traffic distribution data for non-freeway roads with no, low, and moderate congestion)
CMF	Crash Modification Factor
CRFB	Circular Rapid-Flashing Beacon
C-V12	For the closed-course study, one circular 12-inch beacon located above the sign and one circular 12-inch beacon located below the sign
DF	Degrees of Freedom
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
GES	General Estimates System
GLMM	Generalized Linear Mixed Effects Model
GPS	Global Positioning System
HSIS	Highway Safety Information System
IQR	Interquartile Range
IRWL	In-Road Warning Light
ITS	Intelligent Transportation System
LED	Light-Emitting Diode (also used to indicate the sign used in the closed-course study where the LEDs were embedded into the border)
LMM	Linear Mixed Effects Model
MCOP	Marketing, Communication, and Outreach Plan
MOE	Measure of Effectiveness
MUTCD	*Manual on Uniform Traffic Control Devices*
NCHRP	National Cooperative Highway Research Program
NCUTCD	National Committee on Uniform Traffic Control Devices
NHTSA	National Highway Transportation Safety Administration
NMVCSS	National Motor Vehicle Crash Sampling Survey
Ped X-ing	Pedestrian Crossing (sign)
PHB	Pedestrian Hybrid Beacon
Puffin	Pedestrian User-Friendly Intelligent (crossing)
R-A	For the closed-course study, two rectangular beacons located above the sign
R-B	For the closed-course study, two rectangular beacons located below the sign (format currently being used for the RRFB device)
REML	Restricted Maximum Likelihood.
RRFB	Rectangular Rapid-Flashing Beacon
SAE	Society of Automotive Engineers
Std. error	Standard Error of Value
TAP	Technical Advisory Panel

TCRP	Transit Cooperative Research Program
TFHRC	Turner-Fairbank Highway Research Center
TTI	Texas A&M Transportation Institute
TWLTL	Two-Way Left-Turn Lane
TxDOT	Texas Department of Transportation
UMKC	University of Missouri—Kansas City
WO-B	For the closed-course study, diamond-shaped sign with no beacons or LEDs
YTPCD	Yield-to-Pedestrian Channelizing Device

CHAPTER 1. INTRODUCTION

BACKGROUND

Several methods have been used to emphasize the presence of a pedestrian crossing, including methods with beacons or embedded light-emitting diodes (LED). A device that has received national attention is the rectangular rapid-flashing beacon (RRFB). On July 16, 2008, the Federal Highway Administration (FHWA) provided interim approval (formally listed as IA-11) for the optional use of rectangular rapid-flashing beacons.(1) FHWA approved the use of this device at pedestrian and school crosswalks across uncontrolled approaches and defined it in IA-11 as the following:

> 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" in the interim approval.(1)

RRFBs appear to be different than previously used pedestrian crossing treatments, displaying noteworthy characteristics that seem to produce improved vehicle stopping and yielding behavior to pedestrians. These noteworthy characteristics include the following:

- **Brighter.** The use of LEDs appears to provide greater brightness, which could improve recognition.
- **Rapid-flashing pattern.** Compared with slower flashing beacons, the rapid flash appears to imply urgency to drivers.
- **Only flashing when pedestrian is present**. The treatment is activated by a pedestrian, typically via a pedestrian pushbutton, which results in the beacons only being active when a crossing is desired rather than flashing continuously. The activated nature of the treatment better communicates that a pedestrian is actually present and wanting to cross the roadway.

The Signals Technical Committee (STC) of the National Committee on Uniform Traffic Control Devices (NCUTCD) assists in developing language for chapter 4 of the *Manual on Uniform Traffic Control Devices* (MUTCD).(2) The STC is interested in research and/or assistance in developing material on the RRFB. Earlier research studies did not address certain issues that the STC believes are important in crafting language suitable for creating a uniform standard for the MUTCD. The STC sought advice on several issues, including whether the housings have to be rectangular and whether circular-shaped housings will achieve the same effect.

As a result of FHWA providing interim approval (as IA-11) for the optional use of RRFBs and the NCUTCD's interest in addressing issues such as beacon shape and size, this research investigated size and shape of the beacon, brightness/glare issues, and position of the beacon. The research later focused on the shape (rectangular and circular) of rapid-flashing beacons. The research included a closed-course study and an open-road 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 the sign). One of the objectives of the closed-course research effort was to identify assemblies for field (open road) evaluation. Because of the common use of the RRFB below the sign, it was considered the baseline device and was selected for inclusion in the open-road study. Considering the challenges with switching devices at a location, only one additional device was suggested for testing. The suggested alternative was the 12-inch circular beacons located below the sign. It had longer sign legibility distances during the night, and longer object detection distances during both day and night compared with other assemblies.

The open-road study was designed to investigate 1) whether drivers yield differently to circular or rectangular beacons when used with a rapid-flashing pattern, 2) 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 3) whether vehicle traffic volume affects driver yielding.

STUDY OBJECTIVE

The research included a closed-course study and an open-road study. The closed-course study had the following objectives:

- Determine whether the shape, size, and placement of flashing beacon/LEDs affect the following:
    - Sign legibility and symbol identification distances.
    - Object detection.
- Determine driver ratings of disability glare for 8-inch circular beacons and LED-embedded signs using a rapid flash pattern.
- Identify up to two assemblies for field evaluation to be conducted following the conclusion of the closed-course tasks.

The open-road study had the following objectives:

- 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.

SCOPE OF WORK

The goal of this research effort is to improve pedestrian safety at urban and suburban crossing locations by identifying and evaluating low- to medium-cost pedestrian countermeasures to reduce pedestrian fatalities and injuries at these locations. This research effort focuses on countermeasures that can be implemented at unsignalized pedestrian crossing locations and that previously have not been rigorously evaluated from a safety perspective.

STUDY APPROACH

The research was conducted in a series of tasks as follows:

Task 1—Hold Kickoff Meeting. The research team met with FHWA staff to discuss the project direction, scope, and work plan.

Task 2—Organize a Technical Advisory Panel. The research team identified and organized a Technical Advisory Panel (TAP) comprising a diverse set of stakeholders representing Federal, State, and local governments; academia; nonprofit organizations; and private industry. The role of the TAP has been to participate in meetings, provide input to FHWA and the research team, and review documents for the project.

Task 3.1—Conduct a Literature Review on Midblock Crossings. The research team conducted a literature review of pedestrian safety and behavior at midblock crossings in urban and suburban settings. This literature review focused on midblock crossing locations in urban and suburban conditions, but also included literature on pedestrian crossings at intersections.

Task 3.2—Gather Data on Pedestrian Crashes and Local Field Observations. The research team conducted an analysis of pedestrian crash datasets and field observations at selected midblock pedestrian crossing locations. The purpose of the crash dataset review was 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. The purpose of the local field observations was to serve as a first step toward deciding the types of treatment and locations to be studied later in the research.

Task 3.3—Prepare a Draft Work Plan for the Proposed Evaluation. Based on the results of Tasks 3.1 and 3.2, the research team generated a list of five proposed crossing countermeasures for evaluation in the research. A final selection of countermeasures for evaluation was made during Task 4. For each of the potential countermeasures, the research team prepared a draft work plan.

Task 3.4—Develop the Marketing Plan for the Project. The research team developed the Marketing, Communication, and Outreach Plan (MCOP), which summarized the most cost effective, high-leverage communications opportunities, strategies, and tactics for a successful marketing, communications, and outreach campaign explaining how practitioners can use design and operational information related to selected countermeasures.

Task 4.1—Organize, Prepare, and Conduct Briefing Meeting at the Turner-Fairbank Highway Research Center (TFHRC) with FHWA and TAP. The research team conducted a briefing meeting at TFHRC that included FHWA, TAP, and members of the research team. At the meeting, draft work plans and a draft MCOP were presented and discussed. During the meeting, advice and direction for the research team was gathered. At the briefing meeting, it was decided that the research team would conduct a closed-course study and an open-road study, focusing on the shape, size, and location of rapid-flashing beacons. The research team developed a final work plan for these two studies.

Task 4.2—Conduct a Teleconference or Web Conference with FHWA and TAP. The research team conducted a conference call with FHWA and TAP to discuss the final work plan.

Task 5—Evaluate Selected Pedestrian Crossing Countermeasures. The research team conducted a closed-course study to investigate the ability of a driver to detect an object placed beyond a beacon assembly for different combinations of beacon shape, size, and placement. The research team also conducted an open-road study to investigate driver yielding as a function of beacon shape, beacon activation, and traffic volume.

Task 6—Develop Technical Briefs, Final Comprehensive Technical Report, and MCOP. The research team developed the following final documents for the research:

- MCOP.
- Technical Report.
- TechBrief.

REPORT ORGANIZATION

This report includes the following chapters:

- **Chapter 1. Introduction.** This chapter presents general background information along with the research objective and the approach used for the closed-course and open-road studies conducted as part of this research.

- **Chapter 2. Literature Review.** This chapter presents findings from the literature review that relates to the phase II studies along with supplemental literature reviews conducted as part of phase II research efforts. The full literature review is included in the appendix. The literature review findings provided direction regarding the countermeasures to be studied.

- **Chapter 3. Gather Data on Pedestrian Crashes.** This chapter documents the results of a review and analysis of existing pedestrian crash databases.

- **Chapter 4. Local Field Observations.** This chapter documents the results of field observations at midblock pedestrian crossings.

- **Chapter 5. Closed-Course Study.** This chapter documents the results of a closed-course study designed to investigate the ability of a driver to detect an object placed beyond a beacon assembly for different combinations of beacon shape, size, and placement.

- **Chapter 6. Open-Road Study.** This chapter documents the results of an open-road study to investigate driver yielding as a function of beacon shape, beacon activation, and traffic volume.
- **Chapter 7. Summary/Conclusions, Discussion, and Future Research Needs.** The final chapter provides a summary and the conclusions of the research, and presents future research needs.
- **Appendix. Literature Review**. The appendix contains the full literature review conducted during phase I.

CHAPTER 2. LITERATURE REVIEW

Efforts during the initial phase of this project included a comprehensive literature review of pedestrian treatments being used at unsignalized pedestrian crossings. The appendix to the report contains the literature review. Certain parts of the literature review were updated or additional literature reviews were conducted as needed to support work done in later tasks of this project. The following sections contain those updated materials.

PREVIOUS OPEN-ROAD RESEARCH ON RECTANGULAR RAPID-FLASHING BEACONS

The RRFB flashes in an eye-catching sequence to draw drivers' attention to the sign and the need to yield to a waiting pedestrian. It is located on the side of the road below pedestrian crosswalk or school crossing signs or overhead with a sign, and can be activated by a pedestrian either actively (pushing a button) or passively (detected by sensors).

Original FHWA Study on RRFB

An FHWA study evaluated RRFBs at 22 sites in St. Petersburg, FL; Washington, DC; and Mundelein, IL.(3) The RRFBs produced an increase in yielding behavior at all locations. During the baseline period before the introduction of the RRFB, yielding for individual sites ranged between 0 and 26 percent. The average yielding for all sites was 4 percent before installation of the RRFBs. Within 7 to 30 days following installation of an RRFB, the average yielding increased to 78 percent from the baseline condition, a statistically significant increase. Similar yielding values were observed during the remainder of the study period.

Data collected over a 2-year period, at 18 of the sites, confirmed that the RRFBs continue to be effective in encouraging drivers to yield to pedestrians, even over the longer term. By the end of the 2-year follow-up period, the researchers determined that the introduction of the RRFB was associated with yielding that ranged between 72 and 96 percent.

During the baseline measurement phase, the researchers installed advance yield markings to reduce the risk of multiple-threat crashes, which occur when a driver stopping to let a pedestrian cross is too close to the crosswalk, masking the pedestrian from drivers in the adjacent lane. The advance yield markings, which are recommended with an RRFB installation, were typically placed 30 ft in advance of the crosswalk unless a driveway or other issue was present, in which case they could be placed up to 50 ft in advance of the crosswalk. The posted speed limit at the sites ranged from 30 to 40 mi/h.

The observers scored the percentage of drivers yielding and not yielding to pedestrians. Researchers scored drivers as yielding if they stopped or slowed and allowed the pedestrian to cross. Conversely, researchers scored drivers as not yielding if they passed in front of the pedestrian but would have been able to stop when the pedestrian arrived at the crosswalk.

2009 FHWA Study

A 2009 FHWA report presented the results of an evaluation of RRFBs at two sites in Miami, FL.(4) The study team used the following measures of effectiveness (MOE) to assess the effect of the RRFB on pedestrian and driver behavior: 1) the percentage of pedestrians trapped in the roadway, 2) the percentage of drivers yielding to pedestrians, and 3) the percentage of pedestrian-vehicle conflicts. The researchers found statistically significant improvements in all of the MOEs as shown in table 1. For percent drivers yielding, only 4.2 or 4.1 percent of the drivers yielded at the two sites in the before condition. After the installation of the RRFB, yielding at the two sites increased to either 55.2-percent driver yielding or 60.1-percent driver yielding, depending on the site. The researchers concluded that the RRFB offered clear safety benefits, and it was placed into the category of highly effective countermeasures.

Table 1. Measures of effectiveness for RRFBs with pedestrian crossing signs, Miami, FL (compiled from reference 4).

Measure of effectiveness	Site	Before	After	*p*-value
Percent drivers yielding (staged crossings, daytime)	NW 67th and Main Street	4.2 (n=2,330)	55.2 (n=2,131)	0.01 (daytime and nighttime combined at this site)
	S. Bayshore and Darwin	4.1 (n=2,075)	60.1 (n=1,361)	0.01 (daytime and nighttime combined at this site)
Percent drivers yielding (staged crossings, nighttime)	NW 67th and Main Street	4.4 (n=703)	69.8 (n=223)	0.01 (daytime and nighttime combined at this site)
	S. Bayshore and Darwin	2.5 (n=139)	66.0 (n=225)	0.01 (daytime and nighttime combined at this site)
Percent drivers yielding (resident crossings)	NW 67th and Main Street	12.5 (n=137)	73.7 (n=259)	0.001
	S. Bayshore and Darwin	5.4 (n=200)	83.4 (n=111)	0.001
Percent of pedestrians trapped in roadway	NW 67th and Main Street	44	0.5	< 0.01
Percent of vehicle-pedestrian conflicts	NW 67th and Main Street	11	2.5	< 0.05
	S. Bayshore and Darwin	5.5	0	< 0.01

2009 Florida Study

A 2009 report summarized the effects of installing a pedestrian-activated RRFB at the location of one uncontrolled trail crossing at a busy (15,000 average daily traffic (ADT)), four-lane urban street in St. Petersburg, FL.(5) The researchers used a mounted video camera to collect pre- and post-treatment data about pedestrian and driver interactions at the trail crossing. An analysis of the data showed a statistically significant increase in driver yielding (from 2 percent pretreatment to 35 percent post-treatment and 54 percent when the beacon was activated) and ability of pedestrians to cross the entire intersection (from 82 percent pretreatment to 94 percent post-treatment).

2011 Texas Study

A 2011 before-and-after study looked at the effectiveness of RRFBs at an uncontrolled crossing in Garland, TX.(6) The school crosswalk on a five-lane arterial had continental crosswalk markings, supplemented by school crossing signs on either side of the roadway. Before installation, city engineers had observed driver compliance with the crosswalk was poor and planned to install overhead and side-mounted RRFBs to improve compliance and facilitate pedestrian crossing maneuvers. In this study, researchers observed drivers' yielding behavior for crossing-guard-controlled crossings and staged pedestrian crossings, both before and after installation of the RRFBs (see figure 1). Researchers found that while yielding to school-related crossings with a crossing guard remained fairly constant (with yielding rates about 90 percent), drivers' responses to staged crossings in non-school-zone time periods improved from 1 percent before the installation to 80 percent after installation.

Source: Texas A&M Transportation Institute.

Figure 1. Photo. School crosswalk with RRFBs in Garland, TX.(6)

2011 Oregon Study

A 2011 Oregon Department of Transportation report evaluated RRFB installation at three crosswalks in Bend, OR.(7) For two of the locations, the highway has a 45-mi/h posted speed limit and is a four-lane roadway with a center median, bike lanes, and sidewalks. Because the posted speed limit of 45 mi/h was greater than most locations where RRFBs have been installed in Oregon, the plans for the RRFB installations included additional features to increase the visibility of the crosswalks and the pedestrians and bicyclists using them. These include RRFB assemblies at three locations: on the side of the road, on the median at the crosswalk, and 500 ft in advance of the crosswalk. Pavement markings included ladder bars with a continental crosswalk, a stop line 50 ft in advance of the crosswalk, and double white solid no-lane-change lines, as well as the legend "PED X-ING" on the road as vehicles approach the intersection. The signs in the RRFB assembly were 48 inches, and there was a sign in advance of the crosswalk with the legend "Stop Here for Pedestrians." Before the installation of the RRFBs, motorist yield rates were 23 and 25 percent at the 45-mi/h intersections and 6 percent at the third crossing. These rates increased to between 74 and 83 percent following treatment. The researchers concluded that "RRFBs should be considered for installation on high-speed facilities where there are posted speeds greater than 35 mi/h if there are pedestrians and bicyclists using the facility and a history of crashes or the potential for them."(7)

2013 California Study

A study of two sites in Santa Monica, CA, compared the effect of an RRFB and a circular rapid-flashing beacon (CRFB) on yielding behavior at two crossings.(8) The RRFB was installed at one site and the CRFB at the other, and after an evaluation period, they were switched and evaluated again. The study evaluated driver yielding rates both when the beacons were activated and when they were not activated. At both sites, the beacon that was installed first showed better yielding rates than the beacon that was installed second. At site 1, the RRFB resulted in 85-percent yielding when activated and the subsequent CRFB showed 63 percent yielding, while at site 2, the CRFB was installed first and produced 92-percent yielding compared to 80-percent yielding for the RRFB. In all cases, driver yielding rates were higher (between 7 and 22 percentage points) when the beacon was activated than when it was not.

2013 Canada Study

A 2013 pilot project in Calgary, AB, Canada, assessed motorists yielding behavior before and after installation of RRFBs.(9) Overall, the installation of the RRFB improved yielding compliance from 83 percent to 98 percent, which was statistically significant.

2014 Michigan Study

A series of treatments were installed at a bike trail crossing site in Michigan in a study that examined the effectiveness of a "gateway" in-street sign configuration with the RRFB used alone and in combination.(10) Because of the presence of a sharp curve, the posted speed limit was 25 mi/h, and the site had two through lanes (one in each direction) and a center turn lane. When the signs were absent and the RRFB not activated, yielding averaged 20 percent. The RRFB alone produced an average yielding level of 69 percent. The gateway in-street sign treatment, which consisted of in-street signs on the lane line on both sides of the turn lane and on each side of the road, produced 80-percent yielding. The combination of the gateway in-street sign configuration and RRFB produced 85-percent yielding. The authors concluded that the data showed that the gateway in-street signs produced effects that were similar to the RRFB and that the combination of gateway in-street signs and RRFB may produce effects similar to the gateway in-street signs alone, which suggests that the gateway in-street signs can be more cost effective than the more expensive RRFB.

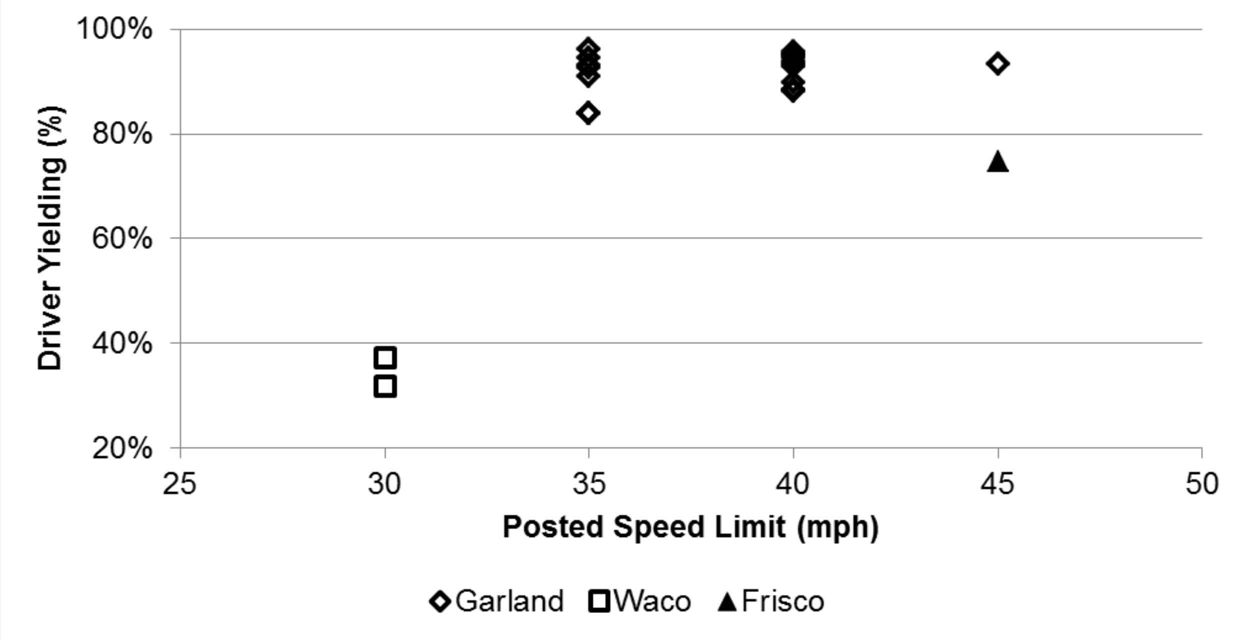
2014 Texas Study

A Texas Department of Transportation (TxDOT) study examined the effectiveness of the following traffic control devices used at pedestrian crossings: traffic control signals, pedestrian hybrid beacon, and RRFBs.(11,12) The 22 RRFB sites had School Crossing signs with the RRFB. While there are some RRFB sites in Texas with Pedestrian Crossing signs, all sites used in the Texas study had School Crossing signs. The FHWA Interim Approval for the RRFB states that when used, two Pedestrian Crossing or School Crossing signs shall be installed at the crosswalk, one on the right-hand side of the roadway and one on the left-hand sign of the roadway.(1) On a divided highway, the left-hand side assembly should be installed on the median, if practical, rather than on the far left side of the highway. A later interpretation indicated that overhead mounting is appropriate, and that if overhead mounting is used, a minimum of only one such sign per approach is required and it should be located over the approximate center of the lanes of the approach.(13) In Garland, some of the sites had the School Crossing signs located over the roadway on a mast arm along with the roadside installation (see figure 2). The overhead placements were on undivided roadways such as those with four through lanes and a two-way left-turn lane (TWLTL) or multilane one-way roads. The side mounts were used on divided roadways when the second sign could be placed in the median. The City of Garland was concerned that the RRFB would be outside the driver's cone of vision or it could easily be obscured by a truck going in the opposite direction when located on the left side of an undivided roadway. The medians on the divided roadways allow a left-side installation next to traffic going in that direction. When the median was less than 4 ft wide, the city used an overhead installation.

Source: Fitzpatrick et al.

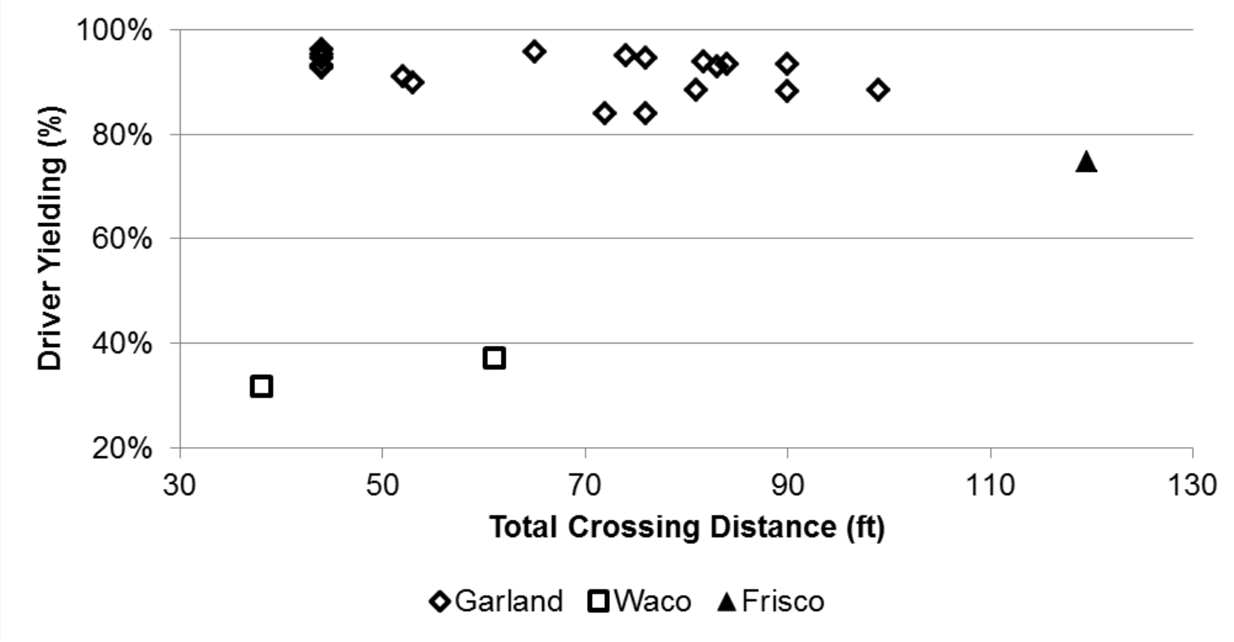
Figure 2. Photo. Study site from TxDOT study showing overhead RRFB installation.(11)

Figure 3 shows the plot of driver yielding versus posted speed limit, and figure 4 shows the plot of driver yielding to total crossing distance for the data from the Texas study.(11) These plots provide an overview of the findings and relationships with the use of average site yielding values. The data for individual crossings were used in the analysis. The modeling results for the RRFBs are shown in table 2. For RRFBs, posted speed limit, total crossing distance, one-way versus two-way traffic, and city were all significant. RRFB sites with higher posted speed limits were associated with higher driver yielding values (see figure 3). As shown in figure 3, the two Waco sites with a 30-mi/h posted speed limit have very low driver yielding (below 40 percent). These sites had low traffic volumes during data collection, which resulted in several crossings having no vehicles yielding. Even when these two sites are removed from the model, the trend of higher driver yielding for higher speed was still present and statistically significant. A closer review of the data reveals that while driver yielding is higher for the 40-mi/h sites compared with the 35-mi/h sites, the overall difference is very small (only 1 percentage point between the two averages). Therefore, while there may be a statistically significant increase in driver yielding by speed limit, the difference is not of practical significance.



Source: Fitzpatrick et al.

Figure 3. Graph. RRFB: driver yielding to posted speed limit plot from 2014 Texas study.(12)



Source: Fitzpatrick et al.

Figure 4. Graph. RRFB: driver yielding to total crossing distance plot from 2014 Texas study.(12)

The data revealed a trend of lower driver yielding rates for wider crossing distances compared with shorter crossing distances (see figure 4). Perhaps drivers believe that the greater distance between their vehicles and the pedestrian presents the opportunity to not stop for the waiting pedestrian. For example, a driver on a six-lane road has multiple lanes in which to adjust position, perhaps feeling that leaving a full traffic lane between the car and the crossing pedestrian is sufficient.

The model shown in table 2 uses Frisco as the base city and provides odds ratios for the two other cities. The driver yielding rate for Waco is lower compared with Frisco (not statistically significant), while driver yielding is higher for Garland (statistically significant). The greater number of the devices in Garland may contribute to drivers being more familiar with the treatment, which could be contributing to the better driver yielding behavior.

Table 2. RRFB total driver yielding model results.(12)

Coefficients[a]	Estimate	Standard error	*z* value	Pr(>$\lvert z\rvert$) [b]
Reference Level[c]	-2.47815	1.51421	-1.637	0.10171
M.PSL	0.12585	0.03872	3.250	0.00115**
Total_CD	-0.01223	0.00617	-1.982	0.04751*
M.O_T: two-way	-0.64290	0.30922	-2.079	0.03761*
City: Garland	1.39867	0.34448	4.060	4.9e-05***
City: Waco	-0.52276	0.61489	-0.850	0.39523

[a] Column headings are defined as follows:

- Coefficients = variables included in model.
    - M.PSL = posted speed limit on major roadway.
    - M.O_T = one-way or two-way operations on major roadway.
    - Total_CD = total crossing distance.
    - City = city where RRFB is located (Frisco, Garland, or Waco).
- Estimate: natural logarithm of the ratio: Odds (coefficient level)/Odds (reference level).
- Standard error: standard error of estimate.
- *z*-value: Standard normal score for Estimate, given the hypothesis that the actual odds ratio equals one.
- *p*-value: Probability that the observed log-odds ratio is at least as extreme as Estimate, given the hypothesis that the actual odds ratio equals one.

[b] Significance values are as follows: $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$.

[c] Reference Level in the model has the following conditions:

- Categorical variables base value: City = Frisco and M.O_T = one-way.
- Continuous variables range: M.PSL = 30 to 45 mi/h and Total_CD = 38 to 120 ft.

DRIVER DETECTION TO OBJECTS

Another area of investigation for this FHWA research became the detection distance to objects located beyond flashing beacons.

Previous studies have investigated detection distance to objects under various conditions. In the 1990s, a National Cooperative Highway Research Program (NCHRP) study investigated stopping sight distance issues, including examining driver capabilities in detecting objects in the roadway.(14) Using the closed course at Texas A&M University, the researchers had 20 drivers detect 7 objects during nighttime conditions. Drivers indicated when they could detect and recognize the objects. With low-beam headlamp illumination, the researchers found that the rear of a vehicle was detected at a range of 725 and 1,000 ft and then recognized between 550 and 725 ft. For high-beam illumination, the recognition distances started at about 1,100 ft, and the detection distances extended to almost 1,800 ft. For their pedestrian, who was a mannequin dressed in dark clothing, recognition under low-beam headlamp illumination was about 100 ft, and the detection distance was about 225 ft. Under high-beam headlamp illumination, the recognition distance was about 300 ft, and the detection distance reached a maxium of almost 500 ft.

A 2012 TxDOT study also used the Texas A&M University closed course to investigate nighttime detection of various objects.(15) The objective of the study was to investigate whether very bright traffic signs in rural conditions limited sight distance beyond the sign. The study included observations using both low-beam and high-beam headlamp illumination. It also included detection tasks without a sign present and with signs made of different retroreflective materials. The objects included a small gray wooden plaque, a pedestrian in blue medical scrubs, and the rear of a parked car. Each of the objects was placed outside the travel lane within 3.2 ft of the right edge line pavement marking. For the data without signs, the detection distance to the pedestrian was about 380 ft with low beams and 550 ft with high beams.

Comparing these two studies, the vehicle detection results look quite similar, whereas the pedestrian detection distances from the TxDOT study are slightly longer than those found in NCHRP Report 400. There are two likely causes. One is that the pedestrian used for the NCHRP Report 400 work was described as wearing dark clothing, while blue medical scrubs, which are not as dark, were used in the TxDOT 2012 study. Another reason could be the evolution of headlamp technologies. The NCHRP Report 400 work was conducted with a vehicle with sealed beam headlamps, while the TxDOT work completed with modern-day tungsten-halogen headlamps. Also confounding the results is the fact that the participants in the 2012 TxDOT study were drivers while in the NCHRP 400 study they were observers in the front seat.

A study done in 2011 looked at the impact of color contrast in the detection and recognition of objects in a road environment.(16) The investigation compared the nighttime object detection distance to several objects under three lighting systems: two LED systems with differing color temperatures and a fluorescent system. The objects included blue-clothed and black-clothed pedestrians. The results showed that the LED lighting types are significant in terms of the average distance at which a driver can identify a pedestrian and provide a longer detection distance than the fluorescent lighting. The mean detection distance was about 475 ft with the fluorescent system and about 600 to 675 ft for the LED systems.

PREVIOUS STUDIES ON LEGIBILITY DISTANCE FOR SYMBOL SIGNS

There is extensive research into how various characteristics of road signs such as sign size, letter size, contrast, luminance, conspicuity, and others affect sign legibility distance. (See, for example, references 17, 18, 19, and 20.) Legibility distance is the location upstream of a sign where a driver can correctly read all of the words on a sign or correctly identify the symbol on a symbol sign. Examples of recent research on road sign symbol recognition are summarized in the following paragraphs.

Paniati conducted a laboratory experiment to determine the relative legibility distance and driver comprehension of 22 symbol warning signs that were in use in the United States in the 1980s.(21) The results showed that legibility distance decreases with participant age and that bold symbols of simple design provide the greatest legibility distance for all age groups. Data were collected using a zoom lens on a slide projector. The participants were presented with a randomly selected slide beginning at a simulated distance of 1,000 ft and moving equivalent to a driving speed of

32 mi/h. The participant pressed a button when he or she could identify the symbol on the projected sign. This study included 16 participants under 45 years old and 16 participants over 55 years old. Paniati noted that, as expected, there was a significant difference between the legibility distances for many of the symbols. The results indicated signs with color cues (e.g., signal, stop, yield ahead) or of simple design (e.g., crossroad, right turn) provided the greatest legibility distance. As increased complexity is added to the symbol (e.g., added lane, winding road, reverse curve) the legibility decreases. As the details of the image to be resolved become finer (e.g., slippery when wet, narrow bridge, pavement ends) or the long-distance appearance of the images begin to resemble one another (e.g., pedestrian, worker, school crossing), the legibility distance continues to decrease.

A study conducted in the early 2000s had participants walk toward a calibrated, fixed-size sign projected on a large projection screen.(22) Two levels of performance were assessed: maximum recognition distance (threshold) and the distance at which the symbol types could be recognized with ease (confident). A total of 40 subjects, half of whom were young and half older, participated in the study. The traffic sign background luminance, luminance contrast, and symbol type were found to be statistically significant in affecting the symbol recognition distance. Observer age and background complexity were statistically nonsignificant.

Zwahlen and Schnell conducted an exploratory daytime and nighttime sign recognition and legibility field driving experiment involving 11 signs and 10 subjects.(23) The instructions emphasized that the subjects were to say aloud the information on the traffic sign at the point during their approach when they could clearly (with near 100-percent certainty) identify all visual details of the message in the symbol. The average daytime legibility and recognition distances were about 1.8 times longer than the average nighttime legibility and recognition distances. One of the signs tested was the Curve Arrow (black paint on yellow engineer grade background) which had an average legibility/recognition distance of 1,045 ft in the daytime and 743 ft at night.

Conspicuity is the capacity of a sign to stand out or be distinguishable from its surroundings and thus be readily discovered.(24) For a sign to be conspicuous, the viewer must be able to differentiate it from the surrounding background. Variables affecting conspicuity include luminance, luminance contrast, and color contrast. The addition of beacons to a roadway sign can improve the conspicuity of a sign. Literature that specifically addresses the legibility distance for symbol signs when used with supplemental beacons was not identified. Therefore, this FHWA study provides an opportunity to gain insights into the situation when beacons are used to supplement a roadside sign. Another unique aspect of this FHWA study is that participants were driving the vehicle while searching for the signs.

CHAPTER 3. GATHER DATA ON PEDESTRIAN CRASHES

This chapter documents the results of the review and analysis of pedestrian crash databases. The analysis of crash datasets had the following two key objectives:

- Review specific potential data sources to assess their suitability for safety evaluations that may be conducted in the research.
- Review the characteristics, circumstances, and contributing factors for crashes at midblock pedestrian crossings.

REVIEW OF CRASH DATABASES

A review of available crash datasets was conducted to assess which datasets were most promising for characterizing the attributes, circumstances, and contributing factors for crashes at midblock pedestrian crossings. National and State databases were considered in this assessment. The following crash databases were reviewed:

- National Highway Traffic Safety Administration (NHTSA) Fatality Analysis Reporting System (FARS).
- NHTSA General Estimates System (GES).
- NHTSA National Motor Vehicle Crash Sampling Survey (NMVCSS).
- FHWA Highway Safety Information System (HSIS) data for California, Illinois, Minnesota, North Carolina, Ohio, and Washington, as well as similar data for Texas.

The databases were selected for review because of their broad scope (especially the national databases), their reputation for quality, and their accessibility. These databases represent complete national or statewide datasets that are made available to researchers. Other agencies are often reluctant to release complete datasets.

An initial screening of the candidate data sources was performed to assess their suitability for analysis of midblock pedestrian crossings. This screening was conducted primarily with documentation rather than with the actual data, although portions of each dataset were given an initial review. The screening of the crash data sources addressed the following questions:

- Can crashes involving pedestrians be distinguished from other crashes?
- Can midblock pedestrian crashes be distinguished from intersection pedestrian crashes?
- Can crashes involving a pedestrian traveling along the road be distinguished from crashes involving a pedestrian crossing the road (or waiting to cross the road)?
- Can crashes involving a pedestrian in the traveled way be distinguished from crashes involving a pedestrian on a roadside or shoulder?

- Can crashes involving a pedestrian in a marked midblock crosswalk be distinguished from other crashes involving pedestrians in the traveled way?
- Can the type of traffic control device present at a midblock pedestrian crossing be determined?
- Can vehicle–vehicle crashes at midblock pedestrian crossings be distinguished from other vehicle–vehicle crashes?

The assessments of these questions are presented in table 3 for the national and State databases reviewed.

Table 3 shows that all of the crash datasets reviewed can distinguish pedestrian crashes from other crash types. Also, all of the crash datasets reviewed, except the NMVCSS, can distinguish midblock pedestrian crashes from intersection pedestrian crashes. NMVCSS was dropped from further consideration because of this deficiency.

The table shows that none of the databases distinguish clearly between crashes involving a pedestrian traveling along the road and crashes involving a pedestrian crossing the road. In other words, the available datasets generally lack a data element that clearly identifies the pedestrian action underway prior to the crash. Lack of data at this level of detail generally limits the application of the FHWA Pedestrian and Bicycle Crash Analysis Tool unless supplementary data were obtained from the review of hard-copy police crash reports.

Most datasets, other than the Washington State crash data, can distinguish crashes involving a pedestrian in a marked midblock crosswalk from other crashes involving pedestrians in the traveled way. It should be noted that only marked crosswalks at midblock locations are considered midblock crosswalks. There is no implied crosswalk at any midblock location unless markings and/or signs identify the location as a crossing. In the Washington data, midblock pedestrian crashes that occur at a signal, stop sign, or yield sign were presumed to occur at or near a crosswalk.

The table shows that only some crash datasets can identify the type of traffic control present at a midblock pedestrian crossing. Roadway characteristics files do not generally identify the locations of midblock crossings or the types of traffic control present at such crossings. However, in most States, the type of traffic control at a midblock crossing can be inferred from the traffic control information in crash data for crossings at which crashes have occurred.

Finally, the table shows that there are only limited cases in which a vehicle–vehicle collision at a midblock crossing (e.g., a rear-end collision with a vehicle stopped at the crossing) can be clearly distinguished from similar collisions at other midblock locations.

Based on the results shown in table 3, a decision was reached to proceed with analysis of all of the datasets tabulated, with the exception of the NMVCSS dataset.

Table 3. Assessment of screening questions for national and State databases.

Question	National data			State data					
	FARS	GES	NMVCSS	CA	MN	NC	OH	TX	WA
What is the scope of the dataset?	See note a	See note b	See note c	See note d	See note e	See note f	See note d	—	See note d
What years of data were reviewed?	2005 to 2009	2005 to 2009	—	2005 to 2008	2003 to 2007	2005 to 2008	2005 to 2008	2003 to 2009	2005 to 2008
Can crashes involving pedestrians be distinguished from other crashes?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Can midblock pedestrian crashes be distinguished from intersection pedestrian crashes?	Yes	—	No	Yes	Yes	Yes	Yes	Yes	Yes
Can crashes involving a pedestrian traveling along the road be distinguished from crashes involving a pedestrian crossing the road?	Yes[g]	Yes	No	No	No	Yes	No	No	No
Can crashes involving a pedestrian in the traveled way be distinguished from crashes involving a pedestrian on a roadside or shoulder?	Yes	No	No	Yes	Yes	Yes	Yes	Yes	No[h]
Can crashes involving a pedestrian in a marked midblock crosswalk be distinguished from other crashes involving a pedestrian in the traveled way?	Yes	Yes	No	Yes	Yes	Yes	Yes	No[h]	No[h]
Can the type of traffic control at a midblock pedestrian crossing be determined?	—	—	No	No	Yes[i]	Yes[i]	Yes[i]	No	No
Can vehicle-vehicle crashes at midblock pedestrian crossings be distinguished from other vehicle-vehicle crashes?	—	—	No	No[j]	No[j]	No[j]	Yes[k]	No	No[k]

[a] Nationwide data for fatal crashes only.
[b] Broad-based sample of nationwide crashes of all severity levels from specific primary sampling units.
[c] A special-purpose sample of crashes of all severity levels whose locations are not identified.
[d] Crashes on State-maintained highways only for all severity levels.
[e] Includes crashes of all severity levels on nearly all roads statewide, including State-maintained and local facilities.
[f] Includes crashes of all severity levels the majority of the State-maintained road system; many State-maintained roads in North Carolina are equivalent to county roads or city streets in other States.
[g] Yes, in some, but not in all cases.
[h] Can be presumed indirectly from traffic control devices present.
[i] Yes, but only in the crash data for locations where crashes occur.
[j] No, except to the extent this can be inferred from the location type.
[k] Yes, to some extent.
— Unknown.

SUMMARY OF RESULTS

This section presents a summary of the results of an analysis of several national and State crash databases. The analysis focused on the characteristics, circumstances, and contributing factors for crashes at midblock pedestrian crossings.

NHTSA FARS

The FARS database contains data on all fatal crashes that occur on public roads in the United States. FARS crash data were reviewed for the years 2005 through 2009, inclusive. During this period, 22,892 pedestrian fatalities occurred in the United States, and 73.0 percent of the pedestrian fatalities occurred at midblock locations. The following statistics apply to the pedestrian fatalities that occurred at midblock locations:

- 1.3 percent occurred at marked midblock crosswalks.
- 30.7 percent occurred not in, but near, a marked midblock crosswalk.
- 68.0 percent occurred at locations that were not near marked midblock crosswalks.

Other highlights from the analysis of FARS data include the following:

- Most midblock pedestrian crashes occur at locations with no traffic control.

- For midblock crashes that occurred in or near a crosswalk, 18.6 percent were classified as “improper crossing.” However, this FARS pedestrian-related factor may be a bit ambiguous because at least two other categories—“failure to yield/obey” and “dart/run into roadway” —appear to be forms of “improper crossing.”

- The data show a general increasing trend in crash frequencies with increasing pedestrian age. Particularly notable is the high proportion of fatal pedestrian crashes for pedestrians of age 70 or older at midblock crosswalks.

- The proportion of male and female pedestrians killed at locations within midblock crosswalks is relatively even. However, for midblock locations near, but not within, crosswalks, and for midblock locations away from crosswalks, more than 70 percent of the victims were male. This suggests greater risk-taking behavior on the part of male pedestrians.

- FARS data for FHWA’s 13 Pedestrian Safety Focus States and 5 Pedestrian Safety Focus Cities were reviewed for fatal midblock pedestrian crashes. Collectively, the 13 Pedestrian Safety Focus States experience 59 percent of total U.S. fatal pedestrian crashes at or near midblock crossings, while the 5 Pedestrian Safety Focus Cities represent 6 percent of total U.S. fatal pedestrian crashes at or near midblock crossings.

NHTSA GES

In a review of a nationwide sample of crash data for all crash severity levels from GES, the database includes 10,079 crashes involving a pedestrian from 2005 to 2009, inclusive. Nearly half of the pedestrian crashes occurred at midblock locations. However, only 2.5 percent of the midblock pedestrian crashes were explicitly identified as midblock crossing crashes.

Other highlights from the analysis of GES data include the following:

- The GES data, which include pedestrian crashes of all severity levels, indicate that midblock crossing crashes are typically less severe than pedestrian crashes elsewhere on the midblock roadway.
- "No control" was the selected traffic control device for 65 percent of midblock crosswalk crashes and 91 percent of the pedestrian crashes that occurred elsewhere on the midblock roadway.
- The GES variable called "pedestrian action" is similar to the FARS "pedestrian-related" factor. For midblock crosswalk crashes, 4.9 percent were classified as "improper crossing," while a substantial number of other midblock crosswalk crashes were classified in categories closely related to "improper crossing": dart/run into roadway, inattentive, and "playing, working, sitting, lying, etc., in the roadway."
- When crashes for a range of severity levels were included, there was a large proportion of crashes (more than 20 percent) for young pedestrians in the age range from 11 to 20 (i.e., primarily teenagers).
- As with the FARS data, there was a greater gender balance in pedestrians crossing at midblock pedestrian crosswalks (actually more females than males), but a substantially higher proportion of male pedestrians crossing at non-crosswalk locations.

FHWA HSIS

California

HSIS data for California include crash data only for the State highway system, consisting of approximately 15,520 mi of highways. Data analyzed for this report include the years from 2006 to 2008, inclusive. During the study period, 3,944 pedestrian crashes occurred on the California State highway system. Nearly 70 percent of the pedestrian crashes occurred at midblock locations. Only 2.6 percent of the midblock crashes were classified as occurring at midblock crosswalks.

Other highlights from the analysis of California pedestrian crash data include the following:

- As observed in the GES data, crash severities appear to be lower for midblock crosswalk crashes than for other pedestrian crashes on the midblock roadway.
- Approximately 75 percent of pedestrian midblock crashes occurred on an undivided roadway.
- Most pedestrian crashes, including midblock crosswalk crashes, occurred at locations with no traffic control present.

Minnesota

HSIS data for Minnesota include crash data for nearly all crashes statewide, including those that occurred on both State-maintained and local-agency-maintained road systems. Data analyzed for this report include the years 2003 to 2007, inclusive. During the study period, 8,271 pedestrian crashes occurred in Minnesota. Approximately 29 percent of the pedestrian crashes occurred at midblock locations. Only 3.0 percent of the midblock crashes were classified as occurring at midblock crosswalks.

Other highlights from the analysis of Minnesota pedestrian crash data include the following:

- In contrast to other States, the proportion of fatal and incapacitating injury crashes is higher for midblock crosswalks than for other midblock locations in Minnesota, but the sample size for midblock crosswalk crashes is so small that this may not be a valid comparison.
- The data for midblock roadways include a substantial number of pedestrian crashes at either signals or stop signs; these crashes must either have occurred at nonintersection signals or stop signs (i.e., driveways) or the basic intersection versus nonintersection classification of the crashes is incorrect.

North Carolina

HSIS data for North Carolina include crash data for approximately 62,000 mi of the 77,000 mi of roadway on the State-maintained highway system. Data analyzed for this report include the years from 2005 to 2008, inclusive. During the study period, 3,847 pedestrian crashes occurred on the North Carolina State highway system. Nearly 85 percent of these pedestrian crashes occurred at midblock locations. Only 2.7 percent of the midblock crashes were classified as occurring at midblock crosswalks.

Ohio

HSIS data for Ohio include crash data only for the State highway system, consisting of approximately 19,500 mi of highways. Data analyzed for this report include the years from 2005 to 2008, inclusive. During the study period, 4,127 pedestrian crashes occurred on the Ohio State highway system. Approximately, 45 percent of these pedestrian crashes occurred at midblock locations. Only 1.2 percent of the midblock crashes were classified as occurring at midblock crosswalks.

Texas

Data for Texas includes crash data for crashes both on and off the State highway system. Data analyzed for this report include the years 2003 to 2009, inclusive. During the study period, 3,134,365 crashes were included in the Texas crash database. Of these, 39,993 (1.3 percent) were pedestrian crashes. Nearly 50 percent of the pedestrian crashes occurred at midblock locations. Only 136 crashes (0.7 percent of the midblock crashes) were classified as occurring at midblock crosswalks.

Washington

HSIS data for Washington include crash data only for the State highway system, consisting of approximately 7,193 mi of highways. Data analyzed for this report include the years from 2005 to 2008, inclusive. During the study period, 1,573 pedestrian crashes occurred on the Washington State highway system. Nearly 40 percent of these pedestrian crashes occurred at midblock locations. Only 5.0 percent of the midblock crashes were classified as occurring at midblock crosswalks.

RESULTS FROM ANALYSIS OF CRASH DATASETS

This section of the report presents the results of the analysis of all the crash datasets reviewed in the preceding section. In the tables presented in this section, unless otherwise stated, all percentages shown in parentheses are column percentages. Crashes classified as "unknown" for a given data element are not included in the percentages for that data element.

The crashes classified as "midblock crosswalk" crashes involved collisions with a pedestrian at or near a marked midblock crosswalk. Only the FARS dataset formally distinguishes between crashes for pedestrians in a crosswalk or near a crosswalk. The crashes classified as "midblock roadway" crashes involve collisions with a pedestrian removed from (i.e., not near) a crosswalk. The "midblock crosswalk" and "midblock roadway" crashes include only nonintersection crashes (i.e., not at or related to an intersection) that occurred in the traveled way or on the roadway shoulder; crashes that occurred outside the shoulder (i.e., on the roadside or on a sidewalk) have been excluded.

Some datasets show a substantial number of "midblock roadway" crashes that occur at signals or stop signs. Such crashes either represent signalized or stop-controlled driveways on the midblock roadway or the basic intersection vs. nonintersection categorization is incorrect.

The first two datasets analyzed are national datasets, the first a census of fatalities and the second a sample of crashes for all severity levels. The remaining datasets are for either the State highway system or a broader set of roads in individual States.

NHTSA FARS

The FARS database contains data on all fatal crashes that occur on public roads in the United States. These data can be queried on a number of crash, vehicle, and person-level variables that are commonly available in crash reports. Queries of several variables related to pedestrian fatalities such as pedestrian age, gender, and action; time of day and day of week; speed limit; number of lanes crossed; weather, lighting and road surface conditions; and presence of a median are shown in the following tables.

Nationwide FARS Data

Table 4 summarizes nationwide data for fatalities from the FARS dataset. The table shows that of the 198,708 fatalities that occurred in the United States in the years 2005 through 2009, inclusive, 22,892 (12.1 percent) involved pedestrians. Of those pedestrian fatalities, 16,700 (73.0 percent) occurred at midblock locations; the remaining 27.0 percent of pedestrian fatalities occurred at intersections. Only 223 (1.3 percent) of the pedestrian fatalities at midblock locations occurred at marked midblock crosswalks. Another 5,129 (30.7 percent) of pedestrian fatalities at midblock locations occurred not in, but near, a marked midblock crosswalk. Thus, 5,352 of pedestrian fatalities at midblock locations occurred in or near a crosswalk. The remaining 11,348 (68.0 percent) of pedestrian fatalities at midblock locations occurred at locations that were not near marked midblock crosswalks.

Table 4. Summary of FARS pedestrian fatalities data (2005–2009).

Crashes	Number of fatal crashes by year					
	2005	2006	2007	2008	2009	Combined
Total fatalities	43,510	42,708	41,259	37,423	33,808	198,708
Pedestrian fatalities	4,892	4,795	4,699	4,414	4,092	22,892
Pedestrian midblock fatalities—in crosswalk	63	48	44	38	30	223
Pedestrian midblock fatalities—near crosswalk	1,373	1,252	860	815	829	5,129
Pedestrian midblock fatalities—total crosswalk	1,436	1,300	904	853	859	5,352
Pedestrian midblock fatalities—no crosswalk	2,240	2,255	2,493	2,323	2,037	11,348
Pedestrian fatalities—all midblock locations	3,676	3,555	3,397	3,176	2,896	16,700

Table 5 presents nationwide data from FARS for the type of traffic control present at the locations of fatal midblock pedestrian crashes. The table shows clearly that most midblock pedestrian crashes occur at locations with no traffic control. For locations at or near marked midblock crossings, 85 percent of fatal pedestrian crashes occurred at locations with no control, while 15 percent occurred at locations with some positive control. Clearly, “no control” in this database is being interpreted to mean no control other than pavement markings or signing, because such controls must be present at a midblock crossing. Table 5 also illustrates some other classification issues in the data. The fatal pedestrian crashes with a “midblock roadway” location presumably occurred at locations removed from midblock pedestrian crossings and intersections, yet 2.1 percent of the crashes appear to have occurred at signals or at stop signs, including 0.1 percent at locations with pedestrian signals. Possibly, these crashes occurred at signalized or stop-controlled driveways; for purposes of this analysis, these might better be classified as intersection crashes.

Table 6 shows nationwide data for a FARS variable called “pedestrian-related factor” that describes the action taken by the pedestrian(s) involved in the crash. For midblock crashes that occurred in or near a crosswalk, 18.6 percent were classified as “improper crossing,” while 8.0 percent were classified as “dart/run into roadway,” and 6.5 percent were classified as “failure to yield/obey.” Both of the latter categories appear to be forms of “improper crossing.” Nearly 3 percent of midblock crosswalk crashes are classified as “walk, etc., in roadway.” This category is ambiguous, because it could imply improper crossing or it could imply that a pedestrian was walking along the roadway (i.e., traveling in a longitudinal direction) in the traveled way and happened to be struck by a motor vehicle at the location of a midblock crosswalk. The “walk, etc., in roadway” crashes in the “midblock roadway” column clearly imply that the pedestrian was walking along the roadway.

Table 5. FARS midblock pedestrian fatalities by traffic control device (2005–2009).

Traffic control device	Number (percent) of fatalities by pedestrian location									
	Midblock—in crosswalk		Midblock—near crosswalk		Midblock—crosswalk total		Midblock—roadway		All midblock locations	
No controls	114	(51.3)	4,417	(86.4)	4,531	(84.9)	10,752	(95.0)	15,283	(91.8)
Control (no pedestrian signal)	4	(1.8)	18	(0.4)	22	(0.4)	5	(0.0)	27	(0.2)
Control (with pedestrian signal)	19	(8.5)	42	(0.8)	61	(1.1)	11	(0.1)	72	(0.4)
Control (pedestrian signal unknown)	39	(17.7)	111	(2.2)	150	(2.8)	116	(1.0)	266	(1.6)
Flashing control	4	(1.8)	4	(0.1)	8	(0.1)	1	(0.0)	9	(0.0)
Flashing beacon	1	(0.4)	0	(0.0)	1	(0.0)	3	(0.0)	4	(0.0)
Flashing signal unknown	0	(0.0)	1	(0.0)	1	(0.0)	3	(0.0)	4	(0.0)
Lane signal	0	(0.0)	10	(0.2)	10	(0.2)	1	(0.0)	11	(0.1)
Other signal	3	(1.3)	8	(0.2)	11	(0.2)	8	(0.1)	19	(0.1)
Unknown signal	3	(1.3)	4	(0.1)	7	(0.1)	7	(0.1)	14	(0.1)
Stop sign	7	(3.1)	47	(0.9)	54	(1.0)	93	(0.8)	147	(0.9)
Yield sign	5	(2.2)	1	(0.2)	6	(0.1)	6	(0.1)	12	(0.1)
Other sign	7	(3.1)	408	(8.0)	415	(7.8)	184	(1.6)	599	(3.6)
Unknown sign	3	(1.3)	1	(0.0)	4	(0.1)	11	(0.1)	15	(0.1)
School: other sign	1	(0.4)	1	(0.0)	2	(0.0)	0	(0.0)	2	(0.0)
School: unknown type	0	(0.0)	4	(0.1)	4	(0.1)	4	(0.0)	8	(0.0)
Warning sign	12	(5.4)	15	(0.3)	27	(0.5)	59	(0.5)	86	(0.5)
Electronic warning sign	0	(0.0)	0	(0.0)	0	(0.0)	11	(0.1)	11	(0.1)
Officer/crossing guard	1	(0.4)	14	(0.3)	15	(0.3)	32	(0.3)	47	(0.3)
RR: Gates	0	(0.0)	0	(0.0)	0	(0.0)	4	(0.0)	4	(0.0)
RR: Flash/lights	0	(0.0)	3	(0.1)	3	(0.1)	0	(0.0)	3	(0.0)
Grade crossing, unknown	0	(0.0)	0	(0.0)	0	(0.0)	1	(0.0)	1	(0.0)
Other	0	(0.0)	3	(0.1)	3	(0.1)	8	(0.1)	11	(0.1)
Unknown	0	—	17	—	17	—	28	—	45	—
Total	223	(100.0)	5,129	(100.0)	5,352	(100.0)	11,348	(100.0)	16,700	(100.0)

RR = Railroad.
— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 6. FARS midblock pedestrian fatalities by pedestrian actions (2005–2009).

	Number (percent) of fatalities by pedestrian location									
Pedestrian-related factor	**Midblock—in crosswalk**		**Midblock—near crosswalk**		**Midblock—crosswalk total**		**Midblock—roadway**		**All midblock locations**	
None, not applicable	143	(65.3)	1,767	(35.0)	1,910	(36.3)	2,928	(26.4)	4,838	(29.6)
Not visible	15	(6.8)	519	(10.3)	534	(10.1)	1,109	(10.0)	1,643	(10.0)
Dart/run into roadway	14	(6.4)	408	(8.1)	422	(8.0)	1,249	(11.3)	1,671	(10.2)
Improper crossing	25	(11.4)	954	(18.9)	979	(18.6)	1,785	(16.1)	2,764	(16.9)
Walk, etc., in roadway	6	(2.7)	888	(17.6)	894	(17.0)	2,041	(18.4)	2,935	(17.9)
Interfere driver	0	(0.0)	2	(0.0)	2	(0.0)	19	(0.2)	21	(0.1)
Blackout	0	(0.0)	7	(0.1)	7	(0.1)	19	(0.2)	26	(0.2)
Emotional	0	(0.0)	5	(0.1)	5	(0.1)	15	(0.1)	20	(0.1)
Mentally challenged	1	(0.5)	5	(0.1)	6	(0.1)	4	(0.0)	10	(0.1)
Construction worker	0	(0.0)	15	(0.3)	15	(0.3)	48	(0.4)	63	(0.4)
Inattentive	1	(0.5)	39	(0.8)	40	(0.8)	70	(0.6)	110	(0.7)
Cane/crutch	0	(0.0)	2	(0.0)	2	(0.0)	8	(0.1)	10	(0.1)
Previous injury	0	(0.0)	5	(0.1)	5	(0.1)	26	(0.2)	31	(0.2)
Influence drug/alcohol/medicine	4	(1.8)	60	(1.2)	64	(1.2)	243	(2.2)	307	(1.9)
Blind	0	(0.0)	1	(0.0)	1	(0.0)	6	(0.1)	7	(0.0)
Other physical	0	(0.0)	4	(0.1)	4	(0.1)	3	(0.0)	7	(0.0)
Dead fetus	0	(0.0)	0	(0.0)	0	(0.0)	3	(0.0)	3	(0.0)
Jogging	0	(0.0)	5	(0.1)	5	(0.1)	10	(0.1)	15	(0.1)
On prohibited traffic way	0	(0.0)	2	(0.0)	2	(0.0)	70	(0.6)	72	(0.4)
Failure to yield/obey	10	(4.6)	333	(6.6)	343	(6.5)	1,368	(12.3)	1,709	(10.4)
On/off moving vehicle	0	(0.0)	9	(0.2)	9	(0.2)	25	(0.2)	34	(0.2)
Non-driver flees	0	(0.0)	2	(0.0)	2	(0.0)	0	(0.0)	2	(0.0)
Weather	0	(0.0)	3	(0.1)	3	(0.1)	1	(0.0)	4	(0.0)
Parked vehicle	0	(0.0)	1	(0.0)	1	(0.0)	0	(0.0)	1	(0.0)
Other obstruction	0	(0.0)	0	(0.0)	0	(0.0)	1	(0.0)	1	(0.0)
Emergency	0	(0.0)	0	(0.0)	0	(0.0)	6	(0.1)	6	(0.0)
Law enforcement officer	0	(0.0)	2	(0.0)	2	(0.0)	17	(0.2)	19	(0.1)
Pushed by pedestrian	0	(0.0)	5	(0.1)	5	(0.1)	25	(0.2)	30	(0.2)
Portable electronic device	0	(0.0)	0	(0.0)	0	(0.0)	2	(0.0)	2	(0.0)
Unknown	4	—	86	—	90	—	249	—	339	—
Total	223	(100.0)	5,129	(100.0)	5,352	(100.0)	11,348	(100.0)	16,700	(100.0)

— Indicates count not included in calculation of percentage.

Column percentages may not appear to add to 100 percent due to rounding.

Table 7 presents nationwide data for fatal pedestrian crashes at midblock locations by pedestrian age. The table shows a general increasing trend in crash frequencies with increasing pedestrian age. Particularly notable is the high proportion of fatal pedestrian crashes for pedestrians of age 70 or older at midblock crosswalks. There is an unexplained trend in all columns of the table showing that pedestrians in the 61 to 70 age group had a lower proportion of crashes than the age groups on either side.

Table 8 presents nationwide data for fatal pedestrian crashes at midblock locations by pedestrian gender. The table shows a relatively even proportion of male and female pedestrians killed at locations within midblock crosswalks (56 and 44 percent). However, for midblock locations near, but not within crosswalks, and for midblock locations away from crosswalks, more than 70 percent of the victims were male. This suggests greater risk-taking behavior on the part of male pedestrians.

Table 9 summarizes the fatal pedestrian crash data by the number of lanes crossed. While interesting, these data are not terribly meaningful without exposure data on the number of lanes crossed by pedestrians who were not killed in crashes. The same is true for table 10, which categorizes fatal pedestrian crashes by the presence of a median, and thus a pedestrian refuge area, on the roadway crossed and table 11, which categorizes crashes by the posted speed limit at the crash location. Table 12 through table 16 present nationwide FARS data for fatal pedestrian crashes at midblock locations classified by weather condition, road surface condition, light condition, hour of the day, and day of the week, respectively.

Table 7. FARS midblock pedestrian fatalities by pedestrian age (2005–2009).

Pedestrian age	Number (percent) of fatalities by pedestrian location									
	Midblock—in crosswalk		Midblock—near crosswalk		Midblock—crosswalk total		Midblock—no crosswalk		All midblock locations	
0 to 10	7	(3.1)	240	(4.7)	247	(4.6)	500	(4.4)	747	(4.5)
11 to 20	13	(5.8)	421	(8.2)	434	(8.1)	1,109	(9.8)	1,543	(9.2)
21 to 30	14	(6.3)	751	(14.6)	765	(14.3)	1,889	(16.6)	2,654	(15.9)
31 to 40	19	(8.5)	708	(13.8)	727	(13.6)	1,705	(15.0)	2,432	(14.6)
41 to 50	26	(11.7)	1,091	(21.3)	1,117	(20.8)	2,327	(20.6)	3,444	(20.6)
51 to 60	43	(19.3)	801	(15.6)	844	(15.8)	1,657	(14.6)	2,501	(15.0)
61 to 70	29	(13.0)	430	(8.4)	459	(8.6)	842	(7.4)	1,301	(7.8)
70+	72	(32.3)	687	(13.4)	759	(14.2)	1,319	(11.6)	2,078	(12.4)
Total	223	(100.0)	5,129	(100.0)	5,352	(100.0)	11,348	(100.0)	16,700	(100.0)

Column percentages may not appear to add to 100 percent due to rounding.

Table 8. FARS midblock pedestrian fatalities by pedestrian gender (2005–2009).

Pedestrian gender	Number (percent) of fatalities by pedestrian gender									
	Midblock—in crosswalk		Midblock—near crosswalk		Midblock—crosswalk total		Midblock—no crosswalk		All midblock locations	
Male	125	(56.1)	3,674	(71.7)	3,799	(71.0)	8,319	(73.4)	12,118	(72.6)
Female	98	(43.9)	1,453	(28.3)	1,551	(29.0)	3,023	(26.6)	4,574	(27.4)
Unknown	0	—	2	—	2	—	6	—	8	—
Total	223	(100.0)	5,129	(100.0)	5,352	(100.0)	11,348	(100.0)	16,700	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 9. FARS midblock pedestrian fatalities by number of lanes crossed (2005–2009).

Number of lanes crossed	Number (percent) of fatalities by number of lanes crossed									
	Midblock—in crosswalk		Midblock—near crosswalk		Midblock—crosswalk total		Midblock—no crosswalk		All midblock locations	
One lane	3	(1.4)	41	(0.8)	44	(0.8)	178	(1.6)	222	(1.4)
Two lanes	131	(60.9)	3,149	(62.3)	3,280	(62.2)	6,591	(59.4)	9,871	(60.3)
Three lanes	15	(7.0)	739	(14.6)	754	(14.3)	1,329	(12.0)	2,083	(12.7)
Four lanes	49	(22.8)	839	(16.6)	888	(16.6)	2,236	(20.1)	3,124	(19.1)
Five lanes	8	(3.7)	121	(2.4)	129	(2.4)	383	(3.4)	512	(3.1)
Six lanes	7	(3.3)	116	(2.3)	123	(2.3)	303	(2.7)	426	(2.6)
Seven or more lanes	2	(0.9)	50	(1.0)	52	(1.0)	87	(0.8)	139	(0.8)
Unknown	8	—	74	—	82	—	241	—	323	—
Total	223	(100.0)	5,129	(100.0)	5,352	(100.0)	11,348	(100.0)	16,700	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 10. FARS midblock pedestrian fatalities by presence and type of median (2005–2009).

Median type	Number (percent) of fatalities by median type									
	Midblock—in crosswalk		Midblock—near crosswalk		Midblock—crosswalk total		Midblock—no crosswalk		All midblock locations	
Not divided	142	(64.8)	2,716	(53.5)	2,858	(53.9)	5,317	(47.5)	8,157	(49.6)
Median—no barrier	39	(17.8)	1,370	(27.0)	1,409	(26.7)	2,690	(24.0)	4,099	(24.9)
Median—with barrier	17	(7.8)	666	(13.1)	683	(12.9)	1,961	(17.5)	2,644	(16.0)
Not divided—one way traffic	7	(3.2)	67	(1.3)	74	(1.4)	181	(1.6)	255	(1.5)
Not divided—two way left-turn lane	13	(5.9)	233	(4.6)	246	(4.6)	869	(7.8)	1,115	(6.8)
Entrance/exit ramp	1	(0.5)	27	(0.5)	28	(0.5)	176	(1.6)	204	(1.2)
Unknown	4	—	50	—	54	—	154	—	208	—
Total	223	(100.0)	5,129	(100.0)	5,352	(100.0)	11,348	(100.0)	16,700	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 11. FARS midblock pedestrian fatalities by posted speed limit (2005–2009).

Posted speed limit (mi/h)	Number (percent) of fatalities by posted speed limit									
	Midblock—in crosswalk		Midblock—near crosswalk		Midblock—crosswalk total		Midblock—no crosswalk		All midblock locations	
No limit	2	(0.9)	5	(0.1)	7	(0.1)	46	(0.4)	53	(0.3)
5	0	(0.0)	3	(0.1)	3	(0.1)	5	(0.0)	8	(0.0)
10	1	(0.5)	6	(0.1)	7	(0.1)	7	(0.1)	14	(0.1)
15	2	(0.9)	17	(0.3)	19	(0.4)	41	(0.4)	60	(0.4)
20	6	(2.8)	24	(0.5)	30	(0.6)	47	(0.4)	77	(0.5)
25	33	(15.6)	382	(7.8)	415	(8.1)	670	(6.1)	1,085	(6.8)
30	30	(14.2)	482	(9.9)	512	(10.0)	739	(6.7)	1,251	(7.8)
35	74	(34.9)	891	(18.2)	965	(18.9)	1,509	(13.8)	2,474	(15.4)
40	27	(12.7)	597	(12.2)	624	(12.2)	1,070	(9.8)	1,694	(10.6)
45	26	(12.3)	1,018	(20.8)	1,044	(20.6)	1,829	(16.7)	2,873	(18.0)
50	7	(3.3)	225	(4.6)	232	(4.5)	555	(5.1)	787	(4.9)
55	4	(1.9)	766	(15.7)	770	(15.1)	2,045	(18.7)	2,815	(17.5)
60	0	(0.0)	121	(2.5)	121	(2.4)	521	(4.8)	642	(4.0)
65	0	(0.0)	226	(4.6)	226	(4.4)	1,353	(12.4)	1,579	(9.8)
70	0	(0.0)	111	(2.3)	111	(2.2)	440	(4.0)	551	(3.4)
75	0	(0.0)	17	(0.3)	17	(0.3)	71	(0.6)	88	(0.5)
95	0	(0.0)	0	(0.0)	0	(0.0)	1	(0.0)	1	(0.0)
Unknown	11	—	238	—	249	—	399	—	648	—
Total	223	(100.0)	5,129	(100.0)	5,352	(100.0)	11,348	(100.0)	16,700	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 12. Midblock pedestrian fatalities by weather condition (2005–2009).

Weather condition	Number (percent) of fatalities by pedestrian location									
	Midblock—in crosswalk		Midblock—near crosswalk		Midblock—crosswalk total		Midblock—no crosswalk		All midblock locations	
Clear/cloudy	205	(92.0)	4,566	(89.3)	4,771	(89.3)	10,144	(90.0)	14,915	(89.8)
Rain/sleet	13	(5.8)	454	(8.9)	467	(8.9)	865	(7.7)	1,332	(8.0)
Snow	4	(1.8)	39	(0.8)	43	(0.8)	95	(0.8)	138	(0.8)
Fog	0	(0.0)	43	(0.8)	43	(0.8)	126	(1.1)	169	(1.0)
Wind	0	(0.0)	1	(0.0)	1	(0.0)	10	(0.1)	11	(0.1)
Blow sand	0	(0.0)	0	(0.0)	0	(0.0)	2	(0.0)	2	(0.0)
Other	1	(0.4)	8	(0.2)	9	(0.2)	31	(0.3)	40	(0.2)
Unknown	0	—	18	—	18	—	75	—	93	—
Total	223	(100.0)	5,129	(100.0)	5,352	(100.0)	11,348	(100.0)	16,700	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 13. FARS midblock pedestrian fatalities by road surface condition (2005–2009).

Road surface condition	Number (percent) of fatalities by pedestrian location									
	Midblock—in crosswalk		Midblock—near crosswalk		Midblock—crosswalk total		Midblock—no crosswalk		All midblock locations	
Dry	199	(89.3)	4,298	(84.1)	4,497	(84.3)	9,741	(86.4)	14,238	(85.7)
Wet	21	(9.4)	725	(14.2)	746	(14.0)	1,340	(11.9)	2,086	(12.6)
Snowy, icy	3	(1.3)	80	(1.6)	83	(1.6)	173	(1.5)	156	(0.9)
Sand	0	(0.0)	0	(0.0)	0	(0.0)	6	(0.1)	6	(0.0)
Water/other	0	(0.0)	9	(0.2)	9	(0.2)	10	(0.1)	19	(0.1)
Unknown	0	—	17	—	17	—	78	—	95	—
Total	223	(100.0)	5,129	(100.0)	5,352	(100.0)	11,348	(100.0)	16,700	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 14. FARS midblock pedestrian fatalities by light condition (2005–2009).

Light condition	Number (percent) of fatalities by pedestrian location									
	Midblock—in crosswalk		Midblock—near crosswalk		Midblock—crosswalk total		Midblock—no crosswalk		All midblock locations	
Daylight	112	(50.2)	1,098	(21.5)	1,210	(22.7)	2,516	(22.3)	3,726	(22.5)
Dusk-dawn	8	(3.7)	218	(4.3)	226	(4.2)	400	(3.6)	626	(3.8)
Dark-street lights	71	(31.8)	1,840	(36.0)	1,983	(37.2)	4,762	(42.3)	6,745	(40.7)
Dark-no street lights	32	(14.3)	1,951	(38.2)	1,911	(35.9)	3,582	(31.8)	5,493	(33.1)
Unknown	0	—	22	—	22	—	88	—	110	—
Total	223	(100.0)	5,129	(100.0)	5,352	(100.0)	11,348	(100.0)	16,700	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 15. FARS midblock pedestrian fatalities by hour of day (2005–2009).

Hour of day	Number (percent) of fatalities by pedestrian location									
	Midblock—in crosswalk		Midblock—near crosswalk		Midblock—crosswalk total		Midblock—no crosswalk		All midblock locations	
12–12:59 a.m.	3	(1.3)	213	(4.2)	216	(4.1)	521	(4.6)	737	(4.4)
1–1:59 a.m.	7	(3.1)	242	(4.8)	249	(4.7)	541	(4.8)	790	(4.8)
2–2:59 a.m.	3	(1.3)	215	(4.2)	218	(4.1)	630	(5.6)	848	(5.1)
3–3:59 a.m.	0	(0.0)	168	(3.3)	168	(3.2)	420	(3.7)	588	(3.5)
4–4:59 a.m.	1	(0.4)	144	(2.8)	145	(2.7)	342	(3.0)	487	(2.9)
5–5:59 a.m.	2	(0.9)	167	(3.3)	169	(3.2)	431	(3.8)	600	(3.6)
6–6:59 a.m.	12	(5.4)	220	(4.3)	232	(4.4)	436	(3.9)	668	(4.0)
7–7:59 a.m.	13	(5.9)	111	(2.2)	124	(2.3)	223	(2.0)	347	(2.1)
8–8:59 a.m.	19	(8.5)	81	(1.6)	100	(1.9)	153	(1.4)	253	(1.5)
9–9:59 a.m.	9	(4.0)	73	(1.4)	82	(1.5)	156	(1.4)	238	(1.4)
10–10:59 a.m.	13	(5.8)	77	(1.5)	90	(1.7)	149	(1.3)	239	(1.4)
11–11:59 a.m.	7	(3.1)	83	(1.6)	90	(1.7)	165	(1.5)	255	(1.5)
Noon–12:59 p.m.	6	(2.7)	82	(1.6)	88	(1.7)	207	(1.8)	295	(1.8)
1–1:59 p.m.	2	(0.9)	72	(1.4)	74	(1.4)	208	(1.8)	282	(1.7)
2–2:59 p.m.	7	(3.1)	82	(1.6)	89	(1.7)	224	(2.0)	313	(1.9)
3–3:59 p.m.	7	(3.1)	110	(2.2)	117	(2.2)	242	(2.1)	359	(2.2)
4–4:59 p.m.	11	(4.9)	126	(2.5)	137	(2.6)	274	(2.4)	411	(2.5)
5–5:59 p.m.	20	(9.1)	263	(5.2)	283	(5.3)	521	(4.6)	804	(4.8)
6–6:59 p.m.	20	(9.1)	420	(8.2)	440	(8.3)	848	(7.5)	1,288	(7.8)
7–7:59 p.m.	15	(6.7)	427	(8.4)	442	(8.3)	954	(8.5)	1,396	(8.4)
8–8:59 p.m.	11	(4.9)	503	(9.9)	514	(9.7)	1017	(9.0)	1,531	(9.2)
9–9:59 p.m.	16	(7.3)	515	(10.1)	531	(10.0)	1075	(9.5)	1,606	(9.7)
10–10:59 p.m.	10	(4.5)	401	(7.9)	411	(7.7)	857	(7.6)	1,268	(7.6)
11–11:59 p.m.	9	(4.0)	299	(5.9)	308	(5.8)	682	(6.0)	990	(6.0)
Unknown	0	—	35	—	35	—	72	—	107	—
Total	223	(100.0)	5,129	(100.0)	5,352	(100.0)	11,348	(100.0)	16,700	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 16. FARS midblock pedestrian fatalities by day of week (2005–2009).

Day of week	Number (percent) of fatalities by pedestrian location									
	Midblock—in crosswalk		Midblock—near crosswalk		Midblock—crosswalk total		Midblock—no crosswalk		All midblock locations	
Sunday	33	(14.8)	729	(14.2)	762	(14.2)	1,764	(15.5)	2,526	(15.1)
Monday	25	(11.2)	636	(12.4)	661	(12.4)	1,385	(12.2)	2,046	(12.3)
Tuesday	32	(14.3)	637	(12.4)	669	(12.5)	1,414	(12.5)	2,083	(12.5)
Wednesday	35	(15.7)	676	(13.2)	711	(13.3)	1,487	(13.1)	2,198	(13.2)
Thursday	33	(14.8)	658	(12.8)	691	(12.9)	1,406	(12.4)	2,097	(12.6)
Friday	36	(16.2)	827	(16.1)	863	(16.1)	1,821	(16.0)	2,684	(16.0)
Saturday	29	(13.0)	966	(18.9)	995	(18.6)	2,071	(18.3)	3,066	(18.3)
Total	223	(100.0)	5,129	(100.0)	5,352	(100.0)	11,348	(100.0)	16,700	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

FARS Data by State

Table 17 presents the frequencies of fatal pedestrian crashes at midblock locations by State. Clearly the fatal crash frequencies are strongly influenced by State population; however, the extent of walking activity and the pedestrian age distribution also likely have an important role. For example, Florida has the highest frequency of fatal pedestrian crashes at midblock crosswalk locations in the United States and nearly as high a frequency of total midblock crashes as California, the most populous State.

The data in table 17 also suggest inconsistencies in the classification of midblock "in crosswalk" versus "near crosswalk" crashes, because the frequency of crashes in midblock crosswalks in many States is so small.

Table 17. FARS midblock pedestrian fatalities by State (2005–2009).

	Number (percent) of fatalities by pedestrian location				
State	**Midblock— in crosswalk**	**Midblock— near crosswalk**	**Midblock— crosswalk total**	**Midblock— no crosswalk**	**All midblock locations**
Alabama	1	146	147	156	303
Alaska	0	14	14	10	24
Arizona	9	36	45	440	485
Arkansas	0	30	30	116	146
California	53	241	294	2,016	2,310
Colorado	3	25	28	147	175
Connecticut	2	2	4	120	124
Delaware	1	9	10	58	68
District of Columbia	0	34	34	6	40
Florida	7	1,262	1,269	691	1,960
Georgia	26	450	476	173	649
Hawaii	8	20	28	41	69
Idaho	0	29	29	10	39
Illinois	2	94	96	372	468
Indiana	0	196	196	19	215
Iowa	1	5	6	73	79
Kansas	1	52	53	25	78
Kentucky	0	33	33	170	203
Louisiana	1	39	40	384	424
Maine	1	17	18	17	35
Maryland	4	377	381	42	423
Massachusetts	16	65	81	121	202
Michigan	2	3	5	492	497
Minnesota	1	42	43	57	100
Mississippi	0	7	7	264	271
Missouri	1	151	152	163	315
Montana	0	22	22	20	42
Nebraska	1	17	18	8	26
Nevada	10	84	94	95	189
New Hampshire	2	14	16	8	24
New Jersey	4	92	96	303	399
New Mexico	4	81	85	119	204
New York	9	289	298	438	736
North Carolina	2	49	51	688	739

State	Number (percent) of fatalities by pedestrian location				
	Midblock—in crosswalk	Midblock—near crosswalk	Midblock—crosswalk total	Midblock—no crosswalk	All midblock locations
North Dakota	1	10	11	11	22
Ohio	7	343	350	24	374
Oklahoma	3	8	11	198	209
Oregon	8	68	76	85	161
Pennsylvania	10	238	248	279	527
Rhode Island	1	14	15	25	40
South Carolina	1	45	46	460	506
South Dakota	0	9	9	23	32
Tennessee	1	70	71	180	251
Texas	7	80	87	1,603	1,690
Utah	4	25	29	45	74
Vermont	0	0	0	5	5
Virginia	2	43	45	232	277
Washington	3	97	100	96	196
West Virginia	0	22	22	66	88
Wisconsin	3	25	28	139	167
Wyoming	0	5	5	15	20
Total	223	5,129	5,352	11,348	16,700

FARS Data for FHWA Pedestrian Safety Focus States and Cities

Table 18 summarizes the FARS data for fatal midblock pedestrian crashes in FHWA's 13 Pedestrian Safety Focus States and 5 Pedestrian Safety Focus Cities, because they were designated during the period reported (2005–2009). Collectively, the 13 Pedestrian Safety Focus States experience 59 percent of the total U.S. fatal pedestrian crashes at or near midblock crossings, while the 5 Pedestrian Safety Focus Cities represent 6 percent of total U.S. fatal pedestrian crashes at or near midblock crossings.

Table 18. FARS midblock pedestrian fatalities for FHWA pedestrian safety focus States and cities (2005–2009).

State/city	Number of fatalities by pedestrian location				
	Midblock—in crosswalk	Midblock—near crosswalk	Midblock—crosswalk total	Midblock—no crosswalk	All midblock locations
Focus States					
Arizona	9	36	45	440	485
California	53	241	294	2,016	2,310
Florida	7	1,262	1,269	691	1,960
Georgia	26	450	476	173	649
Hawaii	8	20	28	41	69
Illinois	2	94	96	372	468
Nevada	10	84	94	95	189
New Jersey	4	92	96	303	399
New Mexico	4	81	85	119	204
New York	9	289	298	438	736
North Carolina	2	49	51	688	739
Pennsylvania	10	238	248	279	527
Texas	7	80	87	1,603	1,690
Focus Cities					
Chicago, IL	1	40	41	119	160
Los Angeles, CA	7	51	58	212	270
New York, NY	3	130	133	135	268
Phoenix, AZ	6	24	30	146	176
Washington, DC	0	39	39	15	54

NHTSA GES

GES is a database of a statistical sample of crashes from across the United States. These data are gathered in established primary sampling units (i.e., selected geographic areas) throughout the United States. The crash frequencies available in the GES database are shown in this section. The crash frequencies have not been inflated by sampling weights.

Table 19 summarizes the nationwide sample of crash data for all crash severity levels from GES. The database includes 680,316 crashes in the period from 2005 through 2009, inclusive. Of these crashes, 10,079 (1.5 percent) involved a pedestrian. Nearly half of the pedestrian crashes (46.7 percent) occurred at midblock locations, while the rest occurred at intersections. Only 127 (2.5 percent) of the 4,707 midblock pedestrian crashes were explicitly identified as midblock crossing crashes.

Because GES includes pedestrian crashes of all severity levels, table 20 presents the distribution of midblock pedestrian crashes by crash severity level. The table shows that midblock crossing crashes are typically less severe than pedestrian crashes elsewhere on the midblock roadway.

Table 21 presents GES data for pedestrian crashes by the type of traffic control device present. There was no control present for 65 percent of midblock crosswalk crashes and 91 percent of pedestrian crashes elsewhere on the midblock roadway. As in the FARS data, a small percentage of "midblock roadway" crashes are shown as having traffic signals, stop signs, or yield signs present. This may represent traffic control at driveways.

Table 19. Summary of GES pedestrian crash data (2005–2009).

Crashes	Number of crashes by year					
	2005	2006	2007	2008	2009	Combined
Total crashes	137,884	141,412	152,727	137,303	110,990	680,316
Pedestrian crashes	1,778	2,007	2,356	2,160	1,778	10,079
Pedestrian midblock crashes	796	892	1,186	1,015	818	4,707
Midblock roadway crashes	780	896	1,153	987	791	4,580
Pedestrian midblock crossing crashes	16	23	33	28	27	127

Table 20. GES midblock pedestrian crashes by injury severity (2005–2008).

Injury severity	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Fatal	5	(3.9)	342	(7.5)	347	(7.4)
Incapacitating injury	35	(27.6)	1,475	(32.3)	1,510	(32.1)
Nonincapacitating injury	78	(61.4)	2,451	(53.6)	2,529	(53.8)
Possible injury	7	(5.5)	237	(5.2)	244	(5.2)
Injury, severity unknown	1	(0.8)	44	(1.0)	45	(1.0)
Property damage only	1	(0.8)	22	(0.5)	23	(0.5)
Unknown	0	—	9	—	9	—
Total	127	(100.0)	4,580	(100.0)	4,707	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 21. GES midblock pedestrian crashes by traffic control device (2005–2009).

Traffic control device	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
No controls	78	(65.0)	4,016	(90.7)	4,094	(90.0)
Traffic signal	6	(5.0)	140	(3.2)	146	(3.2)
Flashing signal/beacon	3	(2.5)	5	(0.1)	8	(0.2)
Other signal	6	(5.0)	0	(0.0)	6	(0.1)
Unknown signal	1	(0.8)	0	(0.0)	1	(0.0)
Stop sign	10	(8.3)	71	(1.6)	81	(1.8)
Yield sign	1	(0.8)	3	(0.1)	4	(0.1)
School zone sign	0	(0.0)	11	(0.2)	11	(0.2)
Other sign	3	(2.5)	10	(0.2)	13	(0.3)
Unknown sign	0	(0.0)	1	(0.0)	1	(0.0)
Advisory speed sign	5	(4.2)	84	(1.9)	89	(2.0)
Warning sign for construction	0	(0.0)	10	(0.2)	10	(0.2)
Officer/crossing guard	1	(0.8)	36	(0.8)	37	(0.8)
Active device at RR crossing	0	(0.0)	1	(0.0)	1	(0.0)
Traffic control present—no details	3	(2.5)	4	(0.1)	7	(0.2)
Other	3	(2.5)	38	(0.9)	41	(0.9)
Unknown	7	—	150	—	157	—
Total	127	(100.0)	4,580	(100.0)	4,707	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 22 shows data for the GES variable called “pedestrian action,” which is similar to the FARS “pedestrian-related” factor. For midblock crosswalk crashes, 4.9 percent were classified as “improper crossing,” while a substantial number of other midblock crosswalk crashes were classified in categories closely related to “improper crossing”: dart/run into roadway, 13.1 percent; inattentive, 2.5 percent; and “playing, working, sitting, lying, etc., in the roadway,” 0.8 percent. The categories related to "improper crossing" taken together constitute 21.3 percent of midblock crosswalk crashes.

Table 22. GES midblock pedestrian crashes by pedestrian action (2005–2009).

Pedestrian action	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
No action	87	(71.3)	697	(15.8)	784	(17.3)
Dart/run into roadway	16	(13.1)	1,265	(28.7)	1,281	(28.3)
Improper crossing	6	(4.9)	1,222	(27.8)	1,228	(27.1)
Inattentive	3	(2.5)	33	(0.8)	36	(0.8)
Jogging	0	(0.0)	14	(0.3)	14	(0.3)
Pushing a vehicle	0	(0.0)	10	(0.2)	10	(0.2)
Walking with traffic	0	(0.0)	244	(5.5)	244	(5.4)
Walking against traffic	0	(0.0)	71	(1.6)	71	(1.6)
Playing, working, sitting, lying, etc, in roadway	1	(0.8)	508	(11.5)	509	(11.2)
Other	9	(7.4)	339	(7.7)	348	(7.7)
Unknown	5	—	177	—	182	—
Total	127	(100.0)	4,580	(100.0)	4,707	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 23 presents the distribution of midblock pedestrian crashes by pedestrian age. When crashes for a range of severity levels are included, there is a large proportion of crashes (more than 20 percent) for young pedestrians in the age range from 11 to 20 (i.e., primarily teenagers). In addition, as with the FARS data, there are relatively fewer crashes in the pedestrian age group from age 61 to 70 than in the age ranges on either side.

Table 23. GES midblock pedestrian crashes by pedestrian age (2005–2009).

Pedestrian age	Number (percent) of crashes by pedestrian age					
	Midblock crosswalk		Midblock roadway		Combined	
0 to 10	9	(7.1)	788	(17.2)	797	(16.9)
11 to 20	27	(21.3)	964	(21.0)	991	(21.1)
21 to 30	15	(11.8)	709	(15.5)	724	(15.4)
31 to 40	11	(8.7)	510	(11.1)	521	(11.1)
41 to 50	17	(13.4)	656	(14.3)	673	(14.3)
51 to 60	18	(14.2)	433	(9.5)	451	(9.6)
61 to 70	11	(8.7)	187	(4.1)	198	(4.2)
70+	19	(15.0)	333	(7.3)	352	(7.5)
All	127	(100.0)	4,580	(100.0)	4,707	(100.0)

Column percentages may not appear to add to 100 percent due to rounding.

Table 24 presents the distribution of midblock pedestrian crashes in the GES data by pedestrian gender. As with the FARS data, there is a more even balance in pedestrian gender at midblock crossings (actually more females than males), but a substantially higher proportion of male pedestrians involved at noncrosswalk locations.

Table 24. GES midblock pedestrian crashes by pedestrian gender (2005–2009).

Pedestrian gender	Number (percent) of crashes by pedestrian gender					
	Midblock crosswalk		Midblock roadway		Combined	
Male	58	(46.4)	2,908	(63.6)	2,966	(63.1)
Female	67	(53.6)	1,664	(36.4)	1,731	(36.9)
Unknown	2	—	8	—	10	—
Total	127	(100.0)	4,580	(100.0)	4,707	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 25 summarizes the GES pedestrian crash data by the number of lanes crossed. While interesting, these data are not very meaningful without exposure data on the number of lanes crossed by pedestrians who were not killed in crashes. The same is true for table 26, which categorizes pedestrian crashes by the presence of a median, and thus a pedestrian refuge area, on the roadway crossed and table 27, which categorizes crashes by the posted speed limit at the crash location.

Table 25. GES midblock pedestrian crashes by number of travel lanes crossed (2005–2009).

Number of travel lanes crossed	Number (percent) of crashes by number of travel lanes crossed					
	Midblock crosswalk		Midblock roadway		Combined	
One	9	(11.1)	208	(6.0)	217	(6.1)
Two	43	(53.1)	1,926	(55.9)	1,969	(55.8)
Three	6	(7.4)	436	(12.6)	442	(12.5)
Four	17	(21.0)	501	(14.5)	518	(14.7)
Five	5	(6.2)	302	(8.7)	307	(8.7)
Six	0	(0.0)	44	(1.3)	44	(1.2)
Seven or more	1	(1.2)	36	(1.0)	37	(1.0)
Unknown	46	—	1,127	—	1,173	—
Total	127	(100.0)	4,580	(100.0)	4,707	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 26. GES midblock pedestrian crashes by presence of median (2005–2009).

Presence of median	Number (percent) of crashes by presence of median					
	Midblock crosswalk		Midblock roadway		Combined	
Not physically divided (center two-way left turn lane)	3	(2.8)	236	(6.4)	239	(6.3)
Not physically divided (two way traffic)	80	(75.5)	2,390	(64.5)	2,470	(64.8)
Divided trafficway (median strip, barrier, etc)	22	(20.8)	864	(23.3)	886	(23.2)
One way traffic	1	(0.9)	216	(5.8)	217	(5.7)
Unknown	21	—	874	—	895	—
Total	127	(100.0)	4,580	(100.0)	4,707	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 27. GES midblock pedestrian crashes by posted speed limit (2005–2009).

Posted speed limit (mi/h)	Number (percent) of crashes by posted speed limit					
	Midblock crosswalk		Midblock roadway		Combined	
No limit	33	(31.1)	125	(3.4)	158	(4.2)
5	0	(0.0)	11	(0.3)	11	(0.3)
10	1	(0.9)	18	(0.5)	19	(0.5)
15	5	(4.7)	75	(2.0)	80	(2.1)
20	5	(4.7)	92	(2.5)	97	(2.6)
25	22	(20.8)	918	(25.0)	940	(24.8)
30	13	(12.3)	553	(15.0)	566	(15.0)
35	21	(19.8)	863	(23.5)	884	(23.4)
40	2	(1.9)	318	(8.6)	320	(8.5)
45	3	(2.8)	371	(10.1)	374	(9.9)
50	0	(0.0)	60	(1.6)	60	(1.6)
55	1	(0.9)	122	(3.3)	123	(3.3)
60	0	(0.0)	75	(2.0)	75	(2.0)
65	0	(0.0)	50	(1.4)	50	(1.3)
70	0	(0.0)	24	(0.7)	24	(0.6)
75	0	(0.0)	3	(0.1)	3	(0.1)
Unknown	21	—	902	—	923	—
Total	127	(100.0)	4,580	(100.0)	4,707	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 28 through table 31 present GES data for pedestrian crashes at midblock locations classified by weather condition, road surface condition, hour of the day, and light condition.

Table 28. GES midblock pedestrian crashes by weather condition (2005–2009).

Weather condition	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Clear/cloudy	111	(87.4)	4,077	(90.5)	4,188	(90.4)
Rain/sleet	14	(11.0)	354	(7.9)	368	(7.9)
Snow	0	(0.0)	47	(1.0)	47	(1.0)
Fog	0	(0.0)	8	(0.2)	8	(0.2)
Rain and fog	0	(0.0)	1	(0.0)	1	(0.0)
Other	2	(1.6)	18	(0.4)	20	(0.4)
Unknown	0	—	75	—	75	—
Total	127	(100.0)	4,580	(100.0)	4,707	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 29. GES midblock pedestrian crashes by road surface condition (2005–2009).

Road surface condition	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Dry	104	(81.9)	3,880	(86.1)	3,984	(86.0)
Wet	20	(15.7)	551	(12.2)	571	(12.3)
Snowy, icy	3	(2.4)	72	(1.6)	75	(1.6)
Other	0	(0.0)	3	(0.1)	3	(0.1)
Unknown	0	—	74	—	74	—
Total	127	(100.0)	4,580	(100.0)	4,707	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 30. GES midblock pedestrian crashes by hour of day (2005–2009).

Hour of day	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		**Midblock roadway**		**Combined**	
12–12:59 a.m.	0	(0.0)	133	(2.9)	133	(2.9)
1–1:59 a.m.	0	(0.0)	91	(2.0)	91	(2.0)
2–2:59 a.m.	0	(0.0)	108	(2.4)	108	(2.3)
3–3:59 a.m.	0	(0.0)	78	(1.7)	78	(1.7)
4—4:59 a.m.	0	(0.0)	41	(0.9)	41	(0.9)
5–5:59 a.m.	1	(0.8)	55	(1.2)	56	(1.2)
6–6:59 a.m.	2	(1.6)	94	(2.1)	96	(2.1)
7–7:59 a.m.	8	(6.3)	173	(3.8)	181	(3.9)
8–8:59 a.m.	10	(7.9)	122	(2.7)	132	(2.8)
9–9:59 a.m.	2	(1.6)	117	(2.6)	119	(2.6)
10–10:59 a.m.	12	(9.5)	111	(2.4)	123	(2.6)
11–11:59 a.m.	7	(5.6)	138	(3.0)	145	(3.1)
Noon–12:59 p.m.	5	(4.0)	169	(3.7)	174	(3.7)
1–1:59 p.m.	4	(3.2)	179	(3.9)	183	(3.9)
2–2:59 p.m.	13	(10.3)	236	(5.2)	249	(5.3)
3–3:59 p.m.	9	(7.1)	295	(6.5)	304	(6.5)
4–4:59 p.m.	11	(8.7)	335	(7.4)	346	(7.4)
5–5:59 p.m.	6	(4.8)	384	(8.5)	390	(8.4)
6–6:59 p.m.	6	(4.8)	402	(8.9)	408	(8.8)
7–7:59 p.m.	14	(11.1)	345	(7.6)	359	(7.7)
8–8:59 p.m.	5	(4.0)	281	(6.2)	286	(6.1)
9–9:59 p.m.	4	(3.2)	291	(6.4)	295	(6.3)
10–10:59 p.m.	5	(4.0)	218	(4.8)	223	(4.8)
11–11:59 pm	2	(1.6)	137	(3.0)	139	(3.0)
Unknown	1	—	47	—	48	—
Total	127	(100.0)	4,580	(100.0)	4,707	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 31. GES midblock pedestrian crashes by light condition (2005–2009).

Light condition	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		**Midblock roadway**		**Combined**	
Daylight	90	(71.4)	2,429	(53.5)	2,519	(54.0)
Dusk-dawn	2	(1.6)	186	(4.1)	188	(4.0)
Dark-street lights	27	(21.4)	1,252	(27.6)	1,279	(27.4)
Dark-no street lights	7	(5.6)	670	(14.8)	677	(14.5)
Unknown	1	—	43	—	44	—
Total	127	(100.0)	4,580	(100.0)	4,707	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

California

HSIS data for California include crash data only for the State highway system, consisting of approximately 15,520 mi of highways. While some city streets and many small town "main streets" and suburban arterials are State highways, many of the areas with the highest concentrations of pedestrians in California are away from the State highway system. Data analyzed for this report include the years from 2006 to 2008, inclusive. Earlier years of data were not used because of changes in the coding of a key variable.

Table 32 shows that, during the study period, 526,898 crashes occurred on the California State highway system. Of these, 3,944 (0.7 percent) were pedestrian crashes. Nearly 70 percent of the pedestrian crashes occurred at midblock locations. Only 76 crashes (2.6 percent of the midblock crashes) were classified as occurring at midblock crosswalks.

Table 32. Summary of pedestrian crash data for California State highways (2006–2008).

Crashes	Number of crashes by year			
	2006	2007	2008	Combined
Total crashes	189,089	180,122	157,687	526,898
Pedestrian crashes	1,426	1,263	1,255	3,944
Pedestrian midblock crashes	1,057	932	917	2,906
Pedestrian midblock roadway crashes	768	637	650	2,055
Pedestrian midblock crossing crashes	20	24	32	76

Table 33 shows the relative frequencies of California crashes by midblock crosswalks and other midblock roadway locations.

Table 33. Midblock pedestrian crashes on California State highways by pedestrian location (2006–2008).

Years	Number (percent) of crashes by pedestrian location				
	Midblock crosswalk		Midblock roadway		Combined
2006	20	(2.5)	768	(97.5)	788
2007	24	(3.6)	637	(96.4)	661
2008	32	(4.7)	650	(95.3)	682
Total	76	(3.6)	2,055	(96.4)	2,131

Percentages in this table are row percentages.

Table 34 classifies midblock pedestrian crashes in California by crash severity level. As observed in the GES data, crash severities appear to be lower for midblock crosswalk crashes than for other pedestrian crashes on the midblock roadway.

Table 34. Midblock pedestrian crashes on California State highways by injury severity (2006–2008).

Injury severity	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Fatal	1	(1.3)	517	(25.2)	518	(24.3)
Severe injury	15	(19.7)	447	(21.8)	462	(21.7)
Other visible injury	23	(30.3)	566	(27.5)	589	(27.6)
Complaint/pain	33	(43.4)	406	(19.8)	439	(20.6)
Property damage only	4	(5.3)	119	(5.8)	123	(5.8)
Total	76	(100.0)	2,055	(100.0)	2,131	(100.0)

Column percentages may not appear to add to 100 percent due to rounding.

Table 35 classifies midblock pedestrian crashes by whether they occurred on a divided or undivided roadway. Approximately 75 percent of pedestrian midblock crashes occurred on an undivided roadway.

Table 35. Midblock pedestrian crashes on California State highways by presence of median (2006–2008).

Presence of median	Number (percent) of crashes by presence of median					
	Midblock crosswalk		Midblock roadway		Combined	
Undivided	56	(73.7)	1,551	(76.2)	1,607	(76.1)
Divided	20	(26.3)	484	(23.8)	504	(23.9)
Unknown	0	—	20	—	20	—
Total	76	(100.0)	2,055	(100.0)	2,131	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 36 classifies midblock pedestrian crashes in California by whether traffic control devices were present and functioning. Most pedestrian crashes, including midblock crosswalk crashes, occurred at locations with no controls present. Presumably, this refers to traffic signals or stop signs, because clearly, crosswalk markings (by definition) and signing were present at marked crosswalks.

Table 36. Midblock pedestrian crashes on California State highways by traffic control device operating (2006–2008).

Traffic control device operating	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Control functioning	32	(42.1)	305	(14.8)	337	(15.8)
Control not functioning	1	(1.3)	7	(0.3)	8	(0.4)
Controls obscured	0	(0.0)	1	(0.0)	1	(0.0)
No controls present	43	(56.6)	1,742	(84.9)	1,785	(83.8)
Total	76	(100.0)	2,055	(100.0)	2,131	(100.0)

Column percentages may not appear to add to 100 percent due to rounding.

Table 37 through table 43 present California data for pedestrian crashes at midblock locations classified by collision factors (contributing circumstances), weather condition, vehicle type at fault, road surface condition, light condition, hour of the day, and day of the week.

Table 37. Midblock pedestrian crashes on California State highways by collision factor (2006–2008).

	Number (percent) of crashes by pedestrian location					
Collision factor	**Midblock crosswalk**		**Midblock roadway**		**Combined**	
Driving/bicycling under influence	1	(1.4)	119	(6.1)	120	(6.0)
Impeding traffic	0	(0.0)	7	(0.4)	7	(0.3)
Unsafe speed	2	(2.8)	379	(19.5)	381	(18.9)
Following too closely	0	(0.0)	3	(0.2)	3	(0.1)
Wrong side of road	0	(0.0)	11	(0.6)	11	(0.5)
Improper passing	0	(0.0)	10	(0.5)	10	(0.5)
Unsafe lane change	0	(0.0)	17	(0.9)	17	(0.8)
Improper turning	3	(4.2)	210	(10.8)	213	(10.6)
Auto right of way	1	(1.4)	7	(0.4)	8	(0.4)
Pedestrian right of way	52	(73.2)	35	(1.8)	87	(4.3)
Pedestrian violation	11	(15.5)	1,011	(52.1)	1,022	(50.8)
Traffic signals and signs	0	(0.0)	2	(0.1)	2	(0.1)
Hazardous parking	0	(0.0)	8	(0.4)	8	(0.4)
Brakes	0	(0.0)	1	(0.1)	1	(0.0)
Other equipment	0	(0.0)	5	(0.3)	5	(0.2)
Other hazard violations	0	(0.0)	13	(0.7)	13	(0.6)
Other than driver (or pedestrian)	0	(0.0)	48	(2.5)	48	(2.4)
Unsafe start/brake	1	1.4	48	(2.5)	49	(2.4)
Other improper driving	0	(0.0)	5	(0.3)	5	(0.2)
Pedestrian/other under influence	0	(0.0)	1	(0.1)	1	(0.0)
Unknown	5	—	115	—	120	—
Total	76	(100.0)	2,055	(100.0)	2,131	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 38. Midblock pedestrian crashes on California State highways by weather condition (2006–2008).

	Number (percent) of crashes by pedestrian location					
Weather condition	**Midblock crosswalk**		**Midblock roadway**		**Combined**	
Clear	62	(81.6)	1,608	(78.6)	1,670	(78.7)
Cloudy	12	(15.8)	325	(15.9)	337	(15.9)
Raining	2	(2.6)	70	(3.4)	72	(3.4)
Snowing	0	(0.0)	19	(0.9)	19	(0.9)
Fog	0	(0.0)	21	(1.0)	21	(1.0)
Other	0	(0.0)	2	(0.1)	2	(0.1)
Unknown	0	—	10	—	10	—
Total	76	(100.0)	2,055	(100.0)	2,131	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 39. Midblock pedestrian crashes on California State highways by vehicle type at fault (2006–2008).

Vehicle type at fault	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Not applicable	11	(14.5)	228	(11.1)	239	(11.2)
Passenger car/station wagon	46	(60.5)	536	(26.1)	582	(27.3)
Passenger car w/trailer	0	(0.0)	1	(0.0)	1	(0.0)
Motorcycle	0	(0.0)	12	(0.6)	12	(0.6)
Pickup/panel truck	9	(11.8)	146	(7.1)	155	(7.3)
Pickup/panel truck w/trailer	0	(0.0)	7	(0.3)	7	(0.3)
Truck/truck tractor	0	(0.0)	21	(1.0)	21	(1.0)
Truck tractor w/1 trailer	0	(0.0)	42	(2.0)	42	(2.0)
Other bus	0	(0.0)	4	(0.2)	4	(0.2)
Emergency vehicle	0	(0.0)	3	(0.1)	3	(0.1)
Highway construction equipment	0	(0.0)	1	(0.0)	1	(0.0)
Bicycle	0	(0.0)	3	(0.1)	3	(0.1)
Other motor vehicle	0	(0.0)	4	(0.2)	4	(0.2)
Other non-motor vehicle	10	(13.2)	1,047	(50.9)	1,057	(49.6)
Total	76	(100.0)	2,055	(100.0)	2,131	(100.0)

Column percentages may not appear to add to 100 percent due to rounding.

Table 40. Midblock pedestrian crashes on California State highways by road surface condition (2006–2008).

Road surface condition	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Dry	68	(89.5)	1,805	(88.2)	1,873	(88.2)
Wet	8	(10.5)	175	(8.5)	183	(8.6)
Snowy, icy	0	(0.0)	63	(3.1)	63	(3.0)
Slippery/muddy	0	(0.0)	4	(0.2)	4	(0.2)
Unknown	0	—	8	—	8	—
Total	76	(100.0)	2,055	(100.0)	2,131	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 41. Midblock pedestrian crashes on California State highways by light condition (2006–2008).

Light condition	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Daylight	40	(52.6)	675	(33.0)	715	(33.7)
Dusk-dawn	3	(3.9)	62	(3.0)	65	(3.1)
Dark-street lights	23	(30.3)	622	(30.4)	645	(30.4)
Dark-no street lights	7	(9.2)	672	(32.8)	679	(32.0)
Dark-light not functioning	3	(3.9)	15	(0.7)	18	(0.8)
Unknown	0	—	9	—	9	—
Total	76	(100.0)	2,055	(100.0)	2,131	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 42. Midblock pedestrian crashes on California State highways by hour of day (2006-2008).

Hour of day	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
12–12:59 a.m.	1	(1.3)	88	(4.3)	89	(4.2)
1–1:59 a.m.	0	(0.0)	94	(4.6)	94	(4.4)
2–2:59 a.m.	1	(1.3)	112	(5.5)	113	(5.3)
3–3:59 a.m.	0	(0.0)	87	(4.2)	87	(4.1)
4–4:59 a.m.	0	(0.0)	59	(2.9)	59	(2.8)
5–5:59 a.m.	1	(1.3)	64	(3.1)	65	(3.1)
6–6:59 a.m.	2	(2.6)	45	(2.2)	47	(2.2)
7–7:59 a.m.	4	(5.3)	50	(2.4)	54	(2.5)
8–8:59 a.m.	5	(6.6)	34	(1.7)	39	(1.8)
9–9:59 a.m.	0	(0.0)	56	(2.7)	56	(2.6)
10–10:59 a.m.	1	(1.3)	43	(2.1)	44	(2.1)
11–11:59 a.m.	4	(5.3)	38	(1.9)	42	(2.0)
Noon–12:59 p.m.	0	(0.0)	60	(2.9)	60	(2.8)
1–1:59 p.m.	2	(2.6)	66	(3.2)	68	(3.2)
2–2:59 p.m.	7	(9.2)	69	(3.4)	76	(3.6)
3–3:59 p.m.	7	(9.2)	85	(4.1)	92	(4.3)
4–4:59 p.m.	3	(3.9)	90	(4.4)	93	(4.4)
5–5:59 p.m.	8	(10.5)	91	(4.4)	99	(4.7)
6–6:59 p.m.	11	(14.5)	133	(6.5)	144	(6.8)
7–7:59 pm	5	(6.6)	132	(6.4)	137	(6.4)
8–8:59 p.m.	5	(6.6)	146	(7.1)	151	(7.1)
9–9:59 p.m.	2	(2.6)	147	(7.2)	149	(7.0)
10–10:59 p.m.	5	(6.6)	146	(7.1)	151	(7.1)
11–11:59 p.m.	2	(2.6)	118	(5.7)	120	(5.6)
Unknown	0	—	2	—	2	—
Total	76	(100.0)	2,055	(100.0)	2,131	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 43. Midblock pedestrian crashes on California State highways by day of the week (2006–2008).

Day of week	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Sunday	9	(11.8)	295	(14.4)	304	(14.3)
Monday	9	(11.8)	267	(13.0)	276	(13.0)
Tuesday	18	(23.7)	266	(12.9)	284	(13.3)
Wednesday	10	(13.2)	237	(11.5)	247	(11.6)
Thursday	12	(15.8)	332	(16.2)	344	(16.1)
Friday	10	(13.2)	349	(17.0)	359	(16.8)
Saturday	8	(10.5)	309	(15.0)	317	(14.9)
Total	76	(100.0)	2,055	(100.0)	2,131	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Minnesota

HSIS data for Minnesota include crash data for nearly all crashes statewide, including those that occurred on both State-maintained and local-agency-maintained road systems. Data analyzed for this report include the years 2003 to 2007, inclusive.

Table 44 shows that, during the study period, 406,786 crashes occurred in Minnesota. Of these, 8,271 (2.0 percent) were pedestrian crashes. Approximately 29 percent of these pedestrian crashes occurred at midblock locations. Only 71 pedestrian crashes (3.0 percent of all midblock pedestrian crashes) are classified as occurring at midblock crosswalks.

Table 45 shows the relative frequency of Minnesota crashes by midblock crosswalk and other midblock roadway locations.

Table 46 classifies midblock pedestrian crashes in Minnesota by crash severity level. In contrast to other States, the proportion of fatal and incapacitating injury crashes is higher for midblock crosswalks than for other midblock locations in Minnesota, but the sample size for midblock crosswalk crashes is so low that this may not be a valid comparison.

Table 44. Summary of pedestrian crash data for Minnesota State highways (2003–2007).

Crashes	Number of crashes by year					
	2003	**2004**	**2005**	**2006**	**2007**	**Combined**
Total crashes	79,825	86,719	85,447	77,243	77,552	406,786
Pedestrian crashes	1,125	1,500	1,844	1,909	1,893	8,271
Pedestrian midblock crashes	377	459	520	492	541	2,389
Pedestrian midblock roadway crashes	277	318	337	313	353	1,598
Pedestrian midblock crossing crashes	14	13	20	11	13	71

Table 45. Midblock pedestrian crashes on Minnesota State highways by pedestrian location (2003–2007).

Year	Number (percent) of crashes by pedestrian location				
	Midblock crosswalk		**Midblock roadway**		**Combined**
2003	14	(4.8)	277	(95.2)	291
2004	13	(3.9)	318	(96.1)	331
2005	20	(5.6)	337	(94.4)	357
2006	11	(3.4)	313	(96.6)	324
2007	13	(3.5)	353	(96.5)	366
Total	71	(4.3)	1,598	(95.7)	1,669

Percentages in this table are row percentages.

Table 46. Midblock pedestrian crashes on Minnesota State highways by injury severity (2003–2007).

Injury severity	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Fatal	0	(0.0)	14	(0.9)	14	(0.8)
Incapacitating injury	5	(7.0)	55	(3.5)	60	(3.6)
Non-incapacitating injury	8	(11.3)	192	(12.1)	200	(12.0)
Possible injury	15	(21.1)	367	(23.0)	382	(23.0)
Property damage only	43	(60.6)	965	(60.6)	1008	(60.6)
Injury unknown	0	—	5	—	5	—
Total	71	(100.0)	1,598	(100.0)	1,669	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 47 classifies midblock pedestrian crashes in Minnesota by the type of traffic control device. The data for midblock roadways in table 45 include a substantial number of pedestrian crashes at either signals or stop signs; these crashes must either have occurred at nonintersection signals or stop signs (i.e., driveways) or the basic intersection versus nonintersection classification of the crashes is incorrect. Table 48 through table 52 present Minnesota data for pedestrian crashes at midblock locations classified by weather condition, road surface condition, light condition, hour of the day, and day of the week.

Table 47. Midblock pedestrian crashes on Minnesota State highways by traffic control device operating (2003–2007).

Traffic control device operating	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Traffic signals	8	11.3	253	(16.0)	261	(15.8)
Overhead flashers	2	2.8	1	(0.1)	3	(0.2)
Stop sign—all approaches	0	(0.0)	25	(1.6)	25	(1.5)
Stop sign—other	14	19.7	201	(12.7)	215	(13.0)
Yield sign	1	1.4	21	(1.3)	22	(1.3)
Officer, flagman, or school patrol	0	(0.0)	2	(0.1)	2	(0.1)
School bus stop arm	0	(0.0)	3	(0.2)	3	(0.2)
School zone sign	0	(0.0)	3	(0.2)	3	(0.2)
No passing zone	1	1.4	8	(0.5)	9	(0.5)
Railroad crossing—flashing lights	0	(0.0)	2	(0.1)	2	(0.1)
Railroad crossing—overhead flashers and gates	0	(0.0)	2	(0.1)	2	(0.1)
Other	4	5.6	9	(0.6)	13	(0.8)
Not applicable	41	57.7	1056	(66.6)	1097	(66.2)
Unknown	0	—	12	—	12	—
Total	71	(100.0)	1,598	(100.0)	1,669	(100.0)

— Indicates count not included in calculation of percentage
Column percentages may not appear to add to 100 percent due to rounding.

Table 48. Midblock pedestrian crashes on Minnesota State highways by weather condition (2003–2007).

Weather condition	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Clear	38	(53.5)	796	(50.2)	834	(50.4)
Cloudy	19	(26.8)	483	(30.5)	502	(30.3)
Raining	2	(2.8)	31	(2.0)	33	(2.0)
Snowing	10	(14.1)	168	(10.6)	178	(10.7)
Sleet/hail/freezing rain	0	(0.0)	67	(4.2)	67	(4.0)
Fog/smog/dust	0	(0.0)	7	(0.4)	7	(0.4)
Blowing sand/dust/snow	2	(2.8)	24	(1.5)	26	(1.6)
Severe crosswinds	0	(0.0)	3	(0.2)	3	(0.2)
Other	0	(0.0)	6	(0.4)	6	(0.4)
Unknown	0	—	13	—	13	—
Total	71	(100.0)	1,598	(100.0)	1,669	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 49. Midblock pedestrian crashes on Minnesota State highways by road surface condition (2003–2007).

Road surface condition	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Dry	26	(36.6)	740	(46.6)	766	(46.2)
Wet	6	(8.5)	197	(12.4)	203	(12.2)
Snow	12	(16.9)	185	(11.7)	197	(11.9)
Slush	2	(2.8)	54	(3.4)	56	(3.4)
Ice/packed snow	23	(32.4)	391	(24.6)	414	(25.0)
Debris	1	(1.4)	0	(0.0)	1	(0.1)
Other	1	(1.4)	20	(1.3)	21	(1.3)
Unknown	0	—	11	—	11	—
Total	71	(100.0)	1,598	(100.0)	1,669	(100.0)

— Indicates count not included in calculation of percentage
Column percentages may not appear to add to 100 percent due to rounding.

Table 50. Midblock pedestrian crashes on Minnesota State highways by light condition (2003–2007).

Light condition	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Daylight	37	(52.1)	944	(59.4)	981	(59.1)
Dusk-dawn	4	(5.6)	93	(5.8)	97	(5.8)
Dark-street lights on	22	(31.0)	386	(24.3)	408	(24.6)
Dark-no street lights	7	(9.9)	153	(9.6)	160	(9.6)
Dark-unknown lighting	1	(1.4)	13	(0.8)	14	(0.8)
Other	0	(0.0)	2	(0.1)	2	(0.1)
Unknown	0	—	7	—	7	—
Total	71	(100.0)	1,598	(100.0)	1,669	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 51. Midblock pedestrian crashes on Minnesota State highways by hour of day (2003–2007).

Hour of day	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
12–12:59 a.m.	2	(2.8)	27	(1.7)	29	(1.7)
1–1:59 a.m.	1	(1.4)	17	(1.1)	18	(1.1)
2–2:59 a.m.	1	(1.4)	32	(2.0)	33	(2.0)
3–3:59 a.m.	0	(0.0)	12	(0.8)	12	(0.7)
4–4:59 a.m.	0	(0.0)	10	(0.6)	10	(0.6)
5–5:59 a.m.	1	(1.4)	15	(0.9)	16	(1.0)
6–6:59 a.m.	1	(1.4)	44	(2.8)	45	(2.7)
7–7:59 a.m.	3	(4.2)	98	(6.1)	101	(6.1)
8–8:59 a.m.	3	(4.2)	92	(5.8)	95	(5.7)
9–9:59 a.m.	2	(2.8)	75	(4.7)	77	(4.6)
10–10:59 a.m.	2	(2.8)	70	(4.4)	72	(4.3)
11–11:59 a.m.	3	(4.2)	75	(4.7)	78	(4.7)
Noon–12:59 p.m.	4	(5.6)	81	(5.1)	85	(5.1)
1–1:59 p.m.	5	(7.0)	74	(4.6)	79	(4.7)
2–2:59 p.m.	2	(2.8)	113	(7.1)	115	(6.9)
3–3:59 p.m.	5	(7.0)	148	(9.3)	153	(9.2)
4–4:59 p.m.	7	(9.9)	118	(7.4)	125	(7.5)
5–5:59 p.m.	12	(16.9)	147	(9.2)	159	(9.5)
6–6:59 p.m.	0	(0.0)	95	(6.0)	95	(5.7)
7–7:59 p.m.	4	(5.6)	68	(4.3)	72	(4.3)
8–8:59 p.m.	2	(2.8)	61	(3.8)	63	(3.8)
9–9:59 p.m.	5	(7.0)	49	(3.1)	54	(3.2)
10–10:59 p.m.	6	(8.5)	52	(3.3)	58	(3.5)
11–11:59 p.m.	0	(0.0)	21	(1.3)	21	(1.3)
Unknown	0	—	4	—	4	—
Total	71	(100.0)	1,598	(100.0)	1,669	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 52. Midblock pedestrian crashes on Minnesota State highways by day of the week (2003–2007).

Day of week	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Sunday	7	(9.9)	190	(11.9)	197	(11.8)
Monday	6	(8.5)	228	(14.3)	234	(14.0)
Tuesday	9	(12.7)	239	(15.0)	248	(14.9)
Wednesday	12	(16.9)	257	(16.1)	269	(16.1)
Thursday	9	(12.7)	230	(14.4)	239	(14.3)
Friday	16	(22.5)	244	(15.3)	260	(15.6)
Saturday	12	(16.9)	210	(13.1)	222	(13.3)
Total	71	(100.0)	1,598	(100.0)	1,669	(100.0)

Column percentages may not appear to add to 100 percent due to rounding.

North Carolina

HSIS data for North Carolina include crash data for approximately 62,000 mi of the 77,000 mi of roadway on the State-maintained highway system. The State-maintained road system in North Carolina is much larger than the State-maintained road systems of most other States and includes many roads that would be county roads in other States. The available data cover approximately two-thirds of the total public road mileage in the State. Data analyzed for this report include the years from 2005 to 2008, inclusive.

Table 53 shows that, during the study period, 579,654 crashes occurred in North Carolina. Of these, 3,847 (0.7 percent) were pedestrian crashes. Nearly 85 percent of these pedestrian crashes occurred at midblock locations. Only 86 crashes (2.7 percent of the midblock crashes) were classified as occurring at midblock crosswalks.

Table 53. Summary of pedestrian crash data for North Carolina State highways (2005–2008).

Crashes	Number of crashes by year				
	2005	2006	2007	2008	Combined
Total crashes	136,842	146,333	149,964	146,515	579,654
Pedestrian crashes	888	994	975	990	3,847
Pedestrian midblock crashes	750	837	824	828	3,239
Pedestrian midblock roadway crashes	630	682	662	665	2,639
Pedestrian midblock crossing crashes	15	27	22	22	86

Table 54 shows the relative frequencies of North Carolina crashes by midblock crosswalk and other midblock roadway locations.

Table 54. Midblock pedestrian crashes on North Carolina State highways by pedestrian location (2005–2008).

Years	Number (percent) of crashes by pedestrian location				
	Midblock crosswalk		Midblock roadway		Combined
2005	15	(2.3)	630	(97.7)	645
2006	27	(3.8)	682	(96.2)	709
2007	22	(3.2)	662	(96.8)	684
2008	22	(3.2)	665	(96.8)	687
Total	86	(3.2)	2,639	(96.8)	2,725

Percentages in this table are row percentages.

Table 55 classifies midblock pedestrian crashes in North Carolina by crash severity level. Table 56 classifies midblock pedestrian crashes in North Carolina by the pedestrian action prior to the crash. Table 57 presents similar data for contributing factors, many of which are related to pedestrian actions.

Table 55. Midblock pedestrian crashes on North Carolina State highways by injury severity (2005–2008).

Injury severity	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Fatal	2	(2.4)	12	(0.5)	14	(0.5)
Incapacitating injury	2	(2.4)	15	(0.6)	17	(0.6)
Non-incapacitating injury	4	(4.8)	176	(6.8)	180	(6.7)
Possible injury	17	(20.5)	589	(22.7)	606	(22.6)
Property damage only	58	(69.9)	1806	(69.5)	1864	(69.5)
Injury unknown	3	—	41	—	44	—
Total	86	(100.0)	2,639	(100.0)	2,725	(100.0)

— Indicates count not included in calculation of percentage.

Column percentages may not appear to add to 100 percent due to rounding.

Table 56. Midblock pedestrian crashes on North Carolina State highways by pedestrian action (2005–2008).

Collision factor	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Entering or crossing specified location	41	(48.2)	685	(26.0)	726	(26.7)
Walking, riding, running with traffic	8	(9.4)	591	(22.4)	599	(22.0)
Walking, riding, running against traffic	6	(7.1)	357	(13.6)	363	(13.4)
Working	13	(15.3)	84	(3.2)	97	(3.6)
Pushing vehicle	2	(2.4)	37	(1.4)	39	(1.4)
Approaching or leaving vehicle	1	(1.2)	105	(4.0)	106	(3.9)
Playing	2	(2.4)	25	(0.9)	27	(1.0)
Standing	3	(3.5)	290	(11.0)	293	(10.8)
Other	9	(10.6)	459	(17.4)	468	(17.2)
Unknown	1	—	6	—	7	—
Total	86	(100.0)	2,639	(100.0)	2,725	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 57. Midblock pedestrian crashes on North Carolina State highways by contributing factor (2005–2008).

Contributing factor	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Coming from behind parked vehicle	1	(1.3)	41	(1.6)	42	(1.6)
Darting	10	(12.5)	461	(18.1)	471	(18.0)
Lying and/or illegally in roadway	1	(1.3)	382	(15.0)	383	(14.6)
Failure to yield right of way	6	(7.5)	348	(13.7)	354	(13.5)
Not visible (dark clothing)	6	(7.5)	306	(12.0)	312	(11.9)
Inattentive	2	(2.5)	74	(2.9)	76	(2.9)
Failure to obey traffic signs, signals	2	(2.5)	23	(0.9)	25	(1.0)
Wrong side of road	3	(3.8)	125	(4.9)	128	(4.9)
Other	5	(6.3)	156	(6.1)	161	(6.1)
None	44	(55.0)	626	(24.6)	670	(25.6)
Unknown	6	—	97	—	103	—
Total	86	(100.0)	2,639	(100.0)	2,725	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 58 through table 62 present North Carolina data for pedestrian crashes at midblock locations classified by weather condition, road surface condition, light condition, hour of the day, and day of week.

Table 58. Midblock pedestrian crashes on North Carolina State highways by weather condition (2005–2008).

Weather condition	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Clear	60	(69.8)	1824	(69.1)	1884	(69.1)
Cloudy	13	(15.1)	501	(19.0)	514	(18.9)
Raining	11	(12.8)	220	(8.3)	231	(8.5)
Snowing	1	(1.2)	30	(1.1)	31	(1.1)
Fog, smog, smoke	0	(0.0)	31	(1.2)	31	(1.1)
Sleet or hail	0	(0.0)	32	(1.2)	32	(1.2)
Severe crosswinds	1	(1.2)	0	(0.0)	1	(0.0)
Blowing sand, dirt, snow	0	(0.0)	1	(0.0)	1	(0.0)
Unknown	0	—	0	—	0	—
Total	86	(100.0)	2,639	(100.0)	2,725	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 59. Midblock pedestrian crashes on North Carolina State highways by road surface condition (2005–2008).

Road surface condition	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Dry	66	(76.7)	2,100	(79.8)	2,166	(79.7)
Wet	20	(23.3)	459	(17.4)	479	(17.6)
Water (standing, moving)	0	(0.0)	10	(0.4)	10	(0.4)
Ice	0	(0.0)	26	(1.0)	26	(1.0)
Snow	0	(0.0)	23	(0.9)	23	(0.8)
Slush	0	(0.0)	11	(0.4)	11	(0.4)
Sand, mud, dirt, gravel	0	(0.0)	1	(0.0)	1	(0.0)
Fuel, oil	0	(0.0)	1	(0.0)	1	(0.0)
Unknown	0	—	8	—	8	—
Total	86	(100.0)	2,639	(100.0)	2,725	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 60. Midblock pedestrian crashes on North Carolina State highways by light condition (2005–2008).

Light condition	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Daylight	58	(67.4)	1,884	(71.4)	1,942	(71.3)
Dusk-dawn	7	(8.2)	130	(4.9)	137	(5.0)
Dark-street lights on	17	(19.8)	387	(14.7)	404	(14.8)
Dark-no street lights	4	(4.7)	231	(8.8)	235	(8.6)
Dark-unknown lighting	0	(0.0)	5	(0.2)	5	(0.2)
Other	0	(0.0)	1	(0.0)	1	(0.0)
Unknown	0	—	1	—	1	—
Total	86	(100.0)	2,639	(100.0)	2,725	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 61. Midblock pedestrian crashes on North Carolina State highways by day of the week (2005–2008).

	Number (percent) of crashes by pedestrian location					
Day of week	**Midblock crosswalk**		**Midblock roadway**		**Combined**	
Sunday	4	(4.7)	151	(5.7)	155	(5.7)
Monday	20	(23.3)	382	(14.5)	402	(14.8)
Tuesday	11	(12.8)	412	(15.6)	423	(15.5)
Wednesday	10	(11.6)	434	(16.4)	444	(16.3)
Thursday	20	(23.3)	490	(18.6)	510	(18.7)
Friday	16	(18.6)	514	(19.5)	530	(19.4)
Saturday	5	(5.8)	256	(9.7)	261	(9.6)
Total	86	(100.0)	2,639	(100.0)	2,725	(100.0)

Column percentages may not appear to add to 100 percent due to rounding.

Table 62. Midblock pedestrian crashes on North Carolina State highways by hour of day (2005–2008).

	Number (percent) of crashes by pedestrian location					
Hour of day	**Midblock crosswalk**		**Midblock roadway**		**Combined**	
12–12:59 a.m.	2	(2.3)	21	(0.8)	23	(0.8)
1–1:59 a.m.	1	(1.2)	14	(0.5)	15	(0.6)
2–2:59 a.m.	0	(0.0)	27	(1.0)	27	(1.0)
3–3:59 a.m.	0	(0.0)	16	(0.6)	16	(0.6)
4–4:59 a.m.	0	(0.0)	17	(0.6)	17	(0.6)
5–5:59 a.m.	0	(0.0)	22	(0.8)	22	(0.8)
6–6:59 a.m.	2	(2.3)	87	(3.3)	89	(3.3)
7–7:59 a.m.	6	(7.0)	176	(6.7)	182	(6.7)
8–8:59 a.m.	12	(14.0)	164	(6.2)	176	(6.5)
9–9:59 a.m.	3	(3.5)	131	(5.0)	134	(4.9)
10–10:59 a.m.	5	(5.8)	123	(4.7)	128	(4.7)
11–11:59 a.m.	3	(3.5)	161	(6.1)	164	(6.0)
Noon–12:59 p.m.	6	(7.0)	186	(7.0)	192	(7.0)
1–1:59 p.m.	4	(4.7)	203	(7.7)	207	(7.6)
2–2:59 p.m.	8	(9.3)	190	(7.2)	198	(7.3)
3–3:59 p.m.	5	(5.8)	228	(8.6)	233	(8.6)
4–4:59 p.m.	7	(8.1)	226	(8.6)	233	(8.6)
5–5:59 p.m.	4	(4.7)	208	(7.9)	212	(7.8)
6–6:59 p.m.	8	(9.3)	162	(6.1)	170	(6.2)
7–7:59 p.m.	3	(3.5)	99	(3.8)	102	(3.7)
8–8:59 p.m.	3	(3.5)	64	(2.4)	67	(2.5)
9–9:59 p.m.	2	(2.3)	51	(1.9)	53	(1.9)
10–10:59 p.m.	0	(0.0)	35	(1.3)	35	(1.3)
11–11:59 p.m.	2	(2.3)	28	(1.1)	30	(1.1)
Total	86	—	2,639	—	2,725	—

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Ohio

HSIS data for Ohio include crash data only for the State highway system, consisting of approximately 19,500 mi of highways. While some city streets and many small town “main streets” and suburban arterials are State highways, many areas with the highest concentrations of pedestrians in Ohio are not on the State highway system. Data analyzed for this report include the years from 2005 to 2008, inclusive.

Table 63 shows that during the study period, 699,595 crashes occurred on the Ohio State highway system. Of these, 4,127 (0.6 percent) were pedestrian crashes. Approximately 45 percent of the pedestrian crashes occurred at midblock locations. Only 22 crashes (1.2 percent of the midblock crashes) were classified as occurring at midblock crosswalks.

Table 63. Summary of pedestrian crash data for Ohio State highways (2005–2009).

Crashes	Number of crashes by year					
	2005	2006	2007	2008	2009	Combined
Total crashes	143,134	144,821	145,810	128,625	137,205	699,595
Pedestrian crashes	705	831	820	873	898	4,127
Pedestrian midblock crashes	334	368	358	378	400	1,838
Pedestrian midblock roadway crashes	102	147	129	123	129	630
Pedestrian midblock crossing crashes	4	1	7	3	7	22

Table 64 shows the relative frequencies of Ohio crashes by midblock crosswalk and other midblock roadway locations. Table 65 classifies midblock pedestrian crashes in Ohio by crash severity level.

Table 64. Midblock pedestrian crashes on Ohio State highways by pedestrian location (2005–2009).

Year	Number (percent) of crashes by pedestrian location				
	Midblock crosswalk		Midblock roadway		Combined
2005	4	(3.8)	102	(96.2)	106
2006	1	(0.1)	147	(99.9)	148
2007	7	(5.1)	129	(94.9)	136
2008	3	(2.4)	123	(97.6)	126
2009	7	(5.2)	129	(94.8)	136
Total	22	(3.4)	630	(96.6)	652

Percentages in this table are row percentages.

Table 65. Midblock pedestrian crashes on Ohio State highways by injury severity (2005–2009).

Injury severity	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Fatal	0	(0.0)	75	(11.9)	75	(11.5)
Incapacitating injury	1	(4.5)	168	(26.7)	169	(25.9)
Non-incapacitating injury	14	(63.7)	213	(33.8)	227	(34.9)
Possible injury	7	(31.8)	123	(19.5)	130	(19.9)
Property damage only	0	(0.0)	51	(8.1)	51	7.8)
Total	22	(100.0)	630	(100.0)	652	(100.0)

Column percentages may not appear to add to 100 percent due to rounding.

Table 66 classified midblock pedestrian crashes in Ohio by the traffic control devices present. The table for Ohio differs markedly from the tables for other States because pavement markings are included as one of the traffic control devices that may be present.

Table 66. Midblock pedestrian crashes on Ohio State highways by traffic control device (2005–2009).

Traffic control device	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
No controls	10	(45.5)	251	(46.7)	261	(46.6)
Traffic signal	4	(18.2)	15	(2.8)	19	(3.4)
Traffic flashers	0	(0.0)	1	(0.2)	1	(0.2)
Construction barricades	0	(0.0)	3	(0.6)	3	(0.5)
Police officer	0	(0.0)	2	(0.4)	2	(0.4)
Pavement markings	2	(9.1)	231	(42.9)	233	(41.6)
Crosswalk lines	5	(22.7)	17	(3.2)	22	(3.9)
Walk/don't walk signal	1	(4.5)	12	(2.2)	13	(2.3)
Other	0	(0.0)	6	(1.1)	6	(1.1)
Unknown	0	—	92	—	92	—
Total	22	(100.0)	630	(100.0)	652	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 67 classifies midblock pedestrian crashes in Ohio by pedestrian action that contributed to the crash. Table 68 through table 74 present Ohio data for pedestrian crashes at midblock locations by number of lanes crossed, presence of a median, weather condition, road surface condition, light condition, hour of the day, and day of the week.

Table 67. Midblock pedestrian crashes on Ohio State highways by pedestrian action (2005–2009).

Collision factor	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
None	10	(71.5)	63	(11.5)	73	(13.0)
Operating defective equipment	0	(0.0)	1	(0.2)	1	(0.2)
Improper crossing	2	(14.3)	238	(43.5)	240	(42.8)
Darting	1	(7.1)	76	(13.9)	77	(13.8)
Lying and/or illegally in roadway	0	(0.0)	54	(9.9)	54	(9.6)
Failure to yield	0	(0.0)	28	(4.9)	28	(4.8)
Not visible (dark clothing)	0	(0.0)	23	(4.2)	23	(4.1)
Inattentive	0	(0.0)	22	(4.0)	22	(3.9)
Failure to obey traffic signs, signals, etc.	0	(0.0)	5	(0.9)	5	(0.9)
Wrong side of the road	0	(0.0)	13	(2.4)	13	(2.3)
Other	1	(7.1)	25	(4.6)	26	(4.6)
Unknown	8	—	82	—	90	—
Total	22	(100.0)	630	(100.0)	652	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 68. Midblock pedestrian crashes on Ohio State highways by number of lanes crossed (2005–2009).

Number of lanes	Number (percent) of crashes by number of lanes crossed					
	Midblock Crosswalk		Midblock Roadway		Combined	
2	4	(18.2)	211	(33.5)	215	(33.0)
3	0	(0.0)	16	(2.5)	16	(2.5)
4	17	(77.3)	342	(54.3)	359	(55.1)
5	0	(0.0)	3	(0.5)	3	(0.5)
6	1	(4.5)	45	(7.1)	46	(7.1)
7	0	(0.0)	1	(0.2)	1	(0.2)
8	0	(0.0)	11	(1.7)	11	(1.7)
9	0	(0.0)	1	(0.2)	1	(0.2)
Unknown	0	—	0	—	0	—
Total	22	(100.0)	630	(100.0)	652	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 69. Midblock pedestrian crashes on Ohio State highways by presence of median (2005–2009).

Presence of median	Number (percent) of crashes by presence of median					
	Midblock Crosswalk		Midblock Roadway		Combined	
Divided	1	(4.5)	101	(16.0)	102	(15.6)
Undivided	21	(95.5)	529	(84.0)	550	(84.4)
Total	22	(100.0)	630	(100.0)	652	(100.0)

Column percentages may not appear to add to 100 percent due to rounding.

Table 70. Midblock pedestrian crashes on Ohio State highways by weather condition (2005–2009).

Weather condition	Number (percent) of crashes by pedestrian location					
	Midblock Crosswalk		Midblock Roadway		Combined	
Clear	19	(86.4)	531	(85.0)	550	(85.0)
Cloudy	2	(9.1)	69	(11.0)	71	(11.0)
Raining	0	(0.0)	12	(1.9)	12	(1.9)
Snowing	0	(0.0)	2	(0.3)	2	(0.3)
Sleet or hail	1	(4.5)	11	(1.8)	12	(1.9)
Unknown	0	—	5	—	5	—
Total	22	(100.0)	630	(100.0)	652	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 71. Midblock pedestrian crashes on Ohio State highways by road surface condition (2005–2009).

Road surface condition	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Dry	17	(77.3)	488	(78.0)	505	(77.9)
Wet	4	(18.2)	118	(18.8)	122	(18.8)
Water	1	(4.5)	12	(1.9)	13	(2.0)
Snowy, icy	0	(0.0)	8	(1.3)	8	(1.3)
Unknown	0	—	7	—	7	—
Total	22	(100.0)	630	(100.0)	652	(100.0)

— Indicates count not included in calculation of percentage.

Column percentages may not appear to add to 100 percent due to rounding.

Table 72. Midblock pedestrian crashes on Ohio State highways by light condition (2005–2009).

Light condition	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Daylight	16	(72.7)	297	(47.7)	313	(48.5)
Dusk-dawn	2	(9.1)	26	(4.1)	28	(4.4)
Dark-street lights on	4	(18.2)	193	(31.0)	197	(30.5)
Dark-no street lights	0	(0.0)	107	(17.2)	107	(16.6)
Unknown	0	—	7	—	7	—
Total	22	(100.0)	630	(100.0)	652	(100.0)

— Indicates count not included in calculation of percentage.

Column percentages may not appear to add to 100 percent due to rounding.

Table 73. Midblock pedestrian crashes on Ohio State highways by day of the week (2005–2009).

Day of week	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Sunday	1	(4.5)	76	(12.1)	77	(11.8)
Monday	5	(22.7)	75	(11.9)	80	(12.3)
Tuesday	3	(13.6)	102	(16.2)	105	(16.1)
Wednesday	3	(13.6)	91	(14.4)	94	(14.4)
Thursday	5	(22.7)	95	(15.1)	100	(15.3)
Friday	3	(13.6)	103	(16.3)	106	(16.3)
Saturday	2	(9.1)	88	(14.0)	90	(13.8)
Total	22	(100.0)	630	(100.0)	652	(100.0)

Column percentages may not appear to add to 100 percent due to rounding.

Table 74. Midblock pedestrian crashes on Ohio State highways by hour of the day (2005–2009).

Hour of day	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
12–12:59 a.m.	2	(9.1)	15	(2.4)	17	(2.6)
1–1:59 a.m.	1	(4.5)	25	(4.0)	26	(4.0)
2–2:59 a.m.	0	(0.0)	30	(4.8)	30	(4.6)
3–3:59 a.m.	0	(0.0)	12	(1.9)	12	(1.8)
4–4:59 a.m.	0	(0.0)	3	(0.5)	3	(0.5)
5–5:59 a.m.	1	(4.5)	9	(1.4)	10	(1.5)
6–6:59 a.m.	2	(9.1)	15	(2.4)	17	(2.6)
7–7:59 a.m.	1	(4.5)	20	(3.2)	21	(3.2)
8–8:59 a.m.	3	(13.6)	11	(1.7)	14	(2.1)
9–9:59 a.m.	0	(0.0)	10	(1.6)	10	(1.5)
10–10:59 a.m.	3	(13.6)	16	(2.5)	19	(2.9)
11–11:59 a.m.	0	(0.0)	21	(3.3)	21	(3.2)
Noon–12:59 p.m.	2	(9.1)	19	(3.0)	21	(3.2)
1–1:59 p.m.	0	(0.0)	22	(3.5)	22	(3.4)
2–2:59 p.m.	2	(9.1)	43	(6.8)	45	(6.9)
3–3:59 p.m.	2	(9.1)	45	(7.1)	47	(7.2)
4–4:59 p.m.	0	(0.0)	43	(6.8)	43	(6.6)
5–5:59 p.m.	1	(4.5)	50	(7.9)	51	(7.8)
6–6:59 p.m.	2	(9.1)	49	(7.8)	51	(7.8)
7–7:59 p.m.	0	(0.0)	48	(7.6)	48	(7.4)
8–8:59 p.m.	0	(0.0)	37	(5.9)	37	(5.7)
9–9:59 p.m.	0	(0.0)	37	(5.9)	37	(5.7)
10–10:59 p.m.	0	(0.0)	27	(4.3)	27	(4.1)
11–11:59 p.m.	0	(0.0)	23	(3.7)	23	(3.5)
Unknown	0	—	0	—	0	—
Total	22	(100.0)	630	(100.0)	652	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Texas

Data for Texas include crash data submitted to the department that can include both on-State and off-State roadways. Data analyzed for this report include the years from 2003 to 2009, inclusive.

Table 75 shows that during the study period, 3,134,365 crashes occurred on the Texas roadway system. Of these, 39,993 (1.3 percent) were pedestrian crashes. Nearly 50 percent of the pedestrian crashes occurred at non-intersection locations (defined as midblock locations for this report). Only 136 crashes (0.7 percent of the midblock crashes) were classified as occurring at midblock crosswalks.

Table 76 shows the relative frequencies of Texas crashes by midblock crosswalk and other midblock roadway locations. Table 77 classifies midblock pedestrian crashes in Texas by crash severity level.

Table 75. Summary of pedestrian crash data for Texas roadways (2003–2009).

Crashes	Number of crashes by year							
	2003	2004	2005	2006	2007	2008	2009	Combined
Total crashes	459,725	447,037	463,830	437,290	458,289	439,527	428,667	3,134,365
Pedestrian crashes	5,998	5,444	5,620	5,146	5,751	6,244	5,790	39,993
Pedestrian midblock crashes[a]	3,042	2,741	2,803	2,392	2,662	2,850	2,493	18,983
Pedestrian midblock roadway crashes[b]	3,042	2,741	2,803	2,354	2,628	2,811	2,468	18,847
Pedestrian midblock crossing crashes	0	0	0	38	34	39	25	136

[a] Crashes at nonintersection and in-roadway along with pedestrian as the code for harmful event, person type, or vehicle unit description.

[b] Midblock roadway crashes not coded with "crosswalk" as the traffic control device present.

Table 76. Midblock pedestrian crashes on Texas roadways by pedestrian location (2003–2009).

Year	Number (percent) of crashes by pedestrian location				
	Midblock crosswalk		Midblock roadway		Combined
2003	0	(0.0)	3,042	(100.0)	3,042
2004	0	(0.0)	2,741	(100.0)	2,741
2005	0	(0.0)	2,803	(100.0)	2,803
2006	38	(1.6)	2,354	(98.4)	2,392
2007	34	(1.3)	2,628	(98.7)	2,662
2008	39	(1.4)	2,811	(98.6)	2,850
2009	25	(1.0)	2,468	(99.0)	2,493
Total	136	(0.7)	18,847	(99.3)	18,983

Percentages in this table are row percentages.

Table 77. Midblock pedestrian crashes on Texas roadways by injury severity (2003–2009).

Injury severity	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Incapacitating injury	29	(21.5)	4,111	(22.0)	4,140	(22.0)
Non-incapacitating injury	48	(35.6)	6,799	(36.3)	6,847	(36.3)
Possible injury	48	(35.6)	4,875	(26.1)	4,923	(26.1)
Fatal	6	(4.4)	2,192	(11.7)	2,198	(11.7)
Not injured	4	(3.0)	734	(3.9)	738	(3.9)
Unknown	1	—	136	—	137	—
Total	136	(100.0)	18,847	(100.0)	18,983	(100.0)

— Indicates count not included in calculation of percentage.

Column percentages may not appear to add to 100 percent due to rounding.

Table 78 presents a classification of midblock pedestrian crashes in Texas by the traffic control devices present. Table 79 through table 83 present Texas data for pedestrian crashes at midblock locations by weather condition, road surface condition, light condition, hour of the day, and day of the week.

Table 78. Midblock pedestrian crashes on Texas roadways by traffic control device (2003–2009).

Traffic control device	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
No control or inoperative	0	(0.0)	3,770	(21.0)	3,770	(20.9)
None	0	(0.0)	5,696	(31.8)	5,696	(31.5)
Inoperative	0	(0.0)	7	(0.0)	7	(0.0)
Officer	0	(0.0)	52	(0.3)	52	(0.3)
Flagman	0	(0.0)	45	(0.3)	45	(0.2)
Signal light	0	(0.0)	648	(3.6)	648	(3.6)
Flashing red light	0	(0.0)	21	(0.1)	21	(0.1)
Flashing yellow light	0	(0.0)	10	(0.1)	10	(0.1)
Stop sign	0	(0.0)	262	(1.5)	262	(1.4)
Yield sign	0	(0.0)	54	(0.3)	54	(0.3)
Warning sign	0	(0.0)	85	(0.5)	85	(0.5)
Center stripe/divider	0	(0.0)	5,609	(31.3)	5,609	(31.0)
No passing zone	0	(0.0)	356	(2.0)	356	(2.0)
RR gate/signal	0	(0.0)	8	(0.0)	8	(0.0)
School zone	0	(0.0)	62	(0.3)	62	(0.3)
Crosswalk	136	(100.0)	0	(0.0)	136	(0.8)
Bike lane	0	(0.0)	5	(0.0)	5	(0.0)
Other	0	(0.0)	1,145	(6.4)	1,145	(6.3)
Officer or flagman	0	(0.0)	76	(0.4)	76	(0.4)
Turn marks	0	(0.0)	29	(0.2)	29	(0.2)
Blank	0	—	907	—	907	—
Total	136	(100.0)	18,847	(100.0)	18,983	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 79. Midblock pedestrian crashes on Texas roadways by weather condition (2003–2009).

Weather condition	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Clear/cloudy	122	(92.4)	17,466	(94.2)	17,588	(94.2)
Rain	10	(7.6)	872	(4.7)	882	(4.7)
Sleet/hail	0	(0.0)	20	(0.1)	20	(0.1)
Snow	0	(0.0)	15	(0.1)	15	(0.1)
Fog	0	(0.0)	86	(0.5)	86	(0.5)
Blowing sand/snow	0	(0.0)	8	(0.0)	7	(0.0)
Severe crosswinds	0	(0.0)	14	(0.1)	14	(0.1)
Blowing dust	0	(0.0)	2	(0.0)	2	(0.0)
Other	0	(0.0)	52	(0.3)	52	(0.3)
Blank	4	—	281	—	285	—
Unknown	0	—	32	—	32	—
Total	136	(100.0)	18,847	(100.0)	18,983	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 80. Midblock pedestrian crashes on Texas roadways by road surface condition (2003–2009).

Road surface condition	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Dry	119	(89.5)	17,073	(91.2)	17,192	(91.2)
Wet	13	(9.8)	1,505	(8.0)	1,518	(8.1)
Standing water	0	(0.0)	8	(0.0)	8	(0.0)
Snowy/icy	0	(0.0)	20	(0.1)	20	(0.1)
Slush	0	(0.0)	3	(0.0)	3	(0.0)
Ice	1	(0.8)	31	(0.2)	32	(0.2)
Muddy	0	(0.0)	4	(0.0)	4	(0.0)
Snow	0	(0.0)	7	(0.0)	7	(0.0)
Sand (mud, dirt)	0	(0.0)	26	(0.1)	26	(0.1)
Other	0	(0.0)	36	(0.2)	36	(0.2)
Unknown	0	—	33	—	33	—
Blank	3	—	101	—	104	—
Total	136	(100.0)	18,847	(100.0)	18,983	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 81. Midblock pedestrian crashes on Texas roadways by light condition (2003–2009).

Light condition	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Daylight	100	(75.2)	9,364	(50.7)	9,464	(50.9)
Dawn	2	(1.5)	191	(1.0)	193	(1.0)
Dark (not lighted)	5	(3.8)	3,893	(21.1)	3,898	(21.0)
Dark (lighted)	26	(19.5)	4,419	(23.9)	4,445	(23.9)
Dusk	0	(0.0)	411	(2.2)	411	(2.2)
Dark (unknown lighting)	0	(0.0)	168	(0.9)	168	(0.9)
Other	0	(0.0)	8	(0.0)	8	(0.0)
Unknown	0	—	27	—	27	—
Blank	3	—	366	—	369	—
Total	136	(100.0)	18,847	(100.0)	18,983	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 82. Midblock pedestrian crashes on Texas roadways by hour of day (2003–2009).

Hour of day	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
12–12:59 a.m.	0	(0.0)	20	(0.1)	20	(0.1)
1–1:59 a.m.	1	(0.7)	496	(2.6)	497	(2.6)
2–2:59 a.m.	2	(1.5)	638	(3.4)	640	(3.4)
3–3:59 a.m.	0	(0.0)	288	(1.5)	288	(1.5)
4–4:59 a.m.	1	(0.7)	203	(1.1)	204	(1.1)
5–5:59 a.m.	3	(2.2)	260	(1.4)	263	(1.4)
6–6:59 a.m.	3	(2.2)	449	(2.4)	452	(2.4)
7–7:59 a.m.	16	(11.8)	653	(3.5)	669	(3.5)
8–8:59 a.m.	13	(9.6)	407	(2.2)	420	(2.2)
9–9:59 a.m.	9	(6.6)	358	(1.9)	367	(1.9)
10–10:59 a.m.	4	(2.9)	423	(2.3)	427	(2.9)
11–11:59 a.m.	6	(4.4)	516	(2.7)	522	(2.8)
Noon–12:59 p.m.	7	(5.1)	1,194	(6.4)	1,201	(6.3)
1–1:59 p.m.	1	(0.7)	623	(3.3)	624	(3.3)
2–2:59 p.m.	13	(9.6)	793	(4.2)	806	(4.3)
3–3:59 p.m.	8	(5.9)	1,179	(6.3)	1,187	(6.3)
4–4:59 p.m.	11	(8.1)	1,252	(6.7)	1,263	(6.7)
5–5:59 p.m.	12	(8.8)	1,400	(7.5)	1,412	(7.5)
6–6:59 p.m.	7	(5.1)	1,680	(8.9)	1,687	(8.9)
7–7:59 p.m.	9	(6.6)	1,539	(8.2)	1,548	(8.2)
8–8:59 p.m.	3	(2.2)	1,388	(7.4)	1,391	(7.4)
9–9:59 p.m.	3	(2.2)	1,330	(7.1)	1,333	(7.0)
10–10:59 p.m.	3	(2.2)	988	(5.3)	991	(5.2)
11–11:59 p.m.	1	(0.7)	707	(3.8)	708	(3.7)
Unknown	0	—	63	—	63	—
Total	136	(100.0)	18,847	(100.0)	18,983	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 83. Midblock pedestrian crashes on Texas roadway by day of week (2003–2009).

Weekday	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Sunday	13	(9.6)	2,814	(14.9)	2,827	(14.9)
Monday	29	(21.3)	2,370	(12.6)	2,399	(12.6)
Tuesday	21	(15.4)	2,317	(12.3)	2,338	(12.3)
Wednesday	25	(18.4)	2,344	(12.4)	2,369	(12.5)
Thursday	22	(16.2)	2,493	(13.2)	2,515	(13.2)
Friday	18	(13.2)	3,150	(16.7)	3,168	(16.7)
Saturday	8	(5.9)	3,359	(17.8)	3,367	(17.7)
Total	136	(100.0)	18,847	(100.0)	18,983	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Washington

HSIS data for Washington include crash data only for the state highway system, consisting of approximately 7,193 mi of highways. While some city streets and many small town “main streets” and suburban arterials are State highways, many areas with the highest concentrations of pedestrians in Washington are not on the State highway system. Data analyzed for this report include the years from 2005 to 2008, inclusive.

Table 84 shows that during the study period, 188,992 crashes occurred on the Washington State highway system. Of these, 1,573 (0.8 percent) were pedestrian crashes. Nearly 40 percent of the pedestrian crashes occurred at midblock locations. Only 29 crashes (5.0 percent of the midblock crashes) were classified as occurring at midblock crosswalks.

Table 84. Summary of pedestrian crash data for Washington State highways (2005–2008).

	Number of crashes by year				
Crashes	**2005**	**2006**	**2007**	**2008**	**Combined**
Total crashes	48,023	48,985	47,732	44,252	188,992
Pedestrian crashes	359	400	410	404	1,573
Pedestrian midblock crashes	159	161	147	152	619
Pedestrian midblock roadway crashes	150	155	141	144	590
Pedestrian midblock crossing crashes	9	6	6	8	29

Table 85 shows the relative frequencies of Washington crashes by midblock crosswalk and other midblock roadway locations.

Table 85. Midblock pedestrian crashes on Washington State highways by pedestrian location (2005–2008).

	Number (percent) of crashes by pedestrian location				
Year	**Midblock crosswalk**		**Midblock roadway**		**Combined**
2005	9	(4.2)	150	(95.8)	159
2006	6	(0.8)	155	(99.2)	161
2007	6	(5.3)	141	(94.7)	147
2008	8	(2.6)	144	(97.4)	152
Total	29	(3.7)	590	(96.3)	619

Percentages in this table are row percentages.

Table 86 classifies midblock pedestrian crashes in Washington by crash severity level. Table 87 classified midblock pedestrian crashes in Washington by contributing factors, many of which are related to pedestrian actions.

Table 88 through table 92 present Washington data for pedestrian crashes at midblock locations by presence of median, road surface condition, light condition, hour of the day, and day of the week.

Table 86. Midblock pedestrian crashes on Washington State highways by injury severity (2005–2008).

Injury severity	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Fatal	0	(0.0)	71	(12.1)	71	(11.5)
Incapacitating injury	4	(13.8)	148	(25.2)	152	(24.6)
Non-incapacitating injury	10	(34.5)	189	(32.1)	199	(32.3)
Possible injury	12	(41.4)	139	(23.6)	151	(24.5)
Property damage only	3	(10.3)	41	(7.0)	44	(7.1)
Injury unknown	0	—	2	—	2	—
Total	29	(100.0)	590	(100.0)	619	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 87. Midblock pedestrian crashes on Washington State highways by contributing factor (2005–2008).

Contributing factor	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Under the influence of alcohol or drugs	0	(0.0)	39	(6.8)	39	(6.5)
Speeding	0	(0.0)	44	(7.7)	44	(7.3)
Pedestrian did not yield to vehicle	0	(0.0)	2	(0.3)	2	(0.3)
Improper passing	1	(3.4)	3	(0.5)	4	(0.7)
Following too closely	0	(0.0)	4	(0.7)	4	(0.7)
Failing to signal	0	(0.0)	1	(0.2)	1	(0.2)
Apparently asleep, ill, or fatigued	0	(0.0)	4	(0.7)	4	(0.7)
Operating defective equipment	0	(0.0)	7	(1.2)	7	(1.2)
Improper U-turn	0	(0.0)	2	(0.3)	2	(0.3)
Motorist did not yield to pedestrian	16	(55.3)	89	(15.6)	105	(17.4)
Inattention	1	(3.4)	13	(2.3)	14	(2.3)
Improper backing	0	(0.0)	7	(1.2)	7	(1.2)
Disregard flagger/officer	0	(0.0)	8	(1.4)	8	(1.3)
Failure to use crosswalk	0	(0.0)	1	(0.2)	1	(0.2)
Other	2	(6.9)	97	(16.9)	99	(16.4)
None	9	(31.0)	252	(44.0)	261	(43.3)
Unknown	0	—	17	—	17	—
Total	29	(100.0)	590	(100.0)	619	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 88. Midblock pedestrian crashes on Washington State highways by presence of median (2005–2008).

Presence of median	Number (percent) of crashes by presence of median					
	Midblock crosswalk		Midblock roadway		Combined	
Divided	5	(19.2)	183	(33.5)	188	(32.9)
Undivided	21	(80.8)	363	(66.5)	384	(67.1)
Unknown	3	—	44	—	47	—
Total	29	(100.0)	590	(100.0)	619	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 89. Midblock pedestrian crashes on Washington State highways by road surface condition (2005–2008).

Road surface condition	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Dry	21	(72.4)	412	(70.5)	433	(70.6)
Wet	7	(24.1)	135	(23.1)	142	(23.2)
Snow/slush	1	(3.4)	22	(3.8)	23	(3.8)
Ice	0	(0.0)	12	(2.1)	12	(2.0)
Sand/mud/dirt	0	(0.0)	1	(0.2)	1	(0.2)
Other	0	(0.0)	2	(0.3)	2	(0.3)
Unknown	0	—	6	—	6	—
Total	29	(100.0)	590	(100.0)	619	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 90. Midblock pedestrian crashes on Washington State highways by light condition (2005–2008).

Light condition	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Daylight	19	(65.6)	266	(45.5)	285	(46.4)
Dusk-dawn	2	(6.9)	23	(3.9)	25	(4.0)
Dark-street lights on	6	(20.7)	176	(30.0)	182	(29.6)
Dark-no street lights	2	(6.8)	120	(20.4)	122	(19.8)
Other	0	(0.0)	1	(0.2)	1	(0.2)
Unknown	0	—	4	—	4	—
Total	29	(100.0)	590	(100.0)	619	(100.0)

— Indicates count not included in calculation of percentage.
Column percentages may not appear to add to 100 percent due to rounding.

Table 91. Midblock pedestrian crashes on Washington State highways by day of the week (2005–2008).

Day of week	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
Sunday	0	(0.0)	78	(13.2)	78	(12.6)
Monday	4	(13.8)	79	(13.4)	83	(13.4)
Tuesday	5	(17.2)	67	(11.4)	72	(11.6)
Wednesday	5	(17.2)	77	(13.1)	82	(13.2)
Thursday	7	(24.1)	81	(13.7)	88	(14.2)
Friday	5	(17.2)	105	(17.8)	110	(17.8)
Saturday	3	(10.3)	103	(17.5)	106	(17.1)
Total	29	(100.0)	590	(100.0)	619	(100.0)

Column percentages may not appear to add to 100 percent due to rounding.

Table 92. Midblock pedestrian crashes on Washington State highways by hour of the day (2005–2008).

Hour of day	Number (percent) of crashes by pedestrian location					
	Midblock crosswalk		Midblock roadway		Combined	
12–12:59 am	0	(0.0)	22	(3.7)	22	(3.6)
1–1:59 am	1	(3.4)	18	(3.1)	19	(3.1)
2–2:59 am	0	(0.0)	22	(3.7)	22	(3.6)
3–3:59 am	1	(3.4)	8	(1.4)	9	(1.5)
4–4:59 am	0	(0.0)	13	(2.2)	13	(2.1)
5–5:59 am	0	(0.0)	13	(2.2)	13	(2.1)
6–6:59 am	1	(3.4)	13	(2.2)	14	(2.3)
7–7:59 am	1	(3.4)	16	(2.7)	17	(2.7)
8–8:59 am	1	(3.4)	18	(3.1)	19	(3.1)
9–9:59 am	0	(0.0)	17	(2.9)	17	(2.7)
10–10:59 am	0	(0.0)	11	(1.9)	11	(1.8)
11–11:59 am	2	(6.9)	23	(3.9)	25	(4.0)
Noon–12:59 pm	1	(3.4)	26	(4.4)	27	(4.4)
1–1:59 pm	2	(6.9)	21	(3.6)	23	(3.7)
2–2:59 pm	2	(6.9)	33	(5.6)	35	(5.7)
3–3:59 pm	4	(13.8)	30	(5.1)	34	(5.5)
4–4:59 pm	3	(10.3)	25	(4.2)	28	(4.5)
5–5:59 pm	5	(17.2)	51	(8.6)	56	(9.0)
6–6:59 pm	1	(3.4)	39	(6.6)	40	(6.5)
7–7:59 pm	3	(10.3)	38	(6.4)	41	(6.6)
8–8:59 pm	1	(3.4)	32	(5.4)	33	(5.3)
9–9:59 pm	0	(0.0)	32	(5.4)	32	(5.2)
10–10:59 pm	0	(0.0)	49	(8.3)	49	(7.9)
11–11:59 pm	0	(0.0)	20	(3.4)	20	(3.2)
Total	29	(100.0)	590	(100.0)	619	(100.0)

Column percentages may not appear to add to 100 percent due to rounding.

CHAPTER 4. LOCAL FIELD OBSERVATIONS

This chapter documents the results of field observations at midblock pedestrian crossings. The purpose of these observations was to serve as a first step toward deciding the types of treatments and locations to be studied in the research.

OBSERVATIONS OF MIDBLOCK PEDESTRIAN CROSSINGS

The research team made observations at selected midblock pedestrian crossings with a range of traffic control treatments. Ten midblock pedestrian crossings in 5 States were observed, including sites in eight different cities. These observations were not intended to be a structured evaluation of these particular crossings; rather they were merely intended as a source of ideas about how particular crossing types could potentially be evaluated later in the study. These observations were generally made in the field during the summer of 2011. The crossings observed were not selected as candidates for evaluation; indeed, many of the observed locations have already been treated in particular ways. The observation periods were typically brief (15 to 30 min), and insights and assessments gained from these observations, by intention, should be regarded as anecdotal rather than definitive. Development of evaluation approaches for specific crossing treatments, which had not yet been selected, were done later in the research.

The midblock pedestrian crossings observed were at the following locations:

- E. Bidwell Avenue between Riley Avenue and Coloma Avenue in Folsom, CA.
- N. El Dorado Avenue between E. Market Street and E. Weber Street in Stockton, CA.
- N. El Dorado Avenue between E. Weber Street and E. Miner Street in Stockton, CA.
- W. 80th Street between Overland Park Drive and Marty Street in Overland Park, KS.
- W. 39th Avenue between Rainbow Boulevard and Cambridge Street in Kansas City, KS.
- Oak Street between 51st Street and 52nd Street in Kansas City, MO.
- Rockhill Road between 50th Street and 51st Street in Kansas City, MO.
- W. Walnut Street at N. Bullock Drive in Garland, TX.
- Barton Springs Road between South 1st Street and Bouldin Avenue in Austin, TX.
- 23rd Street near Crystal City Mall in Arlington, VA.

The observations of the crossings are discussed in the following subsections.

Crosswalk 1: E. Bidwell Avenue Between Riley Avenue and Coloma Avenue in Folsom, CA

Crosswalk 1 is a midblock crossing that adjoins Folsom Lakes High School and Sutter Middle School. There is a marked unsignalized pedestrian crossing with two fixed upright "State Law-Yield to Pedestrian" paddles near the center of the road. Pedestrian pushbuttons activate flashing lights embedded in the pavement surface immediately in advance of the crosswalk. The street crossed has one lane in each direction of travel plus a center TWLTL. Figure 5 is a photograph of this crossing. Figure 6 shows the pedestrian view of the crosswalk, and figure 7 shows the pedestrian pushbutton.

Figure 5. Photo. Unsignalized pedestrian crosswalk in Folsom, CA.

Figure 6. Photo. Unsignalized pedestrian crosswalk in Folsom, CA, pedestrian view.

Figure 7. Photo. Unsignalized pedestrian crosswalk in Folsom, CA, pedestrian pushbutton.

Two crossing maneuvers by school-age pedestrians were observed, one by a single pedestrian and one by a group of approximately 30 students accompanied by their teacher. The pedestrian pushbutton was pressed to activate the in-pavement flashing lights prior to both crossing maneuvers. Based on limited observation, the traffic control, including the in-pavement flashing lights, was only partially effective in producing driver compliance with the legal requirement to yield to pedestrians. Prior to both crossing maneuvers, two vehicles that should have yielded to the pedestrian(s) proceeded through the crosswalk without stopping, while the third vehicle to arrive stopped in advance of the crosswalk and allowed the pedestrian(s) to cross. No vehicle–pedestrian conflicts were observed because the pedestrians did not leave the curb until a vehicle stopped, but the pedestrians effectively yielded the right of way to the first two vehicles to arrive at the crosswalk, rather than vice versa.

All observed pedestrian crossing maneuvers were made within the marked crosswalk. The pedestrian pushbutton was located such that pedestrians who activated the pushbutton were likely to cross within the crosswalk.

Crosswalk 2: N. El Dorado Street Between E. Market Street and E. Weber Street in Stockton, CA

Crosswalk 2 is a midblock crossing located in downtown Stockton. There is a marked unsignalized crosswalk with pedestrian crosswalk signs (W11-2). Pedestrian pushbuttons activate flashing lights mounted on the pedestrian crosswalk signs and embedded in the pavement surface in advance of the crosswalk. The pushbuttons also activate an audible message to pedestrians: “Cross street with caution. Vehicles may not stop.” The street crossed is one-way northbound with three travel lanes and metered curb parking on the east side of the street. The crossing connects pedestrian malls on each side of the street that extend through the adjacent blocks. Figure 8 is a photograph of this crossing. Figure 9 shows the pedestrian view of the crosswalk, and figure 10 shows the pedestrian pushbutton.

Even during an early evening observation period, there was some pedestrian activity at this location. Two pedestrian crossing maneuvers were observed. In both cases, the pedestrian used the pushbutton to activate the flashing lights, and all approaching traffic immediately stopped. All observed pedestrian crossing maneuvers were made within the marked crosswalk.

The pedestrian pushbutton was located such that pedestrians who activated the pushbutton were likely to cross within the crosswalk.

Figure 8. Photo. Unsignalized pedestrian crosswalk in Stockton, CA.

Figure 9. Photo. Unsignalized pedestrian crosswalk in Stockton, CA, pedestrian view.

Figure 10. Photo. Unsignalized pedestrian crosswalk in Stockton, CA, pedestrian pushbutton.

Crosswalk 3: N. El Dorado Street Between E. Market Street and E. Miner Street in Stockton, CA

Crosswalk 3 is a midblock crossing located in downtown Stockton. There is a marked unsignalized crosswalk with pedestrian crosswalk signs (W11-2). Pedestrian pushbuttons activate flashing lights mounted on the pedestrian crosswalk signs and embedded in the pavement surface in advance of the crosswalk. The pushbuttons also activate an audible message to pedestrians: "Crosswalk system has been activated. Vehicles may not stop." The street crossed is one-way northbound with three travel lanes and metered curb parking on the east side of the street. The crossing connects a pedestrian plaza and parking area on the west side of the street with an entertainment center, including a movie theatre and several restaurants, on the east side of the street. This crossing is one block north of the preceding crossing. Figure 11 is a photograph of this crossing.

During the early evening hours, there was moderate pedestrian activity at this location. All observed pedestrians used the pushbutton to activate the flashing lights and, in all cases, the approaching traffic immediately stopped. All observed pedestrian crossing maneuvers were made within the marked crosswalk. The pedestrian pushbutton was located such that pedestrians who activated the pushbutton were likely to cross within the crosswalk.

Several other midblock crossings were noted in downtown Stockton, but the other locations appeared likely to have pedestrian crossing activity only during normal work hours.

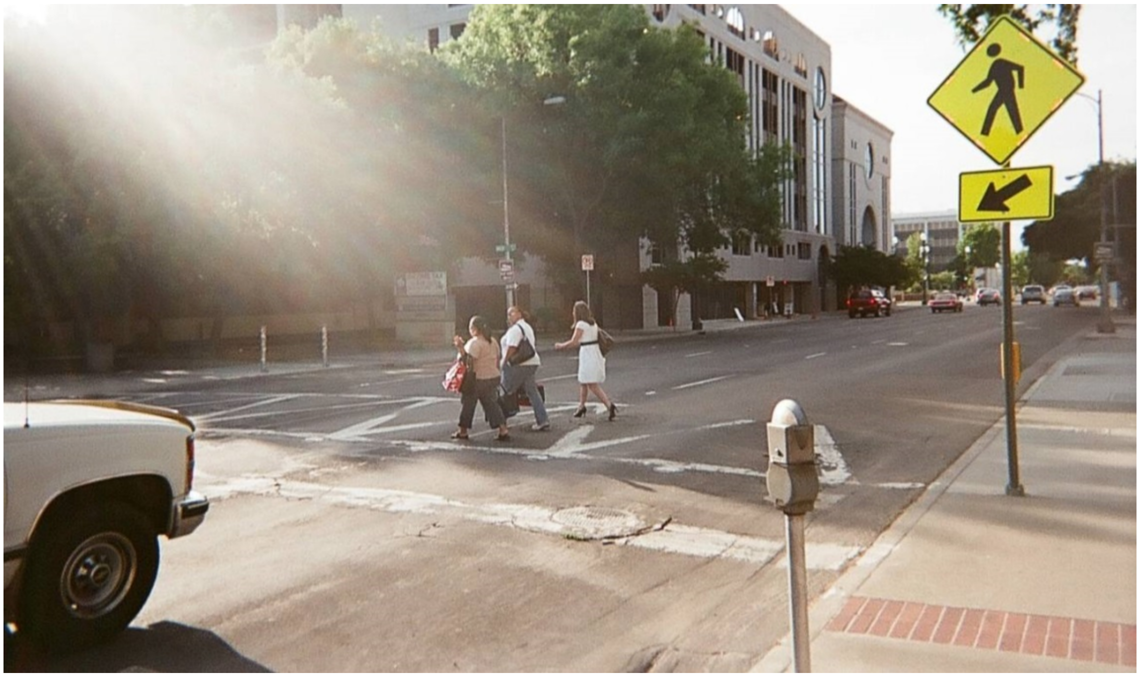


Figure 11. Photo. Unsignalized pedestrian crosswalk in Stockton, CA.

Crosswalk 4: W. 80th Street Between Overland Park Drive and Marty Street in Overland Park, KS

Crosswalk 4 is a midblock crossing located in downtown Overland Park, KS. There is a brick textured marked unsignalized crosswalk with pedestrian crosswalk signs (W11-2). Curb extensions have been implemented at this crosswalk to shorten the crossing distance. The street crossed is a two-way street with two travel lanes and curb parking on both sides of the street. The crossing connects restaurants and shops on either side of the street. Figure 12 is a photograph of this crossing.

Figure 12. Photo. Unsignalized pedestrian crosswalk in Overland Park, KS.

Three midblock crossing maneuvers were observed, but only one of them was made in the crosswalk. This may be because of the low traffic volumes at the time the observation was conducted.

Crosswalk 5: W. 39th Avenue Between Rainbow Blvd and Cambridge Street in Kansas City, KS

Crosswalk 5 is a midblock crossing located on the campus of the University of Kansas Medical Center. There is a marked unsignalized crosswalk with pedestrian crosswalk signs (W11-2 and K-2025). Yellow flashers alert approaching motorists of the crosswalk. The street crossed is a two-way street with two travel lanes in each direction and a raised median. The crosswalk cuts through the raised median. The crossing connects a large parking lot to the medical center. Figure 13 is a photograph of the crossing.

Figure 13. Photo. Unsignalized pedestrian crosswalk in Kansas City, KS.

Several pedestrian crossing maneuvers were observed. All observed pedestrian crossing maneuvers were made within the marked crosswalk, and the approaching traffic immediately stopped in all cases.

Crosswalk 6: Oak Street Between 51st Street and 52nd Street in Kansas City, MO

Crosswalk 6 is a midblock crossing located near the campus of the University of Missouri—Kansas City (UMKC). There is a marked signalized crosswalk with pedestrian crosswalk signs (W11-2). Pedestrian pushbuttons activate the signal. The street crossed is two-way street with two travel lanes, a TWLTL, and limited parking on the west side of the street. The crossing connects a large parking area on the west side of the street with the UMKC campus. Figure 14 and figure 15 are photographs of this crossing.

Several pedestrian crossing maneuvers were observed. All observed pedestrian crossing maneuvers were made within the marked crosswalk. However, not all were made during the red signal phase; some were made during the green and yellow phases of the signal.

Figure 14. Photo. Signalized pedestrian crosswalk in Kansas City, MO.

Figure 15. Photo. Another view of signalized pedestrian crosswalk in Kansas City, MO.

Crosswalk 7: Rockhill Road Between 50th Street and 51st Street in Kansas City, MO

Crosswalk 7 is a midblock crossing located near the UMKC campus. There is an unmarked unsignalized crosswalk with pedestrian crosswalk signs (W11-2) and overhead yellow flashers that flash continuously. The street crossed is a two-way street with two travel lanes in each direction. The crossing connects a parking area on the west side of the street with UMKC campus buildings. Figure 16 is a photograph of this crossing. No pedestrian crossings were observed at this crosswalk.

Figure 16. Photo. Unsignalized pedestrian crosswalk in Kansas City, MO.

Crosswalk 8: W. Walnut Street at N. Bullock Drive in Garland, TX

Crosswalk 8 is located in Garland, TX. It is part of the school route to Bullock Elementary School and connects the Harris Hollabaugh Park and Community Center on the north side of Walnut Street with the residences and school on the south side. The school is located about 1,000 ft south of Walnut Street on Bullock. Walnut is a four-lane arterial with a center TWLTL and a posted speed limit of 35 mi/h. The subject crosswalk was recently improved as part of the development that opened the community center. Curb ramps were added at either end of the crosswalk where none previously existed, new fluorescent yellow-green school crosswalk warning assembly signs (S1-1 and W16-7L) were posted on either end of the crosswalk, and a pole-and-mast arm assembly was installed on the south end of the crosswalk, to enable the future installation of an overhead RRFB. The school crosswalk warning assembly sign for eastbound traffic is mounted on the pole. A crossing guard is stationed at the crosswalk during most of the periods during which the reduced speed limit is in place, approximately 6:55 to 8:00 a.m. and 2:55 to 3:45 p.m. Figure 17 is a photograph of the crossing.

Onsite observations indicated that yielding at this location was very low during periods in which the crossing guard was not present. In fact, researchers observed almost no vehicles yielding to pedestrians during any non-school period. However, yielding was nearly 100 percent when the crossing guard facilitated crossings. Researchers observed 3 pedestrians using the crosswalk during nonschool zone periods and 13 crossings that occurred away from the crosswalk during the observation period.

Figure 17. Photo. A different view of the crosswalk in Garland, TX.

Crosswalk 9: Barton Springs Road Between South 1st Street and Bouldin Avenue in Austin, TX

Crosswalk 9 connects the Austin Energy office building on the south side of Barton Springs Road with the parking garage attached to the Palmer Events Center on the north. The crosswalk has ladder markings and had previously employed in-pavement pedestrian-activated flashing lights adjacent to the crosswalk. Those lights have been deactivated, and an overhead pedestrian hybrid beacon has been installed for each direction of vehicle traffic. Although there is a narrow median refuge area present, both directions of traffic are stopped when the beacon is activated, and the WALK signal is provided for the entire width of the roadway. Figure 18 is a photograph of this crossing.

Figure 18. Photo. Crosswalk on Barton Springs Road in Austin, TX.

Onsite observations during a portion of an afternoon peak period suggested that vehicle compliance was good, with no driver observed running the steady red signal. Researchers also observed that drivers' response to the final flashing red phase of the beacon was mixed. Some drivers recognized that the "wig-wag" red display allowed them to proceed after stopping if no pedestrians were present, while other drivers continued to wait at the stop line until the beacon went dark. The stop line for eastbound traffic is an advance stop line, located upstream of the nose of the median island; although all of the observed drivers stopped prior to the crosswalk, compliance with the stop line in the eastbound direction was not as high as that in the westbound direction.

Crosswalk 10: 23rd Street Near Crystal City Mall in Arlington, VA

A crosswalk on 23rd Street between Crystal City Mall and office buildings was observed in Arlington, VA, following the kickoff meeting on October 20, 2010. This midblock crossing had continental pavement markings and a pedestrian crossing sign. In this region, 23rd Street is a divided roadway with a wide brick median with trees and benches. The crosswalks for each side of the street are in alignment with entrances to the mall or to an office building. Because of the split, several of the crossing pedestrians were observed to be walking outside the crosswalk markings (see figure 19). The pedestrians tended to walk a straight (shortest distance) path between the buildings rather than follow the crosswalk markings. Good yielding behavior by the drivers was observed.

An interesting feature that was present during this observation period was temporary markings that had the appearance of a colorful crossing. These markings, shown in figure 20, were located on Crystal Drive, which intersects 23rd Street. Later investigation revealed that it was pavement tattooing used as a promotion for the area.

Figure 19. Photo. Example of pedestrians outside of crosswalk at site on 23rd Street.

Figure 20. Photo. Colored pavement markings used to promote local area.

ASSESSMENT OF RESULTS

The limited field observations described above indicated the following:

- Field studies of driver compliance with laws requiring drivers to yield to pedestrians and the location of pedestrian crossing maneuvers (within marked crosswalk, partially within marked crosswalk, outside of marked crosswalk) can be readily conducted at a variety of pedestrian crossing types.

- The inclusion of flashing lights on pedestrian crosswalk signs (such as at the Stockton, CA, sites) rather than just in the pavement surface (such as at the Folsom, CA, site) appeared to substantially increase driver compliance with the law requiring yielding to pedestrians. (However, no nighttime observations were made of the in-pavement flasher treatment by itself; given that this installation was at a school crossing, such observation would not have been relevant.)

- School area locations such as the ones in Folsom, CA, and Garland, TX, can be effectively studied only at selected times of day when students are arriving at and departing from school or after-school activities.

CHAPTER 5. CLOSED-COURSE STUDY

OVERVIEW

Pedestrian crossing traffic control options include numerous combinations of signs and flashing beacons/LEDs. The breadth of combinations gives rise to a number of design variables; the optimal combination of these variables that results in long-term driver yielding to pedestrians (rather than just a "honeymoon phase" of compliance) has not been established. Several design factors have not been fully researched to determine the optimal design, including the following:

- Flash rate of beacons or LEDs.
- Shape and size of beacons/LEDs (round, rectangular, 8-inch, 12-inch, 5- by 2-inch, etc.).
- Placement of beacons or LEDs in the assembly units (within the sign, top, sides, bottom, overhead, in-road, etc.)
- Placement and message of signs and markings (warning and/or regulatory) for uncontrolled crossings (with and without beacons/LEDs).
- Brightness and how it influences driver behavior and how it affects glare and message recognition (especially given various lighting conditions such as day, night, fog, rain, snow).
- Influence of vehicle speed.

This research endeavors to provide the analytical basis for addressing several of these variables. Although it will not address every variable, the findings build a foundation and future research can fill the remaining gaps.

Closed-Course Study Objective

There are several questions regarding the optimal configuration of beacons used with Pedestrian Crossing signs (abbreviated as "Ped X-ing" in tables and figures in this document). Specific research objectives for this closed-course study are the following:

- Determine whether the shape, size, and placement of flashing beacon/LEDs affects the following:
    - Sign legibility distances (legibility distance is the location upstream of a sign where a driver can correctly read all of the words on a sign or correctly identify the symbol on a symbol sign).
    - Object detection.
- Determine driver ratings of disability glare for 8-inch circular beacons and LED-embedded signs using a rapid flash pattern.

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

Study Approach Overview

As part of this FHWA study, participants drove a Texas A&M Transportation Institute (TTI) vehicle (a 2009 Ford Explorer) on a closed course at the Texas A&M University Riverside Campus. During each lap, the participants viewed 8 study assemblies, 9 distractor signs, and up to 11 objects. Each participant drove the course twice, with a pause between laps for the field crew to switch the signs and objects for the second lap. Lessons learned from a previous study demonstrated that the position of traffic control devices on the course could affect the detection distance.(25) Therefore, researchers rotated the assemblies during this study. The rotation was done when approximately 25, 50, and 75 percent of the participants had completed the study. Figure 21 shows the driving study course, along with the positions of the signs and objects (when present). Based on the available budget, the goal was to have 64 participants in the study; therefore, researchers planned rotations to occur after 16 participants drove the course.

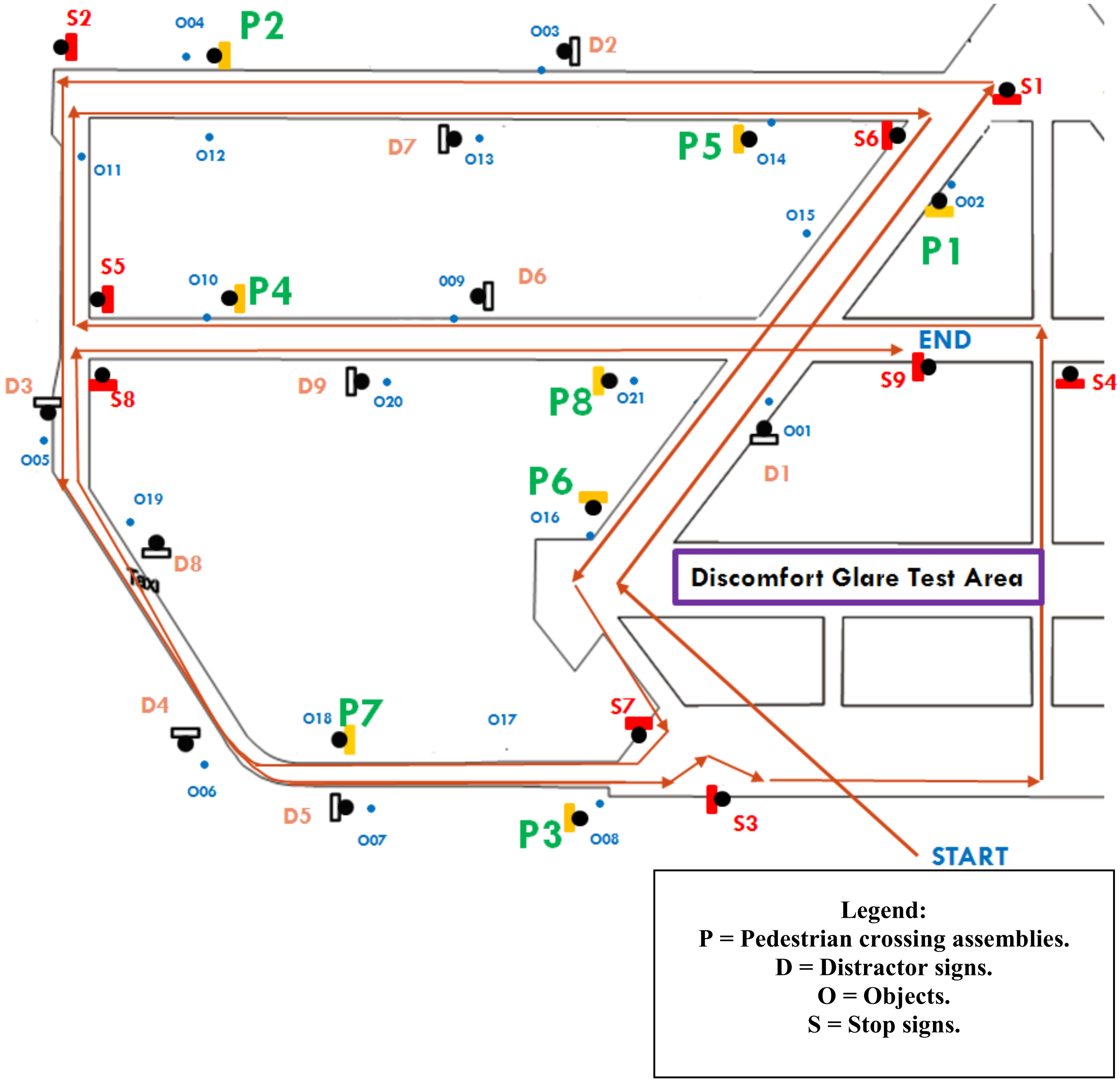


Figure 21. Diagram. Test route for Riverside study along with signs and objects positions.

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

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

As soon as the driver said "lights," "sign," "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 detection. Associated with this mark would be the Global Positioning System (GPS) coordinates of the vehicle along with the vehicle's speed and the time the key was pressed.

After participants completed the driving portion of the study, researchers directed them to the discomfort glare portion of the study. The driver would position the vehicle at set distances from an assembly and would then answer questions following increases in the brightness of the beacons or LEDs. Figure 22 is a plan view of the discomfort glare study layout.

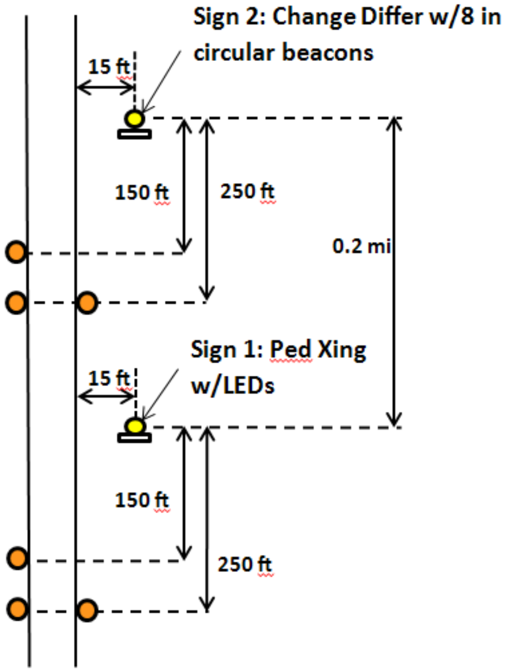


Figure 22. Diagram. Layout for the discomfort glare study.

COURSE DEVELOPMENT

Riverside Campus

The runway system on Texas A&M Riverside campus served as the test roadway for data collection. The runways offer a mixture of long straightaways, short intersecting segments, and curves. Researchers designed a route to permit participants to see every study assembly at a distance of at least 2,100 ft. To maximize the number of study assemblies, participants drove each runway section in both directions during a single lap. Each subject drove two laps, between which research team members changed the face of all distractor and study assembly signs, and the location of the objects (gray boxes, trash cans, and pedestrians).

Researchers added the following devices and objects to the Riverside runways:

- Pedestrian crossing assemblies that included a sign with or without optional beacons.
- Stop signs and distractor signs.
- Objects.

Pedestrian Crossing Assemblies

The study assemblies selected included the following:

- Two circular 12-inch beacons located above the sign (named C-A12 in the study) (see figure 23 and figure 24).
- Two circular 12-inch beacons located below the sign (C-B12) (see figure 25 and figure 26).
- Two circular 8-inch beacons located below the sign (C-B8) (see figure 27 and figure 28).
- One circular 12-inch beacon located above the sign and one circular 12-inch beacon located below the sign (C-V12) (see figure 29 and figure 30).
- Two rectangular beacons located above the sign (R-A) (see figure 31 and figure 32).
- Two rectangular beacons located below the sign (R-B), the format currently being used for the RRFB device (see figure 33 and figure 34).
- Sign with LEDs embedded into the border (LED) (see figure 35 and figure 36).
- Diamond-shaped sign with no beacons or LEDs (WO-B) (see figure 37 and figure 38).

Figure 23. Photo. C-A12, lap A study assembly.

Figure 24. Photo. C-A12, lap B study assembly.

Figure 25. Photo. C-B12, lap A study assembly.

Figure 26. Photo. C-B12, lap B study assembly.

Figure 27. Photo. C-B8, lap A study assembly.

Figure 28. Photo. C-B8, lap B study assembly.

Figure 29. Photo. C-V12, lap A study assembly.

Figure 30. Photo. C-V12, lap B study assembly.

Figure 31. Photo. R-A, lap A study assembly.

Figure 32. Photo. R-A, lap B study assembly.

Figure 33. Photo. R-B, lap A study assembly.

Figure 34. Photo. R-B, lap B study assembly.

Figure 35. Photo. LED, lap A study assembly.

Figure 36. Photo. LED, lap B study assembly.

Figure 37. Photo. WO-B, lap A study assembly.

Figure 38. Photo. WO-B, lap B study assembly.

To serve as a baseline, one of the assemblies had neither beacons nor embedded LEDs. A mix of pedestrian crossing and other warning signs were selected for the study assemblies. The warning signs either had a pedestrian-related message or had a logo that was similar to a pedestrian. Study signs included Pedestrian Crossing (W11-2), Bike (W11-1), Playground (W15-1), Wheelchair (W11-9), TRAIL CROSSING (W11-15a), Pedestrian and Bike (W11-15), Deer (W11-3), T-intersection Ahead (W2-2), and Offset Intersections (W2-7L). All signs used in the assemblies had fluorescent yellow-green background so that the color of the signs used with beacons or LEDs would be similar. Table 93 describes the signs used along with the average retroreflectivity reading for each sign.

Table 93. Study assemblies used in closed-course Riverside track study.

Portion[a]	Sign face[b]	Beac[c]	Lap[d]	Position[e]	Retro[f]
Driving	Trail Crossing	C-A12	A	P4(I), P5(II), P6(III), P8(IV)	783
	Wheelchair	C-A12	B	P4(I), P5(II), P6(III), P8(IV)	750
	Ped Crossing	C-B12	A	P2(I), P3(II), P4(III), P5(IV)	906
	Bike	C-B12	B	P2(I), P3(II), P4(III), P5(IV)	783
	Deer	C-B8	A	P8(I), P2(II), P3(III), P4(IV)	703
	Ped Crossing	C-B8	B	P8(I), P2(II), P3(III), P4(IV)	904
	Offset Intersection	C-V12	A	P6(I), P8(II), P2(III), P3(IV)	812
	Ped Crossing	C-V12	B	P6(I), P8(II), P2(III), P3(IV)	907
	Ped Crossing	LED	A	P1	797
	Offset Intersection	LED	B	P1	798
	Ped Crossing	R-A	A	P3(I), P4(II), P5(III), P6(IV)	879
	Playground	R-A	B	P3(I), P4(II), P5(III), P6(IV)	779
	Bike & Ped	R-B	A	P5(I), P6(II), P8(III), P2(IV)	724
	Ped Crossing	R-B	B	P5(I), P6(II), P8(III), P2(IV)	884
	Ped Crossing	WO-B	A	P7	896
	T-Intersection Ahead	WO-B	B	P7	911
Comfort	Change Differ	C-B8	Comfort	Discomfort Glare	502
	Ped Crossing	LED	Comfort	Discomfort Glare	691

[a] Portion = part of the study, either driving (for those assemblies viewed during the driving portion) or comfort (for those assemblies viewed during the discomfort glare portion). All study signs used on the driving portion of the study (i.e., lap A and lap B) were 36-inch, fluorescent yellow-green background color on type IV sheeting.

[b] Sign Face = description of the face of the sign. Figure 23 to figure 38 show photographs of the sign faces and the types of beacons or LEDs included with the signs.

[c] Beac = type of beacons or LEDs included in the assembly: C = circular, R = rectangular, A = above, B = beneath, V = both above and beneath, 12 = 12-inch circular beacon, 8 = 8-inch circular beacon, LED = embedded LEDs on the edge of the sign, WO-B = without beacons (i.e., no lights associated with assembly).

[d] Lap = assembly included in either lap A or B of the driving portion or as part of the discomfort glare potion.

[e] Position = location of the assembly on the course depending on the rotation. The first number (P1 to P8) indicates position while the value within the parentheses (I, II, III, IV) indicates the rotation. Four rotations of the signs occurred during the study (see figure 21).

[f] Retro = average of four retroreflectivity readings in cd/lx/m^2.

Assemblies Selected for Discomfort Glare Study

For the discomfort glare study, researchers asked the participants to park the study vehicle 250 ft and 150 ft away from a traffic sign assembly (see figure 22). The two assemblies tested included two 8-inch circular beacons mounted below a sign that said “Change Differ” (see figure 39) and a pedestrian crossing sign with embedded LEDs (see figure 40). The Pedestrian Crossing sign was 36 inches, fluorescent yellow-green background color on type 4 sheeting. The “Change Differ” sign was 36 inches with an orange background. A plan view of the study area is shown in figure 22, and an image from the start of the study area is shown in figure 41.

Figure 39. Photo. Discomfort glare assembly with circular beacons.

Figure 40. Photo. Discomfort glare assembly with embedded LEDs.

Figure 41. Photo. View of discomfort glare course.

Flash Pattern for Assemblies

The flash pattern used with the assemblies was selected based on FHWA official interpretation 4(09)-21 (I) released on June 13, 2012.(26) The flash pattern used with the circular and rectangular beacons in this closed-course study is shown in table 94. Figure 42 shows an oscilloscope reading of the light output for the rapid flash pattern. For the LED-embedded sign, the research team decided to use the same flash pattern used with the right or top beacon in the other assemblies. Table 95 shows the flash pattern used with the LED-embedded sign with figure 43 showing the oscilloscope version.

Table 94. Rapid flash pattern.

Left or Bottom Beacon	Right or Top Beacon	Time Increment (milliseconds)
On	Off	124
Off	Off	76
On	Off	124
Off	Off	76
Off	**On**	25
Off	Off	25
Off	**On**	25
Off	Off	25
Off	**On**	25
Off	Off	25
Off	**On**	25
Off	Off	25
Off	**On**	200
Total		800

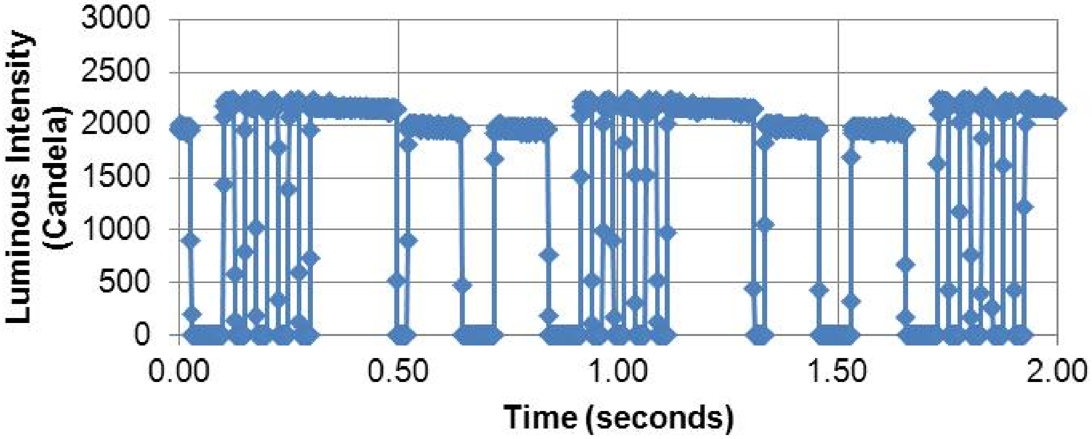


Figure 42. Graph. Flash pattern for rapid-flashing beacons.

Table 95. LED-embedded sign flash pattern.

LEDs	Time Increment (milliseconds)
Off	400
On	**25**
Off	25
On	**25**
Off	25
On	**25**
Off	25
On	**25**
Off	25
On	**200**
Total	800

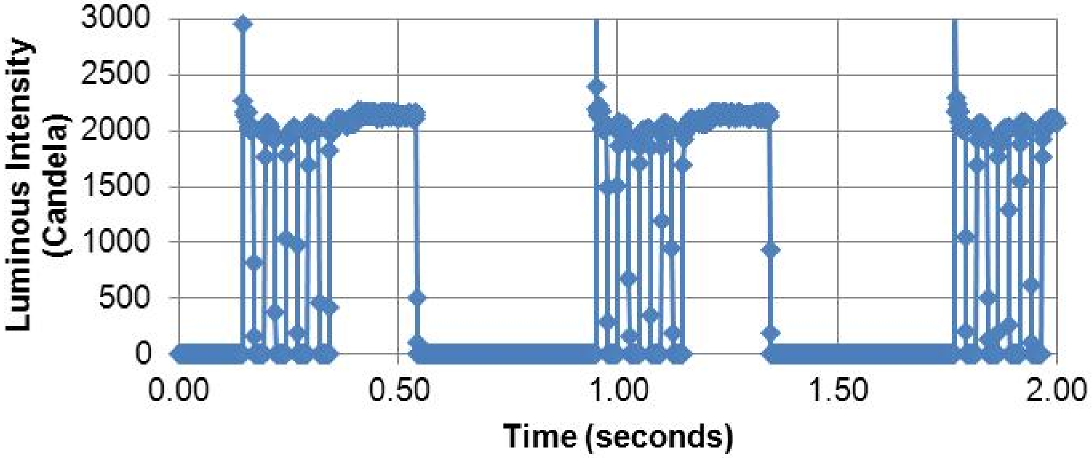


Figure 43. Graph. LED-embedded sign flash pattern (uses same five-pulse pattern as that used by the right beacon in a rapid flash pattern).

Brightness of Beacons/LEDs

After the detection distance data and ramp-up data were collected, the light output for the beacons and LED-embedded signs were measured. To quantify the brightness of the pulsing lights, researchers used the TTI Photometric Range within the Visibility Laboratory. For each beacon and LED-embedded sign, a technician measured the 95th percentile peak intensity and the optical power of the device. For the discomfort glare devices, these measurements were taken at each of the six levels of the controller. The researcher took the measurements at a vertical angle of 0 degrees and a horizontal angle of 0 degrees. Figure 44 and figure 45 show examples of devices being measured.

Figure 44. Photo. LED-embedded sign mounted on goniometer.

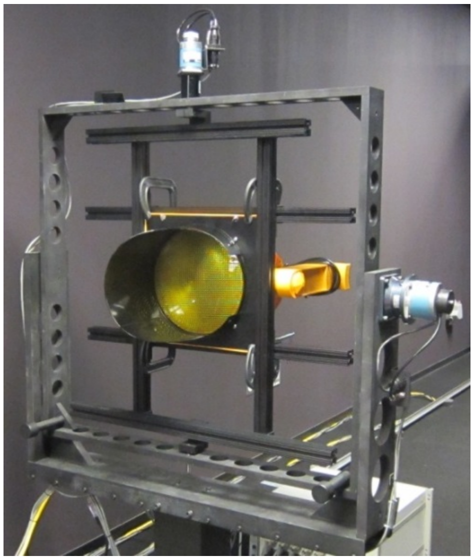


Figure 45. Photo. Mounted 12-inch circular beacon.

Figure 46 shows example of the peak intensity and the 95th percentile intensity. Peak luminous intensity is the maximum luminous intensity for a given flash. For the flash in figure 46, the peak intensity is 3,715 cd, which is 6.2 times greater than the Society of Automotive Engineers (SAE) standard J595 requirement for the center test point. The 95th percentile luminous intensity is the luminous intensity in which 95 percent of the instantaneous intensity measurements are less than or equal to during the duration of the flash; instantaneous intensities measured during the dark period are not included in this measurement. The 95th percentile luminous intensity for the flash in figure 46 is 1,726 cd, which is 2.9 times greater than the SAE standard J595 requirement for peak luminous intensity at the center test point.

Optical power is the integrated total of all flashes in a minute, in candela-seconds per minute (cd-s/min). Figure 46 shows an example where the flash has an integrated value of 836 cd-s. Within a minute, there are 58.7 of these flashes; therefore, the optical power is 49,073 cd-s/min, which is 3.4 times the SAE standard J595 minimum optical power for the center test point.

Figure 47 shows the measured optical power brightness for the devices used in the closed-course study. The measurements for those devices used in the driving portion have the same value (i.e., appear as a horizontal line) in the graph. The light intensity for these devices was not changed during the driving portion of the study. The two devices used in the discomfort glare portion of the study were changed from a setting of 1 to 6. The rectangular beacons had much higher optical powers compared with the other devices. Figure 48 shows the 95th percentile intensity brightness. Using 95th percentile intensity, the LED-embedded signs have similar values as the rectangular beacons.

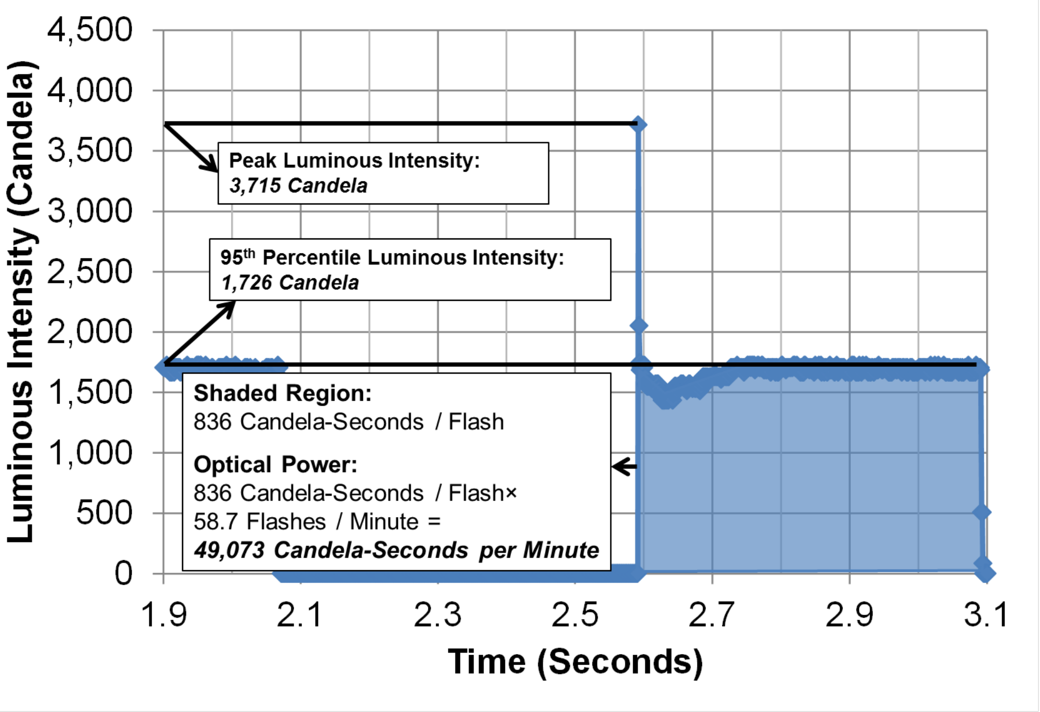


Figure 46. Graph. Example peak luminous intensity and optical power calculations.

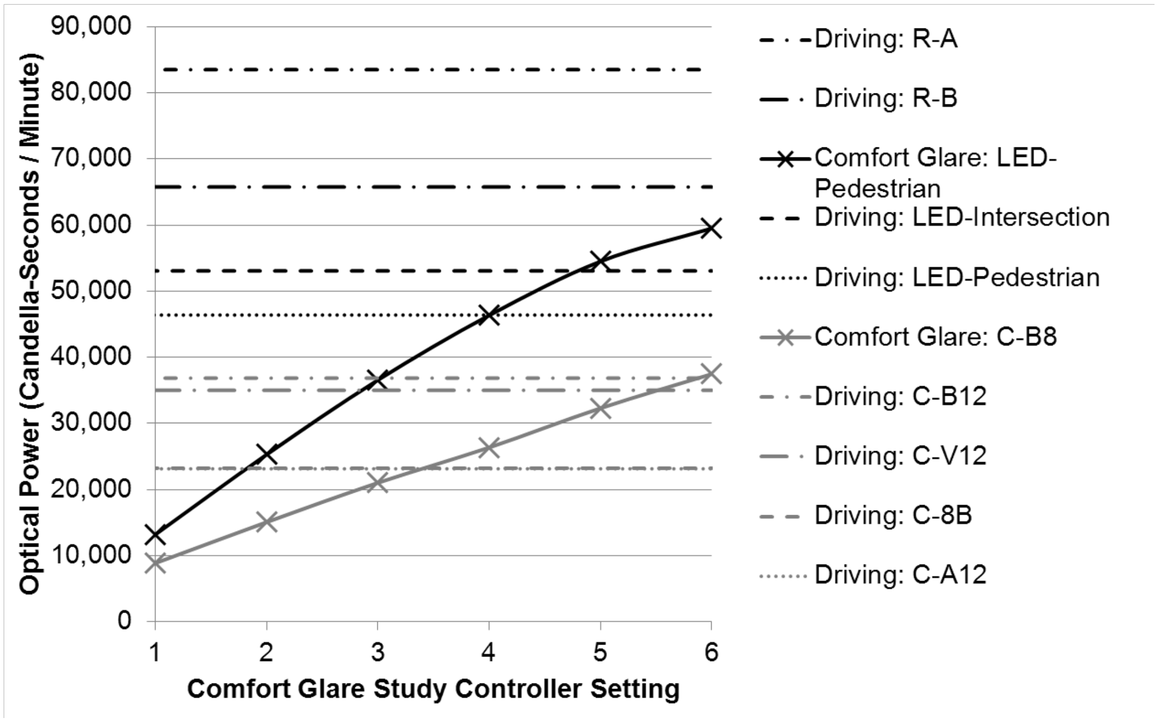


Figure 47. Graph. Optical power measurements for driving study assemblies compared with discomfort glare study controller settings (one setting in driving study).

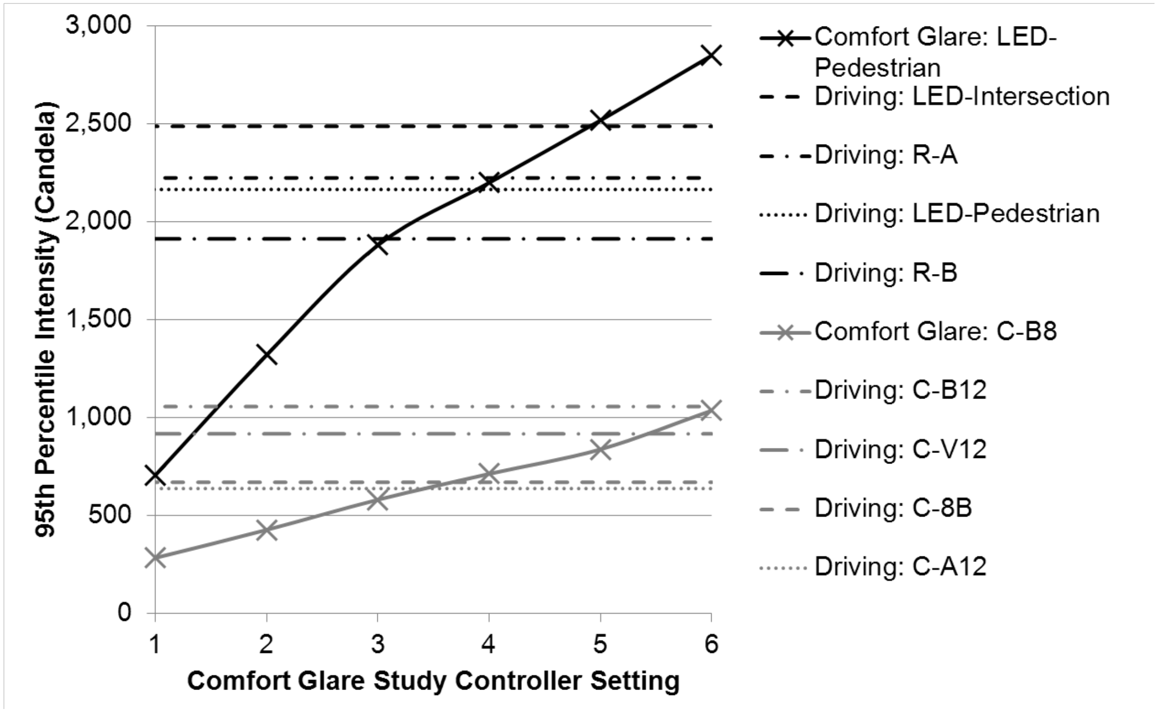


Figure 48. Graph. 95th percentile intensity measurements for driving study assemblies compared with discomfort glare study controller settings (one setting in driving study).

Stop Signs and Distractor Signs Selected for Driving Study

In addition to the study assemblies, distractor warning signs, distractor speed limit signs, and stop signs were included along the test route. The distractor signs served several purposes: to help hold participants' attention on the course, to distract participants (to some extent) from the fact that the study assemblies were the focus of the research, and to provide some additional data points to observe detection and legibility distances. The stop signs were included on the course to ensure that the participants would stop at selected locations so that the researcher in the car could give instructions or make notes in the computer file.

The distractor signs included along the test route are listed in table 96, which also provides the average retroreflectivity reading for each sign. The retroreflectivity varies widely between the different stop and distractor signs; however, this was not a concern because these signs were not the focus of this study.

Objects

Three objects were used in the study: a small gray wooden box, a trash can, and a pedestrian in blue medical scrubs. The pedestrian was selected because the assemblies being tested are for pedestrian crossings. The small gray wooden box has been used in other TTI nighttime detection studies.(15) Desired was a third object that would be between a pedestrian and small box in height; a trash can was selected.

Objects could be located downstream of each study assembly and distractor sign. The research team decided that objects would not be located immediately downstream of the stop signs. Objects would also be located between signs so participants would need to look for objects at locations other than just when a sign was present. In most cases, if an object was present at a location in lap A, then an object was not present at that location in lap B. Table 97 lists the objects by position number for lap A and lap B. Figure 21 shows the positions for the objects.

The box was placed approximately 3 ft downstream of the sign (see figure 49). Because of the potential for the generator to block the view of the box when the box was used in conjunction with a study sign, the boxes were placed about 2 ft to the left of the sign post, which is approximately 11 ft from the edgeline of the lane. The dimension of the box was 9.25 inches at the widest point by 7.5 inches from the ground. Figure 50 provides a close-up of the box.

Table 96. Distractors and stop signs used in closed-course study.

Type[a]	Sign face[b]	Lap[c]	Position[d]	Retro[e]
S	STOP	A&B	S1	116
S	STOP	A&B	S2	13
S	STOP	A&B	S3	23
S	STOP	A&B	S4	22
S	Blank	A&B	S5	79
S	STOP	A&B	S6	6
S	STOP	A&B	S7	49
S	STOP	A&B	S8	17
S	STOP	A&B	S9	152
D	Speed Limit 42	A	D1	398
D	Speed Limit 35	B	D1	297
D	Speed Limit B3	A	D2	268
D	Speed Limit 45	B	D2	289
D	Enough Silent	A	D3	488
D	Energy Supper	B	D3	272
D	Speed Limit 35	A	D4	865
D	Speed Limit F4	B	D4	42
D	Stop Ahead (Symbol)	A	D5	616
D	Simple Design	B	D5	513
D	Loose Gravel	A	D6	99
D	Rough Road	B	D6	107
D	Speed Limit 48	A	D7	268
D	Speed Limit Y2	B	D7	256
D	Speed Limit H8	A	D8	226
D	Speed Limit 25	B	D8	28
D	Train (Symbol)	A	D9	61
D	Always Animal	B	D9	483

[a] Type = either D for distractor signs or S for stop signs. The distractor signs had various sizes, backgrounds, and sheeting because these signs were obtained from previous studies. The stop signs were either 30- or 36-inch typical stop signs, except the sign at position S5. The sign at position S5 was alum high-intensity prismatic and did not have a legend (i.e., it was blank). The sheeting for the remaining stop signs varied because these signs were obtained from previous studies.

[b] Sign Face = description of the face of the sign.

[c] Lap = assembly included in either lap A or B of the driving portion on as part of the discomfort glare portion.

[d] Position = location of the sign on the course (see figure 21).

[e] Retro = average of four retroreflectivity readings.

Table 97. Object location on course.

Object position[a]	Follows[b]	Lap A object	Lap B object
O01	D1	small gray box	empty
O02	P1	trash can	empty
O03	D2	empty	small gray box
O04	P2	empty	pedestrian
O05	D3	pedestrian	empty
O06	D4	empty	trash can
O07	D5	trash can	empty
O08	P3	small gray box	empty
O09	D6	empty	small gray box
O10	P4	trash can	pedestrian
O11	After turn, S5	small gray box	empty
O12	After turn, S5	empty	trash can
O13	D7	empty	empty
O14	P5	pedestrian	small gray box
O15	After turn, S6	small gray box	trash can
O16	P6	empty	small gray box
O17	After turn, S7	small gray box	empty
O18	P7	empty	small gray box
O19	D8	trash can	empty
O20	D9	empty	pedestrian
O21	P8	pedestrian	trash can

[a] Object position = location of the object on the course (see figure 21).

[b] Follows = the position of the sign preceding the object or that the object is after a turn (see figure 21).

Figure 49. Photo. Small gray box on course.

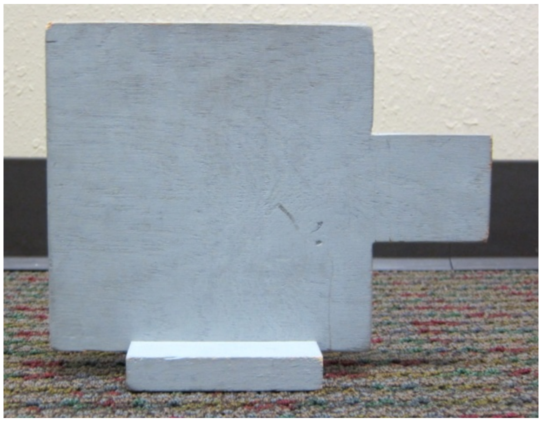


Figure 50. Photo. Close-up of small gray box.

The trash cans selected for this study were 42 inches high and 25 inches wide. The trash can was located 3 ft downstream of the sign (example shown in figure 51) when associated with a sign. Figure 52 shows an example of a pedestrian. Because of the length of the study and having three pedestrians present on each lap, several TTI staff members were used as pedestrians. The heights of the pedestrians ranged between 5 ft 2 inches and 6 ft 3 inches with the average height being 5 ft 10 inches. The pedestrian stood approximately 3 ft downstream of the sign post and did not move as the participant approached the sign. Table 98 lists the study assemblies and distractor signs that preceded a pedestrian. Each of the study assemblies with circular or rectangular beacons was tested prior to a pedestrian at a minimum of one location. In some cases, the study assembly was tested prior to a pedestrian in two locations.

Figure 51. Photo. Trash can on course.

Figure 52. Photo. Pedestrian on course.

Table 98. Study device and sign face by object position (view distance in ft) used with pedestrians.

Study device[a]	Sign face[b]	Object					
		O04 (4308)	O10 (4900)	O14 (3965)	O21 (3617)	O05 (1452)	O20 (2137)
C-A12	Trail Crossing	—	—	X	X	—	—
C-A12	Wheelchair	—	X	—	—	—	—
C-B12	Bike	X	X	—	—	—	—
C-B12	Ped Crossing	—	—	X	—	—	—
C-B8	Deer	—	—	—	X	—	—
C-B8	Ped Crossing	X	X	—	—	—	—
C-V12	Ped Crossing	X	—	—	—	—	—
C-V12	Offset Intersection	—	—	—	X	—	—
R-A	Ped Crossing	—	—	X	—	—	—
R-A	Playground	—	X	—	—	—	—
R-B	Bikes & Ped	—	—	X	X	—	—
R-B	Ped Crossing	X	—	—	—	—	—
Distractor	Always Animal	—	—	—	—	—	X
Distractor	Enough Silent	—	—	—	—	X	—

[a]Study Device = type of device, either distractor sign or study assembly where the beacons or LEDs included in the study assembly have C = circular, R = rectangular, A = above, B = beneath, V=both above and beneath, 12 = 12-inch circular beacon, 8 = 8-inch circular beacon.

[b]Sign Face = description of the symbol or text on the face of the sign used with the study device.

X = object (pedestrian) was present beyond the study device with the given sign face.

— indicates object (pedestrian) was not present beyond the study device with the given sign face.

Site Selection for Study Assemblies, Distractor Signs, Stop Signs, and Objects

Warning signs and speed limit signs were placed throughout the course as distractor signs. These additional signs helped to maintain participants' attention and interest between assemblies, distracted participants from the study's focus, and provided additional information regarding legibility distance (because drivers could not as easily guess at the words/numbers appearing on the distractor signs).

Figure 21 shows the route and the sign placements. Numbers on the graphic indicate the study assemblies (preceded by a "P"), distractor signs (preceded by a "D"), stop signs (preceded by an "S"), and objects (proceeded by an "O"), in the order in which they appeared on the route. Table 99 lists the travel distance and viewing distance for each sign or object. Viewing distance is the distance between where a participant turned onto the tangent and where the sign or object was located. It represents the theoretical maximum detection distance. Because of how some drivers positioned themselves at a turn or stop sign, longer distances could be measured.

Position P7 on the course required the installation of the sign in the grass. The pre-existing lane markings are close to the edge of the concrete, which caused the sign to be located in the grass to maintain a 12-ft offset between the edgeline and the sign. The researchers selected the lightest study sign assembly for the in-ground installation at position P7.

The Riverside runways are used by many groups within Texas A&M University system and were experiencing high demand during the summer 2012. While groups were willing to share the facility, some accommodations had to be made in this study. The signs in positions P1, S1, and S6 had to be removed at the conclusion of the daytime session (about 4 p.m.) and reinstalled prior to the start of the nighttime session (about 8 p.m.) to allow the landing of airplanes. Because a study assembly had to be removed every day, the researchers selected the assembly that would be easiest to remove, which was the sign with the embedded LEDs.

A previous study revealed that the position of a device on the runway could affect the detection distance.(25) Because beacons can be seen several thousand feet in advance of the device, the researchers decided to have one set of beacons on each straightaway on the course. This limited the study to a maximum of eight study assemblies with two of those assemblies in positions where the limited advanced viewing distances may affect the results. Therefore, the two study assemblies with lowest priority for the study—the without-beacon sign and the LED-embedded sign—were placed at these locations (positions P1 and P7) (see figure 21).

Another approach used to try to minimize the potential impact of position on the results was to rotate selected assemblies during the study. After data were recorded for a quarter of the participants, selected devices were rotated to a new position. With a goal of 64 total participants, researchers planned to rotate signs after data were collected for 16 (8 day and 8 night), 32, and 48 participants. The rotation typically took more than 5 hours to uninstall, transport, and reinstall the devices at their new location. Another benefit of rotation was the ability to gather detection to pedestrian data for different assemblies while the background to the pedestrian remained constant. While selected assemblies were rotated, the objects were not rotated. An object for a given lap was present for all participants. Because of the number of participants for the study (set based on available budget) and the desire to have a reasonable number of participants viewing the assemblies in each rotation, the researchers decided to have only four rotations. Given the number of assemblies included in the study, the preference would have been to have more rotations; however, all studies have limitations and this is recognized as one of the limitations for this study. The position for each of the assemblies is shown in table 99.

Route Preparation

Several of the Riverside campus runways were already marked with yellow centerline striping and white edgeline striping to simulate rural roadways. Where striping was not present, the research team installed temporary raised pavement markers (RPM) to act as a roadway centerline.

Signs without beacons were installed using a base as shown in figure 53. Figure 54 shows the larger base used with study assemblies that had the increased weight of beacons or embedded LEDs. In one case (position 7), the sign was installed in the ground because the edgeline was too close to the pavement edge to install the sign on the concrete.

Table 99. Order of device presentation on closed course.

Order	Position[a]	Travel[b] (ft)	View[c] (ft)	Group[d]	Order	Position[a]	Travel[b] (ft)	View[c] (ft)	Group[d]
0	Start	0	Start	Start	24	O10	3	4,900	Object
1	D1	2,000	1,100	Distract	25	S5	380	5,280	Stop
2	O01	3	1,103	Object	26	O11	630	630	Object
3	P1	1,291	2,394	Study	27	O12	949	800	Object
4	O02	3	2,397	Object	28	D7	717	1,517	Distract
5	S1	363	2,759	Stop	29	O13	3	1,520	Object
6	D2	2,239	2,239	Distract	30	P5	2,442	3,962	Study
7	O03	3	2,242	Object	31	O14	3	3,965	Object
8	P2	2,064	4,306	Study	32	S6	371	4,336	Stop
9	O04	3	4,308	Object	33	O15	667	667	Object
10	S2	371	4,679	Stop	34	P6	1,521	2,188	Study
11	D3	1,449	1,449	Distract	35	O16	3	2,191	Object
12	O05	3	1,452	Object	36	S7	978	3,169	Stop
13	D4	1,379	1,379	Distract	37	O17	1,035	1,035	Object
14	O06	3	1,382	Object	38	P7	1,457	2,492	Study
15	D5	1,240	1,240	Distract	39	O18	3	2,495	Object
16	O07	3	1,243	Object	40	D8	1,229	1,229	Distract
17	P3	1,380	2,623	Study	41	O19	3	1,232	Object
18	O08	3	2,626	Object	42	S8	896	900	Stop
19	S3	230	230	Stop	43	D9	2,134	2,134	Distract
20	S4	2,449	2,449	Stop	44	O20	3	2,137	Object
21	D6	2,972	2,972	Distract	45	P8	1,477	3,614	Study
22	O09	3	2,975	Object	46	O21	3	3,617	Object
23	P4	1,922	4,897	Study	47	S9	1,620	5,237	Stop

[a] Position = location of the object (or sign) on the course (see figure 21).

[b] Travel = distance traveled from previous position (ft).

[c] View = distance (rounded) the item can be viewed after participant makes a turn (ft).

[d] Group = start, stop, distract, study, or object. Start and stop represents the starting point or ending point of the course, distract represents the distractor signs. "Study" represents the study assemblies (see table 93), and "Object" represents the objects (see table 97).

Figure 53. Photo. Base for signs without beacons/LEDs.

Figure 54. Photo. Base for signs with beacons/LEDs.

The study assemblies were to be located a minimum of 360 ft prior to the stop sign. The 360 ft represents the stopping sight distance for 45 mi/h. It was selected as a compromise to have enough distance before the end of the segment but also provide the largest amount of advanced viewing distance. The distance between the edgeline and the left edge of sign was 12 ft. The height between the pavement and the bottom of downward sloping arrow plaque was 6 ft minimum based on MUTCD Section 2A.18 (see paragraph 06, page 42, option for secondary signs to be 1 ft less than 7 ft).(2) The height between the pavement and the bottom of the diamondshaped sign was 7 ft minimum.

The distractor and stop signs also had a distance of 12 ft between the edgeline and the left edge of the sign. The distance between the pavement and the bottom of stop and distractor signs was 6 ft or 7 ft minimum, respectively.

For all signs except the sign with embedded LEDs, the sign changes between laps were accomplished by lifting the sign up and out of the bottom bracket and then out of the top bracket (see figure 55 and figure 56). For the embedded LED sign, the bolts holding the sign onto the pole were removed, and the sign was exchanged. The stop signs were not changed between the laps, only the distractor signs and the study signs.

Figure 55. Photo. Example of sign change.

Figure 56. Photo. Another example of sign change.

Practitioner Review

A practitioner review of the assemblies and the course occurred prior to collecting the participant study data. Several engineers local to the area were invited to review the course during both daytime and nighttime conditions. In addition to another TTI staff member, an engineer from a nearby city reviewed the assemblies in a late afternoon and then returned after dark to review the course during nighttime conditions. The review confirmed that the study assemblies did represent how a city would have integrated the beacons with the sign. The review did not result in any changes to the study assemblies or the course. Another city engineer reviewed the study course in the initial days of data collection, again confirming that the devices used were appropriate.

DATA COLLECTION

Study Periods

The study was conducted under both daytime and nighttime conditions over 2 weeks in July/August 2012. The actual dates for the study were as follows:

- Wednesday, July 25, 2012 for practitioner review.
- Thursday, July 26–Friday, July 27, 2012.
- Monday, July 30–Friday, August 3, 2012.
- Sunday, August 5–Wednesday, August 8, 2012.

For July 26, 2012, sunset occurred at 8:24 p.m. On August 8, 2012, sunset occurred at 8:14 pm.

Initially, the arrival times for the participants were staggered with the idea that only one participant would be driving on the course at a time. That participant would drive the first lap, and members of the sign crew would follow behind the participant, changing signs in preparation for the second lap. This was the approach used successfully in previous studies. Because of the large number of sign and object changes required for this study, that approach resulted in large time gaps when the participant had to wait while sign changes and object changes were made and verified.

After the initial days of data collection, the TTI team developed a different approach for conducting the study. The revised approach required additional vehicles for members of the field crew along with extra objects to facilitate the placing and removing of objects; however, the benefits were a much faster study time for the participants and fewer staff needed to conduct the study (only 8 instead of 10 staff members). Another bonus for this approach was that couples could be scheduled for similar times. Previous experience has shown that older couples who participate in a study at night prefer having this option.

In the revised approach, used for the majority of the data collection, two participants drove the course a few minutes apart. The researcher in the test vehicle gave instructions to the participants that resulted in the participants being one stop sign (or straightaway) apart. For example, when the first participant was leaving S3, the second participant would be leaving S2. This ensures that the headlights of the following participant would not shine into the first participant's rear view mirror and that the two participants would not cross paths at any point on the course. Both participants would wait between laps while the field crew changed signs and objects. When first implemented, it took the field crew slightly less than 20 min to change all the signs and objects. They quickly improved their time to less than 10 min for sign and object changes between laps.

The study took about 1.5 hours from meeting the participant to the participant receiving his or her payment (see table 100). Half of the participants drove during daylight hours and half during nighttime conditions. The following start times were used:

- 12:20 p.m.
- 2:20 p.m.
- 8:40 p.m.
- 10:10 p.m.

Table 100. Participant time in study.

Activity	**Time (min)**
Escorting participant from front gate of Riverside to building where processing occurred	5
Initial processing, training	10
Drive to start, first lap	20
Wait time for sign changes (time allocated for this task decreased as sign crew became more familiar with duties)	10–20
Second lap, drive to discomfort glare location	20
Discomfort glare task	10
Final processing and payment	5
Total	80–90

Participants

The initial intent was to recruit a group of participants composed of one-quarter males over 55 years, one-quarter females over 55 years, one-quarter males under 55 years, and one-quarter females under 55 years. Within each of those demographic groups, the goal was to have 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. Therefore, the following divisions were used in structuring participant recruitment:

- Light level: day or night.
- Age group: young (younger than 55 years) and old (55 years or older).
- Gender: male or female.
- Lap driven first: A or B.

These divisions resulted in 16 participant categories. The research goal was to have 4 participants in each of the 16 categories, resulting in 64 participants. The study included 71 participants because participants were added to 1) replace participants whose data were not recorded successfully and 2) add additional data to offset missing data points not collected because signs were temporarily disabled or objects were not appropriately placed. The final participant pool is shown in table 101. Participants were at least 18 years old and possessed a valid driver's license with no restrictions.

Table 101. Distribution of participants.

		Day		Night		
Age	**Gender**	**Lap A first**	**Lap B first**	**Lap A first**	**Lap B first**	**Total**
Younger than 55	Female	3	5	6	2	16
	Male	5	5	3	6	19
55 or older	Female	4	5	5	4	18
	Male	6	2	3	7	18
Total		18	17	17	19	71

Participants were recruited by word of mouth, flyer distribution, and communication with people who participated in past studies and indicated an interest in future studies. Flyers with information about the study, location, contact information, dates, and compensation were distributed among friends and acquaintances and were posted in public places. Upon completion of the survey, participants received monetary compensation of $50.

Tasks

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

- See warning lights.
- See road sign.
- Read the words or identify the symbol on the road sign.
- See object.

Instrumented Vehicle

Two similar vehicles—2009 Ford Explorers—served as the participant cars for this experiment. The headlamps for these vehicles are 35 inches from the ground and 27 inches from center of the vehicle. Each vehicle was equipped with Qstarz BT-Q8181XT GPS receivers that reported the vehicle location at 10 Hz. The GPS receiver is a WAAS, EGNOS, and MSAS differential GPS device that uses WGS-84 datum with a position accuracy of 8.2 ft. Each receiver was affixed to the passenger side of the front windshield near the rear view mirror. TTI-developed software recorded the incoming GPS data stream into a text file along with single American Standard Code for Information Interchange (ASCII) character keyboard inputs from the researcher in the vehicle. The ASCII characters indicate responses by a participant during the study.

Participant Intake

Participant intake was headquartered at TTI's Environmental Emissions Research Facility on the Riverside campus. This location was selected because it was near the driving route, had public parking available, included restroom facilities, and was available for both daytime and nighttime use during the data collection period.

After meeting with a member of the research team to review the informed consent documentation and complete the demographic questionnaire, participants were given an overview of the study including how the data would be collected. They were also given a Snellen visual acuity test and the Dvorine color vision test.

To ensure consistency, the research team used scripts and slide shows to aid in providing instructions to each participant. The following script was used during intake:

> You will be driving a state-owned passenger vehicle on a closed course we have set up on airport runways, taxiway, and roadways here at the Riverside Campus. The vehicle is specially equipped to record and measure various driving characteristics, but drives just like a normal car. The researcher will be using a distance measuring instrument to mark various points as you drive. A researcher will be in the car with you at all times and will direct you when, where and how fast you will need to go. The fastest you will be asked to drive is 45 mi/h.
>
> Most of the route is marked with white and yellow striping just like you would see on an actual road. Part of the route is not striped, and when we reach these segments, the researcher will point you to the reflective pavement markings that will act as our road's "center line."
>
> While driving the test course you will see a number of road signs. There may be multiple signs on each stretch of road. As you approach each of the road signs, please tell the researcher:
>
> - If you can see warning lights.
> - When you can see the road sign.

- Then read the word or words on the sign as soon as you can read them. Some signs may not have words, and for these signs just tell me what you think the sign means. It is OK to make mistakes, just tell the researcher when you have made a mistake and the corrected word or words on the sign.

- Occasionally, you may see something at the edge of the road, such as a small box, a trash can, or a pedestrian. If you do see one of these, please tell me by saying “box,” “can,” or “pedestrian.”

> We will drive the entire course twice. There will be a brief pause at the end of your first drive through the course to allow field personnel time to set up the study area.
>
> While we want you to focus on the road signs as accurately as possible, your most important job is to drive safely, always paying attention to the road ahead and keeping the test vehicle under control. In addition, while this is a restricted area and there should not be any other vehicles in our area, on occasion there are vehicles on the roadway. So you will need to pay close attention to other vehicles on the roadway and obey all STOP signs you see.
>
> Once in the study vehicle, a researcher will give you more specific instructions on the study procedures. If you do not have any questions, we will proceed to the study course. Do you have any questions?

A slide show on a laptop computer was used to illustrate the types of signs the participants might see. The slide show also included the three types of objects that would be placed on the course.

Response Time Testing

As part of the intake process, a computer measured the participant and experimenter’s response times to develop a correction factor for each driver. Along the course, the experimenter pressed a button when the participant indicated he or she saw lights, a road sign or an object, or read the words or identified the symbol on a road sign. There is a small lag between the participant speaking a word, e.g., “lights,” and the experimenter pressing the button. The lag could vary between the experimenters collecting the data. To address this concern, a pretest was developed to measure the lag time between when the participant saw a symbol on the computer screen and spoke the symbol’s name and when the experimenter pressed the button. The following four images were used in the exercise: down arrow, up arrow, plus sign, and black circle (or dot). Each symbol was repeated five times for a total of 20 random images. The task required the participant to identify which stimulus was present and say the correct word, a task analogous to the in-vehicle task of saying “lights” or “sign.” For the experimenters, the task was a simple reaction time test. They pressed a single button regardless of what the participant said, again analogous to the in-vehicle task.

The participant was instructed to say the name of the shape as quickly as possible once the image appeared on the computer screen. The experimenter pressed a button upon hearing the participant say the shape name. The software recorded the time difference between the shape appearing on the screen and when the button was pushed. The participant faced the computer screen, and the experimenter's back was to the participant to avoid any anticipation on the part of the experimenter. Actual detection distance was determined from an average of the pretest reaction time for a participant along with the vehicle's speed.

Vehicle Review

The participant was escorted to the instrumented vehicle and given a walk-through of the vehicle's features. The participant was provided with the opportunity to adjust the seat and mirrors and to become accustomed to the controls of the vehicle.

Participants were informed that they would drive the instrumented vehicle on a closed course and were instructed to drive at a speed not exceeding 45 mi/h on the runways. They were asked to drive the runway system as though it were a regular roadway and were reminded that they had complete control of the vehicle at all times. A researcher accompanied the participant in the back seat, controlling the data collection equipment and providing direction. Participants were told to keep the vehicle's headlamps on the low setting if testing at night. Conversation between the participant and the experimenter was kept to a minimum to ensure that the participant did not miss identifying any of the signs and lights on the course.

First Lap of Driving Course

The participant drove the instrumented vehicle to the start position of the course, marked with an orange construction-zone barrel, waited while the researcher confirmed the lap (A or B) with the field crew and started recording a new data file on the computer, and then proceeded toward the first sign position.

The participant was to signify detection of the item by saying a preselected word to indicate the presence of warning lights, road sign, or object, and to read the words or identify the symbol on a road sign as soon as the sign was close enough to be legible. The experimenter recorded the response on the computer. The following instructions were given to the participants:

> Each time I tell you to start, you will do the following:
>
> - Accelerate to a speed you are comfortable with, up to a maximum speed of 45 mi/h.
> - When you first see warning lights or a road sign on the right side of the road, I would like for you to say "lights" or "sign." If you initially saw lights, as soon as you can see the road sign, tell me "sign." Third, as soon as you are sure what the sign says, please read me the words or numbers on the sign. If you change your mind and see that the sign says something different than you initially thought, read me the new word or words. If a sign has no words on it, tell me what you think the sign means.
> - If you see an object such as a box or trash can close to the edge of the roadway, I would like for you say "box" or "trash can." If you see a pedestrian close to the edge of the roadway, please say "pedestrian."

- The study course has several stopping points that we will use to provide you an opportunity to ask questions and rest, and provide me with an opportunity to give you further instruction if necessary.
- You may stop at any time if you are uncomfortable.
- Because you will be watching for a lot of signs, we won't be able to carry on other conversation while you are driving.
- Please remember that safety comes first and follow all transportation and traffic laws.

If you don't have any questions, we will start. Are you ready?

Second Lap of Driving Course

After completing the initial route, the participant was told to return to the orange construction barrel marking the route's start point. Following notification from the sign crew that the signs had been changed from lap A to lap B (or vice versa), the researcher started a new data file and instructed the participant to proceed with the second lap. Following the second lap, the participant was directed to drive to the discomfort glare section of the course.

Discomfort Glare

At the beginning of the discomfort glare study, researchers asked the participants to park 250 ft away from sign 1 (the first two orange barrels) (see figure 22 or figure 41). After the participant parked the vehicle, researchers turned on the beacon and asked the participant to indicate whether the brightness of the light was comfortable, irritating, or unbearable, which were defined as follows:

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

After the participant rated the first level of the controller, a technician increased the controller setting to level two. This process continued until the participant indicated the brightness was unbearable or the technician reached level six on the controller (the highest setting for the device). Figure 48 shows the brightness measurements for each device at the six controller levels; measurements were taken at vertical and horizontal angle of zero.

Once the participant indicated the brightness was unbearable or the technician reached level six, the researcher asked the participant to move to the next position. In order, the positions were the following:

- LED-embedded sign, 250 ft.
- LED-embedded sign, 150 ft.
- 8-inch circular beacons, 250 ft.
- 8-inch circular beacons, 150 ft.

This order remained the same for every participant, which is a limitation of this study.

DATA REDUCTION

Participant Demographics

Table 102 lists the demographic information for the 71 participants. The large number that selected retired for employment (29 percent) is a reflection of the emphasis on having half of the drivers over 55 years of age.

Response Time

The response lag time between participants and researcher were determined for each participant during the intake procedure. The average response time for each participant in conjunction with the experimenter who was collecting data for that participant was determined. A review of the data revealed several potential errors. Very long response times were deemed to be caused by some distraction to the participant or the experimenter, which happened occasionally in the intake room. Very short response times were eliminated because, on occasion, the experimenter accidentally pressed the button before the participant spoke. To eliminate these outliers, data points that were outside of two standard deviations of the average response time for that participant were removed. These steps removed 83 responses (about 6 percent). Table 103 lists the average response time by experimenter before and after removing data. In general, the response time was about 1 s for any experimenter.

Table 102. Demographic information for 71 participants.

Characteristics		Number (percent)
Gender	Male	37 (52)
	Female	34 (48)
Age Groups	< 55	35 (49)
	≥ 55	36 (51)
Race	Caucasian	57 (80)
	African American	1 (1)
	Hispanic	8 (11)
	Not reported	5 (7)
Employment	Full time	26 (37)
	Part time	13 (18)
	Retired	19 (27)
	Not reported	5 (7)
	Student	4 (6)
	Other	4 (5)
Miles Driven Per Year	< 10,000	19 (27)
	10,000–15,000	27 (38)
	> 15,000	20 (28)
	Not reported	5 (7)
Normal Driving Conditions	Rural roads	20 (28)
	Freeways	3 (2)
	City streets	31 (44)
	Mixed	17 (26)

Table 103. Response time by experimenter.

Researcher	Number of responses	Average response time (ms)	Number of outliers (responses more than two standard deviations from average)	Number of responses without outliers	Average response time after outliers removed (ms)
L	499	972	28	471	931
C	438	1,072	26	412	1,014
O	320	947	20	300	906
J	100	1,049	6	94	1,018
S	40	1,071	3	37	1,038
All	1,397	1,006	83	1,314	960

A more detailed review of the response time data indicates that adjusting the detection distance for response time should occur uniquely for each participant rather than using a per-experimenter average response time. Figure 57 shows the plot of the responses measured for each participant before eliminating the outliers. Figure 58 shows the plot of the responses measured after eliminating the outliers. As can be seen in the plots, some participants had average response time below 0.8 s, while other participants' response times averaged above 1.2 s. Therefore, the average response time by participant rather than by experimenter was used to adjust the detection distance.

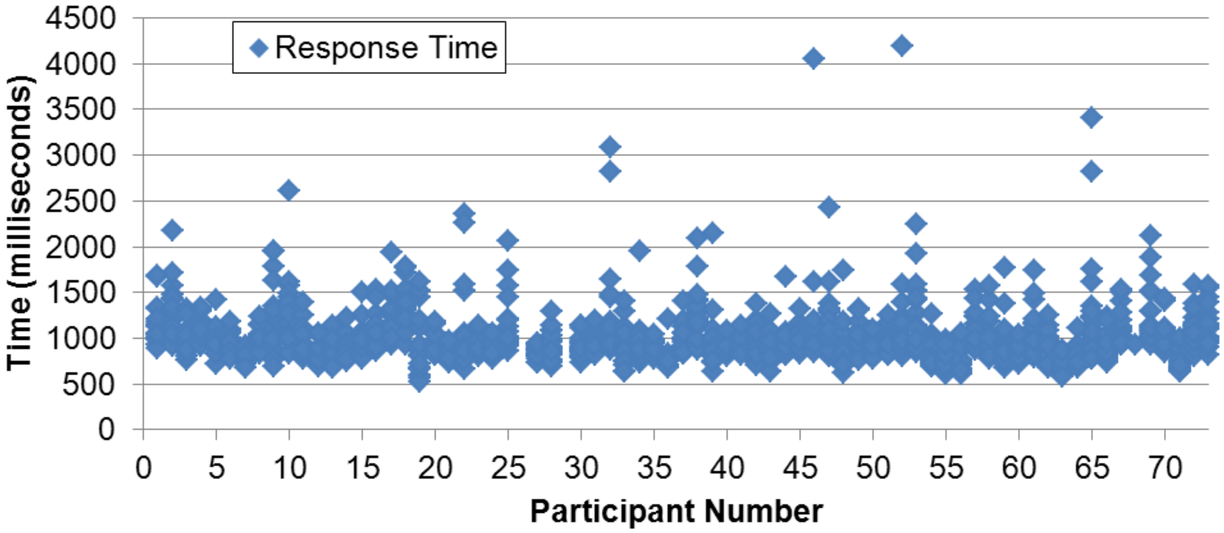


Figure 57. Graph. Measured response times by participant.

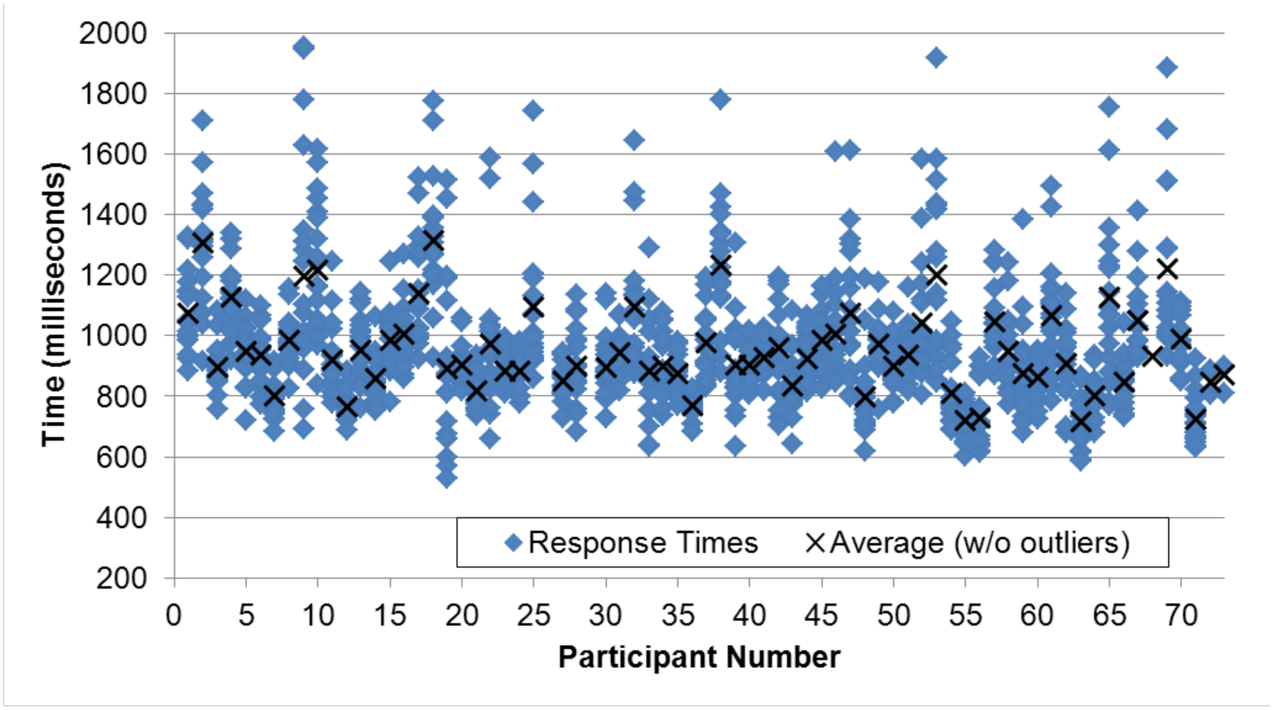


Figure 58. Graph. Response times by participant after removing outliers.

The measured detection distance was adjusted using the average response time for the participant and the speed of the vehicle at the point when the participant responded to a light or sign. The adjusted detection distance was an average of 2 percent higher than the GPS-based detection distance across all participants and sign/object locations. When the detection distances was shorter, such as to objects or reading the sign face, the average adjustment was about 4 to 6 percent. The maximum response time adjusted distance was 47 ft, while the minimum was 0 ft, a situation that occurred when the vehicle was stationary.

Detection Distance

The computer software program along with the GPS unit were used to determine the velocity and GPS coordinates when the driver identified a light, sign, or object, or when the participant read the sign. The data are recorded in a spreadsheet that contains a continuous stream of time, GPS coordinates, and velocity data. The time, velocity, GPS coordinates when the driver said "light," "sign," or "object," or read the words on the sign were marked in the data streams.

The GPS locations of each of the signs and objects were recorded before the study began. The detection distance was determined by subtracting the location of the sign or object from the locations marked by the experimenter in the vehicle. This calculated distance was then adjusted to account for the response time of the experimenter and participant. Average response time of the experimenter and specific participant was multiplied by the vehicle's velocity at the time of identification to obtain the response distance. The response distance was added to the detection distance to obtain the adjusted detection distance. The adjusted detection distance was used in all the analyses.

Box Plots

For some analyses, results are presented visually, in the form of box-plots, or quantitatively, in the form of statistical analysis. Box plots presented in this report were generated using the convention that the central line in the "box" represents the median data point (see figure 59). The top of the box represents the 75th percentile and the bottom represents the 25th percentile. Thus, the relative position of the median score within the 75th and 25th percentiles can give some indication about the skewness of the data. The "whiskers" represent the data that lay 1.5 times beyond the interquartile range (IQR). This is the range between the 25th and 75th percentiles. If all data below the 25th percentile and above the 75th percentile are within 1.5 times the IQR, then the end of the whisker represents the greatest or smallest value. Otherwise, all outliers beyond 1.5 times the IQR, added or subtracted from the 25th and 75th percentiles, respectively, are plotted using small black circles.

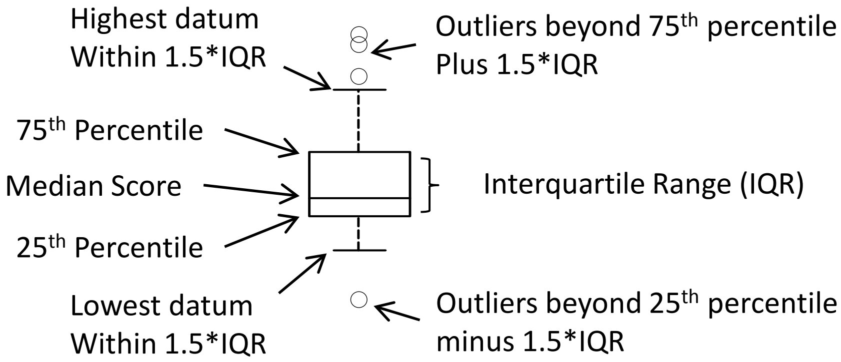


Figure 59. Diagram. Box plot details.

Data Cleaning

Before proceeding with the statistical analyses, the data were reviewed in a search for records with duplicate information regarding the participant, and miscoded information regarding the response type, lap number, specific position of assembly or sign face presented in the assembly. These records typically generated duplicate data points that were corrected later. For example, a participant said "Word," but after a few seconds said "Word" again for the same sign. After identifying all 262 instances (about 2 percent of the data stream), they were removed from further analysis.

As a second stage of data cleaning, extreme data points were identified from various box-plot representations of the data as potential outliers whenever their distance from the mean exceeded 2.5 standard deviations (roughly corresponding to the 99.38th percentile of a normal distribution). Some of these early candidates were identified as anomalous and removed at that point. For example, for participants who were perceived as guessing at a long distance from the signs, the first stage of the data cleaning could not remove the instances when they guessed correctly, but in the second stage they appeared as extremely long distances.

A final stage of this process consisted of observing outlying data points after performing the statistical analysis. In addition, some data points were identified in the second stage of data cleaning and therefore were removed at this stage. Eighteen data points were removed from the second and third stages of data cleaning.

RESULTS

Detection Distance—Light

As expected, the detection distance to the beacons/LEDs was large. During the daytime, the average detection distance to the assemblies with beacons or LEDs was 2,244 ft. At night, the average detection distance was even longer, 3,236 ft. In several cases, the "light" detection distance was limited by the amount of viewing distance to the assembly. Therefore, the detection distances reported here could be shorter than the distance that a driver could detect a blinking beacon or LED. The conditions of the closed-course study; however, should result in very long detection distances. The participants were told to look for lights, and there were minimal background elements, such as billboards or street activity, competing for a driver's attention.

Detection Distance—Sign

The average detection distance to the sign (i.e., when the participants stated that they could see a sign) by type of sign (study assembly, distractor, or stop) along with age group and night or daytime conditions is shown in table 104. Caution is offered with the data because there are several elements that affect the results, such as viewing distance, position on the course, and the preceding sign or assembly. The focus of this study was legibility (i.e., the distance to read the study sign) and detection of the object located beyond a study sign. Therefore, the researchers did not attempt to control for those elements that could affect the detection of a sign and only presented averages and general observations regarding sign detection. The presence of beacons/LEDs along with the better quality retroreflectivity appears to contribute to the ability of the participants to see the sign from a greater distance when comparing the results for the assemblies (nighttime detection distance of 1,855 ft) with the results for the distractor signs (nighttime detection distance of 1,301 ft). Detection to the stop signs was lower than detection to other signs; however, there was always another sign located close to the stop sign, so the shorter detection distance may be affected by the presence of the other signs. Note that the average detection distances for all the sign types are greater than the stopping sight distance for 45 mi/h (360 ft). The results in table 104 do reveal a difference owing to old versus young; however, a difference by daytime versus nighttime is not as evident. Overall, the participants had a slightly longer sign detection distance during the day compared with the night.

Table 104. Sign detection distance by sign type without attempts to control for external elements such as viewing distance that could affect results.

Old or Young	Sign type	Daytime			Nighttime		
		Count	DD (ft)	SD (ft)	Count	DD (ft)	SD (ft)
Old	Assembly	262	1,925	782	219	1,814	921
Old	Distractor	314	1,121	420	297	1,235	523
Old	Stop	288	737	460	280	834	540
Old Total		864	1,237	743	796	1,253	765
Young	Assembly	262	2,311	829	284	1,886	733
Young	Distractor	303	1,277	447	338	1,360	551
Young	Stop	291	1,135	796	336	1,083	789
Young Total		856	1,545	871	958	1,419	768
Assembly		524	2,118	828	503	1,855	820
Distractor		617	1,198	440	635	1,301	541
Stop		579	937	680	616	970	697
Grand Total		1,720	1,390	823	1,754	1,344	771

Count = number of participants.
DD = average detection distance (ft).
SD = standard deviation detection distance (ft).

Legibility Distance

One of the objectives of this study was to determine whether sign legibility distance to a study assembly is affected by the shape, size, or placement of the beacon/LEDs. The preliminary evaluations revealed confounding issues between the sign face and the beacon type, which is not surprising because each beacon type had only two sign faces. To handle this issue in the analysis, the following two approaches were used:

1. Pedestrian Crossing Sign Only Data: This approach focused on the findings when the Pedestrian Crossing sign was used in an assembly.
2. All Assemblies Data: This approach included a new variable to group the sign faces into one of three groups so that the data for all assemblies could be considered. The following groups were identified for the new variable “sign.fam” (for sign family):
    - Ped X-ing sign: Pedestrian Crossing sign (W11-2).
    - Other common signs: Deer (W11-3), T-Intersection Ahead (W2-2), and Offset Intersections (W2-7L).

- Uncommon signs: Bike (W11-1), Playground (W15-1), Wheelchair (W11-9), Trail Crossing (W11-15a), and Ped and Bike (W11-15).

To show the range of legibility distance being considered, table 105 lists the average and standard deviation of the legibility distance for daytime and nighttime. The analyses were separated into daytime and nighttime because 1) daytime and nighttime detection distances differed considerably and 2) to permit the opportunity to determine whether variables were affecting legibility distances differently in day and night conditions.

Table 105. Legibility distance by assembly type and sign face.

		Daytime			Nighttime		
Assembly	**Sign face**	**Count**	**DD (ft)**	**SD (ft)**	**Count**	**DD (ft)**	**SD (ft)**
A: C-A12	Trail Crossing	34	284	100	34	226	89
A: C-A12	Wheelchair	35	714	350	35	538	206
A: C-B12	Bike	34	617	199	36	602	467
A: C-B12	Ped X-ing	35	993	410	36	786	236
A: C-B8	Deer	34	1,007	397	36	643	279
A: C-B8	Ped X-ing	35	1,002	330	35	724	263
A: C-V12	Offset Intersection	34	973	381	35	777	282
A: C-V12	Ped X-ing	36	1,028	320	36	780	284
A: LEDs	Offset Intersection	35	970	423	35	822	352
A: LEDs	Ped X-ing	34	1,020	290	35	839	332
A: R-A	Ped X-ing	33	994	360	35	708	190
A: R-A	Playground	35	536	294	36	377	204
A: R-B	Bike & Ped	34	535	276	33	423	259
A: R-B	Ped X-ing	34	980	377	36	672	221
A: WO-B	Ped X-ing	34	1,061	437	35	784	233
A: WO-B	T-Intersection	35	1,102	414	36	886	326
Grand Total		551	864	415	564	663	326

Count = number of participants.
DD = average detection distance (ft).
SD = standard deviation detection distance (ft).

Each dataset was analyzed using linear mixed effects models (LMM). These kinds of models combine characteristics from both linear regression and analysis of variance (ANOVA) with replication. The model was specified such that the data structure, known associations between variables, and systematic variation in the response variable were appropriately accounted. The analysis treated the co-dependency of data points from different drivers by explicitly adding a random effect for each participant in the experiment. The order of the laps was also treated this way. Within the blocking structure described above (i.e., light condition/driver/lap number), the analysis incorporated fixed effects for other variables of interest. In the case of legibility distance, the fixed effect variables were age group, sign family, and type of assembly. Estimates, confidence intervals, and conclusions were later extracted for these effects.

Finally, the analysis applied weights in inverse proportion to the estimated travel time between the point of detection and the assembly. This adjustment was necessary because data showed larger variability at greater distances from the assemblies. (This condition is known as heteroskedasticity in the statistics literature.) Preliminary examinations considered several other variables, such as position on the course and view distance. For some of the analyses, interactive terms were included to account for interaction between variables. All statistical analyses were performed using open source data analysis packages. (See references 27 through 30.)

It was necessary to adjust the model standard errors when comparing various pairs of assemblies. In such instances, the confidence in the model estimates decreases as the number of comparisons increases. This occurs because the chance of a type-I error is greater for simultaneous comparisons than for single comparisons.

A similar adjustment was made when comparing groups of assemblies. The reason given above is valid in this case too, but more important, the adjustment also permits accounting for correlation among the model estimates, which greatly affects the standard error of group comparisons. An example of group comparisons is investigating for a difference between all assemblies with rectangular and all assemblies with circular beacons.

Daytime Legibility Distance

An objective of this study was to investigate whether the shape of the beacons (circular or rectangular), the size of the beacon (e.g., 12 inches or 8 inches), or the placement of the beacon (e.g., above or below the sign) affected the results.

Table 106 shows the LMM results, and table 107 shows the ANOVA results for daytime. Preliminarily, the estimates for the effects of particular assemblies do not seem statistically significant (compared with their standard errors). This observation is consistent with the ANOVA results for the model (showed at the end of the table) where Assembly as a group is a statistically insignificant factor to explain legibility distance variation (*p*-value of 0.0565).

Table 108 shows the daytime pair comparison results from the model in table 106. The shape of the beacon—circular or rectangular—did not have an effect on legibility distance as shown by the non-significant result for the paired comparison of circular to rectangular. The individual pair comparisons of C-B12 to R-B and R-A to C-A12 were also not statistically significant, indicating that the daytime legibility distances are similar for each pair. The comparison of the legibility distance with comparison of size of beacon (i.e., C-B8 and C-B12) also did not show a significant difference between legibility distances.

The evaluation that examined legibility when the beacons were placed above or below the signs found no significant difference in distances. When reviewing the comparisons of individual pairs, the legibility distance for R-A and R-B were similar; however, C-B12 and C-A12 were different (statistically significant) (see table 108). This finding is additional evidence that the uncommon signs are confounding the results. When the circular beacons were located below the sign, drivers could read the signs at a greater distance upstream than when beacons were located above the sign. The assemblies with the 12-inch circular beacons above the sign had uncommon signs (Trail Crossing and Wheelchair) while the assemblies with the circular beacons below the sign had the more familiar signs of Ped X-ing and Bike, which confounds the validity of this finding. To offset this limitation, only the data when the Pedestrian Crossing sign was present was examined.

Table 106. Linear mixed-effects model results using all assemblies for daytime legibility distance.[a]

Variable	Value	Std. error	DF	*t*-value	*p*-value
Reference Level[b]	560.6991	55.77835	490	10.05227	0.0000
O.Y: young	531.4206	63.2773	33	8.398282	0.0000
Sign.Fam: Ped X-ing	92.5412	36.11634	490	2.562309	0.0107
Sign.Fam: Uncommon	-216.2926	46.45764	490	-4.655694	0.0000
Type_AsA: C-A12	-54.663	30.64454	490	-1.783778	0.0751
Type_AsA: C-B12	68.5406	35.13588	490	1.950728	0.0517
Type_AsA: C-B8	73.4926	46.41126	490	1.583508	0.1140
Type_AsA: C-V12	72.4622	46.20551	490	1.568259	0.1175
Type_AsA: LEDs	56.3263	47.01232	490	1.198118	0.2315
Type_AsA: R-A	6.2942	33.8891	490	0.185729	0.8527
Type_AsA: WO-B	89.4155	47.13876	490	1.896858	0.0584
O.Y: young X Sign.Fam: Ped X-ing	-37.1006	57.0205	490	-0.650654	0.5156
O.Y: young X Sign.Fam: Uncommon	-279.2907	52.69738	490	-5.299899	0.0000

[a]Notes:

1. Linear mixed-effects model fit by REML.
2. Fixed effects: Adj_Dis ~ O.Y + Sign.Fam + Type_As + O.Y X Sign.Fam.

[b]Reference level in the model has the following conditions:

- O.Y. (age: old or young) = older driver.
- Sign.Fam (sign family) = common signs.
- Type_AsA (assembly type, see figure 23 to figure 38) = R-B.

Std. error = Standard error of value.
DF = Degrees of Freedom.

Table 107. ANOVA results using all assemblies for daytime legibility distance.

Variable	numDF	denDF	*F*-value	*p*-value
(Intercept)	1	490	789.9444	< .0001
O.Y	1	33	60.4778	< .0001
Sign.Fam	2	490	284.1375	< .0001
Type_As	7	490	1.9768	0.0565
O.Y X Sign.Fam	2	490	21.9561	< .0001

Table 108. Daytime legibility distance multiple comparison using all assemblies data.

Test	Item	Comparison	Estimate	Std. error	*Z*-value	Pr(>|*z*|) [a]
Simultaneous Tests for General Linear Hypotheses	Place	(Above) - (Below) = 0	-58.455	24.211	-2.414	0.08335 .
	Shape	(Circular) - (Rectangular) = 0	3.792	23.555	0.161	0.99978
	Size	(C-B8) - (C-B12) = 0	4.952	46.579	0.106	0.99996
Confirmation (Individual Pair Comparisons)	Shape	(C-B12) - (R-B) = 0	68.541	35.136	1.951	0.23267
		(R-A) - (C-A12) = 0	60.957	33.396	1.825	0.29364
	Place	(R-A) - (R-B) = 0	6.294	33.889	0.186	0.9996
		(C-B12) - (C-A12) = 0	123.204	35.553	3.465	0.00334**

[a]Significance values are as follows: $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$.

When the evaluation only considered those conditions when the pedestrian crossing sign was present, no significant differences between assemblies (LEDs, WO-B, R-B, R-A, C-V12, C-B8, C-B12) were identified. Stated in another manner, the presence of a yellow rapid-flashing beacon did not affect the legibility distance to the pedestrian crossing sign during daytime conditions.

Nighttime Legibility Distance

The linear mixed-effects model for the nighttime legibility distance when using the data for all assemblies (see table 109) shows that the following variables are significant: age (old, young), sign family, assembly type, and interaction between age and sign family. Assembly type was not significant at the 0.05 level in the daytime model while it was in the nighttime model. This suggests assembly type influences sign legibility at night more than it does during daytime conditions. Table 110 shows the ANOVA results.

Table 111 shows the results for the nighttime comparisons regarding the shape, size, and placement of beacon. As shown in table 111, the circular beacons were associated with longer legibility distances as compared to rectangular beacons. Examining the pairs of circular to rectangular beacons in similar positions revealed that the shape of the beacons was not significant when the beacons were above the sign (see R-A compared with C-A12); however, the shape of the beacons was significant when the beacons were below the sign (see C-B12 with R-B). The participants read the sign 157 ft earlier when the beacon was a 12-inch circular beacon as compared to a rectangular beacon located below the sign.

The comparison of the legibility distance for size of beacon (i.e., C-B8 and C-B12) also shows a significant difference between legibility distances. Drivers were able to read the sign earlier with 12-inch lenses compared with 8-inch lenses.

The placement of the beacon above or below the sign was also significant; however, examining the specific pair comparisons reveals no significant difference between R-A and R-B and a significant difference between CA-12 and CB-12. Therefore, this comparison may be compromised by the sign choice for C-A12.

Table 109. Linear mixed-effects model results using all assemblies for nighttime legibility distance.[a]

Variable	Value	Std. error	DF	*t*-value	*p*-value
Reference Level[b]	479.2589	51.06080	501	9.386044	0.0000
O.Y: young	294.0365	59.69037	34	4.926029	0.0000
Sign.Fam: Ped X-ing	60.1758	29.94397	501	2.009615	0.0450
Sign.Fam: Uncommon	-243.4851	36.84204	501	-6.608892	0.0000
Type_AsA: C-A12	4.2572	24.39833	501	0.174495	0.8615
Type_AsA: C-B12	156.5475	27.49044	501	5.694617	0.0000
Type_AsA: C-B8	-18.2307	34.48298	501	-0.528688	0.5973
Type_AsA: C-V12	59.7811	35.08480	501	1.703902	0.0890
Type_AsA: LEDs	95.5236	36.33491	501	2.628975	0.0088
Type_AsA: R-A	16.0609	24.88700	501	0.645354	0.5190
Type_AsA: WO-B	145.0945	36.24990	501	4.002619	0.0001
O.Y: young X Sign.Fam: Ped X-ing	-99.4175	41.93428	501	-2.370793	0.0181
O.Y: young X Sign.Fam: Uncommon	-144.0525	38.82845	501	-3.709974	0.0002

[a] Notes:

1. Linear mixed-effects model fit by REML.
2. Fixed effects: Adj_Dis ~ O.Y + Sign.Fam + Type_As + O.Y:Sign.Fam.

[b] Reference level in the model has the following conditions:

- O.Y. (age: old or young) = older driver.
- Sign.Fam (sign family) = common signs.
- Type_AsA (assembly type, see figure 23 to figure 38) = R-B.

Table 110. ANOVA results using all assemblies for nighttime legibility distance.

Variable	numDF	denDF	*F*-value	*p*-value
(Intercept)	1	501	405.479	< 0.0001
O.Y	1	34	15.1728	0.0004
Sign.Fam	2	501	313.0319	< 0.0001
Type_As	7	501	9.6389	< 0.0001
O.Y X Sign.Fam	2	501	6.9101	0.0011

Table 111. Nighttime legibility distance multiple comparisons using simultaneous tests for general linear hypostheses.

Group[a]	Item	Linear Hypotheses	Estimate	Std. error	*z*-value	Pr(>|*z*|) [b]
ALL	Place	(Above) - (Below) = 0	-68.11	18.65	-3.651	0.0017**
ALL	Shape	(Circular) - (Rectangular) = 0	72.37	18.08	4.002	< 0.001***
ALL	Size	(C-B8) - (C-B12) = 0	-174.78	35.70	-4.896	< 0.001***
IPC	Shape	(C-B12) - (R-B) = 0	156.55	27.49	5.695	< 0.001***
IPC	Shape	(R-A) - (C-A12) = 0	11.80	24.33	0.485	0.9835
IPC	Place	(R-A) - (R-B) = 0	16.06	24.89	0.645	0.9538
IPC	Place	(C-B12) - (C-A12) = 0	152.29	27.76	5.487	< 0.001***
Sign	Assembly	(R-A) - (WO-B) = 0	-74.58	37.97	-1.964	0.12317
Sign	Assembly	(R-B) - (WO-B) = 0	-123.70	37.64	-3.287	0.00293**
Sign	Assembly	(C-B8) - (WO-B) = 0	-84.96	37.92	-2.240	0.06509

[a] Group:

1. ALL = all assemblies data.
2. IPC = All Assemblies Data: Confirmation (Individual Pair Comparisons).
3. Sign = Pedestrian Crossing Only Data (i.e., Data for Assemblies when Pedestrian Crossing Sign is Present).

[b] Significance values are as follows: $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$.

Box plots were generated to aid in the review of the Pedestrian Crossing sign data. Figure 60 shows the legibility distance for young drivers to assemblies with a pedestrian crossing symbol, while figure 61 is a similar plot for old drivers. The average legibility distance was similar between the R-B and the C-B8 or the R-A for both young and old drivers. In the remaining cases, the average legibility distance for R-B was less than the legibility distance for C-B12, C-V12, LEDs, and WO-B.

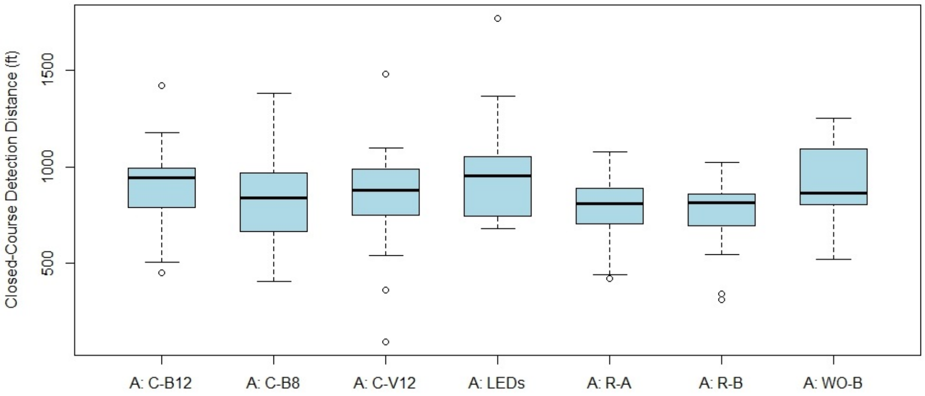


Figure 60. Graph. Box plots for nighttime legibility distance for assemblies with pedestrian crossing sign for young participants.

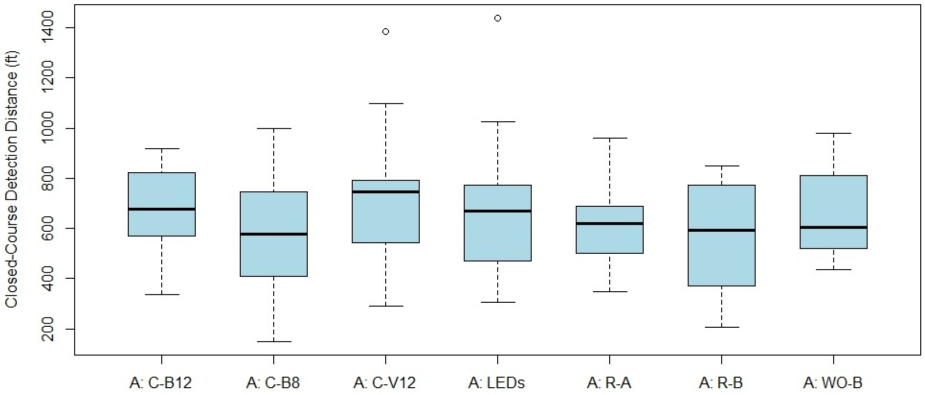


Figure 61. Graph. Box plots for nighttime legibility distance for assemblies with pedestrian crossing sign for old participants.

The evaluation that considered only those conditions when the Pedestrian Crossing sign was present again confirms the finding that the yellow rapid-flashing beacon is affecting drivers' ability to read signs. Table 112 contains the results of the statistical model and shows that the following variables were significant: age (young or old), R-A, R-B, and C-B8. Next, the pair comparisons were done for these beacons (see table 111). The pair comparison showed that the difference between R-A and WO-B was not significant, that the difference between C-B8 and WO-B was significant at a *p*-value less than 0.1, and that the difference between R-B and WO-B was significant at a *p*-value less than 0.05. Stated in another manner, the presence of the RRFB located below the sign affected the legibility distance to the Pedestrian Crossing sign during nighttime conditions. Drivers were 124 ft closer to the sign before they could read the symbol compared with the distance when they could read the symbol when an RRFB was not present.

Table 112. Linear mixed-effects model results for assemblies with pedestrian crossing sign for nighttime legibility distance.[a]

Variable	Value	Std. error	DF	*t*-value	*p*-value
Reference Level[b]	664.5759	49.31322	206	13.476627	0.0000
O.Y: young	208.1935	58.40199	34	3.564836	0.0011
Type_AsA: R-A	-72.9047	38.09806	206	-1.913607	0.0571
Type_AsA: R-B	-112.0146	37.26261	206	-3.006086	0.0030
Type_AsA: C-B12	2.7815	38.06915	206	0.073063	0.9418
Type_AsA: C-B8	-80.8886	37.88780	206	-2.13495	0.0339
Type_AsA: C-V12	-29.944	37.89882	206	-0.790103	0.4304
Type_AsA: LEDs	20.2158	38.81704	206	0.520798	0.6031

[a] Notes:

1. Linear mixed-effects model fit by REML.
2. Fixed effects: Adj_Dis ~ O.Y + Type_As.

[b] Reference level in the model has the following conditions:

- O.Y. (age: old or young) = older driver.
- Type_AsA (assembly type, see figure 23 to figure 38) = WO-B.

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 indicate the following:

- As expected, 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. Previous studies on crosswalk markings and on stop signs with LEDs found age to be not significant.(25,31) In those studies, the participant did not have to "read" a sign. In the crosswalk marking study, the participant indicated when they could see the markings. For stop signs, the stop sign's shape and color are more important than reading the word "stop." Finding age to be significant indicates that future studies of beacons may need to focus on older participants explicitly.
- The symbol or word(s) on the sign face confounds the results. When the study was planned, different signs were desired to provide variety during the study. The researchers were concerned that the driver would always anticipate a pedestrian crossing sign when he or she saw a beacon, so alternative signs were needed. The researchers selected signs that could be associated with a pedestrian crossing, such as pedestrian crossing, trail crossing, bike, playground, bike & ped, and wheelchair. The researchers also selected signs that had a look similar to the pedestrian crossing sign such as the deer crossing, t-intersection, and offset intersection signs. Because the type of sign confounds the results, understanding how the beacons/LEDs influence the detection distance is more complex. A new variable, sign family, was added to the evaluation to reflect whether the symbol is common or uncommon. In the sign family variable, the signs were grouped into the following three classes: pedestrian crossing, other common signs (deer, t-intersection, offset), and uncommon signs (wheelchair, trail crossing, bike, playground, and bike & ped). Finding that the sign face is significant in this study indicates that the profession needs to be concerned with the messages placed on a sign when the sign is used with beacons/LEDs. The estimated closed-course legibility distance to an uncommon sign (e.g., trail crossing) for an older driver at night was 236 ft, which while greater than the MUTCD estimation of legibility distance for a sign with 6-inch letters, is much less than the legibility distance for the symbol signs.
- During the nighttime, drivers were able to read the sign earlier with 12-inch lenses compared with 8-inch lenses. During daytime, the distance to read the sign was similar for 12- and 8-inch lenses.
- The type of assembly was significant at night and nearly not significant (*p*-value = 0.0565) during the day. This indicates that the effects of the beacons/LEDs on reading the message on the sign are more influential during nighttime conditions, an expected finding.

- Based on the sign legibility results, the suggested alternative beacon arrangement for testing in the on-road portion is the C-B12 assembly; the primary beacon assembly is the R-B assembly.

Observations Regarding Legibility Distance

- The presence of a yellow flashing beacon communicates warning to a driver. Even if the flashing beacon limits the ability to read a sign, its presence can warn drivers to take additional care at the location. Unfortunately, the extensive and continuous use of the flashing yellow beacon on U.S. highways may not effectively communicate to drivers the needed action of slowing down or searching for a potential roadway entry. The use of a specific flash pattern, however, could offset some of these concerns. The profession should investigate the message that different styles of blinking lights (e.g., rapid flash versus uniform flash, etc.) communicate to drivers.

Detection Distance—Object

An objective of this study was to determine whether the detection of objects located beyond an assembly was affected by the shape, size, and/or placement of the yellow RRFBs/LEDs. This analysis is separated into daytime and nighttime because of large differences in detection distance between day and night and to determine whether variables were affecting object detection distances differently in day and night conditions. Each set was analyzed using LMMs. A number of different evaluations were conducted to focus on different elements of the study, such as day/night, different groups to account for sign face, or upstream conditions. The following variables were considered:

- Age (young or old).
- Object type (box, trash can, or pedestrian).

When focusing on characteristics of the study assemblies, the following variables were considered:

- Previous assembly (C-A12, C-B12, C-B8, C-V12, R-B, R-A, or LED). Preliminary results demonstrated that the WO-B device had too many unique qualities and should not be included in the evaluation. Those qualities included having only one object—the box—that followed the sign.

- Previous sign family (Ped X-ing, common signs, and uncommon signs).

When evaluating the effects of all upstream conditions, the following three new groups were created:

- Signs w/Bea-LED (C-A12, C-B12, C-B8, C-V12, R-B, R-A, or LED).

- Signs without Bea-LED (included the distractor signs and the WO-B assembly).

- Turn (represents the situation when the object was not located beyond a sign, i.e., the object was located alongside the road after the driver had just made a turn on the course).

To provide an appreciation of the range of object detection distance considered, table 113 lists the average and standard deviation of the object detection distance for the pedestrian, Table 114 is similar data for the trash can, and table 115 contains data for the small box.

Figure 62 shows the box plots for the data for the daytime while figure 63 shows the nighttime box plots. The limits of the box plots are at 25th and 75th percentiles. The whiskers were drawn at 1.5 times the interquartile range, and the widths were drawn proportional to the square root of the number of observations.

Table 113. Object detection distance for the pedestrian by upstream device and sign face.

	Day			Night		
Upstream device[a]	**Count**[b]	**DD (ft)**	**SD (ft)**	**Count**	**DD (ft)**	**SD (ft)**
A: C-A12-Trail Crossing	16	962	617	11	54	33
A: C-A12-Wheelchair	11	668	414	5	181	180
A: C-B12-Bike	17	710	396	15	195	89
A: C-B12-Ped X-ing	8	1,361	502	9	164	89
A: C-B8-Deer	11	1,020	472	9	76	44
A: C-B8-Ped X-ing	16	790	349	10	149	69
A: C-V12-Offset Intersection	8	1,087	986	6	84	51
A: C-V12-Ped X-ing	8	554	185	9	154	110
A: R-A-Ped X-ing	8	1,242	527	11	177	119
A: R-A-Playground	8	1,066	400	3	99	39
A: R-B-Bike & Ped	19	980	788	18	82	75
A: R-B-Ped X-ing	8	479	204	5	75	12
D: Always Animal	34	1,228	438	30	98	105
D: Energy Supper	0	0	NA[c]	1	102	NA[c]
D: Enough Silent	35	664	312	24	89	55
Total Count/Average Distance	207	911	539	166	116	93

[a] A: = assembly (see figure 23 to figure 38), D: = distractor sign (see table 96).
[b] Count = number of participants, DD = average detection distance (ft), SD = standard deviation detection distance (ft).
[c] NA = not applicable, two or more points are required for a standard deviation.

Table 114. Object detection distance for the trash can by upstream device and sign face.

Upstream device[a]	Day			Night		
	Count[b]	DD (ft)	SD (ft)	Count	DD (ft)	SD (ft)
A: C-A12-Trail Crossing	9	722	215	6	135	67
A: C-A12-Wheelchair	7	992	404	7	53	18
A: C-B12-Ped X-ing	8	684	387	6	102	21
A: C-B8-Deer	8	823	249	5	79	55
A: C-B8-Ped X-ing	10	1,302	964	9	149	209
A: C-V12-Ped X-ing	8	1,031	427	5	140	114
A: LEDs-Ped X-ing	27	617	242	21	147	115
A: R-A-Ped X-ing	7	1,341	978	5	155	92
A: R-B-Ped X-ing	8	591	453	11	117	192
D: Speed Limit F4	31	657	336	22	75	45
D: Speed Limit H8	34	949	154	30	187	91
D: Stop Ahead (symbol)	32	763	185	29	174	81
Turn	69	650	109	65	276	137
Total Count/Average Distance	258	773	378	221	179	133

[a] A: = assembly (see figure 23 to figure 38), D: = distractor sign (see table 96).
[b] Count = number of participants, DD = average detection distance (ft), SD = standard deviation detection distance (ft).

Table 115. Object detection distance for the box by upstream device and sign face.

Upstream device[a]	Day			Night		
	Count[b]	DD (ft)	SD (ft)	Count	DD (ft)	SD (ft)
A: C-A12-Trail Crossing	0	0	NA[c]	1	100	NA[c]
A: C-A12-Wheelchair	12	359	153	15	153	84
A: C-B12-Bike	5	228	52	6	110	22
A: C-B12-Ped X-ing	6	685	380	6	160	112
A: C-B8-Deer	6	518	248	12	188	234
A: C-B8-Ped X-ing	0	0	NA[c]	1	137	NA[c]
A: C-V12-Offset Intersection	11	459	400	7	112	112
A: C-V12-Ped X-ing	8	233	176	7	190	102
A: R-A-Ped X-ing	9	233	216	8	337	293
A: R-A-See Saw	9	294	143	13	117	100
A: R-B-Ped X-ing	14	311	231	13	132	64
A: WO-B-T-Intersection	27	200	170	33	145	62
D: Rough Road	24	237	174	27	138	85
D: Speed Limit 42	12	309	141	23	150	92
D: Speed Limit 45	26	293	164	27	209	94
Turn	56	235	139	81	166	84
Total Count/Average Distance	225	286	210	280	162	110

[a] A: = assembly (see figure 23 to figure 38), D: = distractor sign (see table 96).
[b] Count = number of participants, DD = average detection distance (ft), SD = standard deviation detection distance (ft).
[c] NA = not applicable, two or more points are required for a standard deviation.

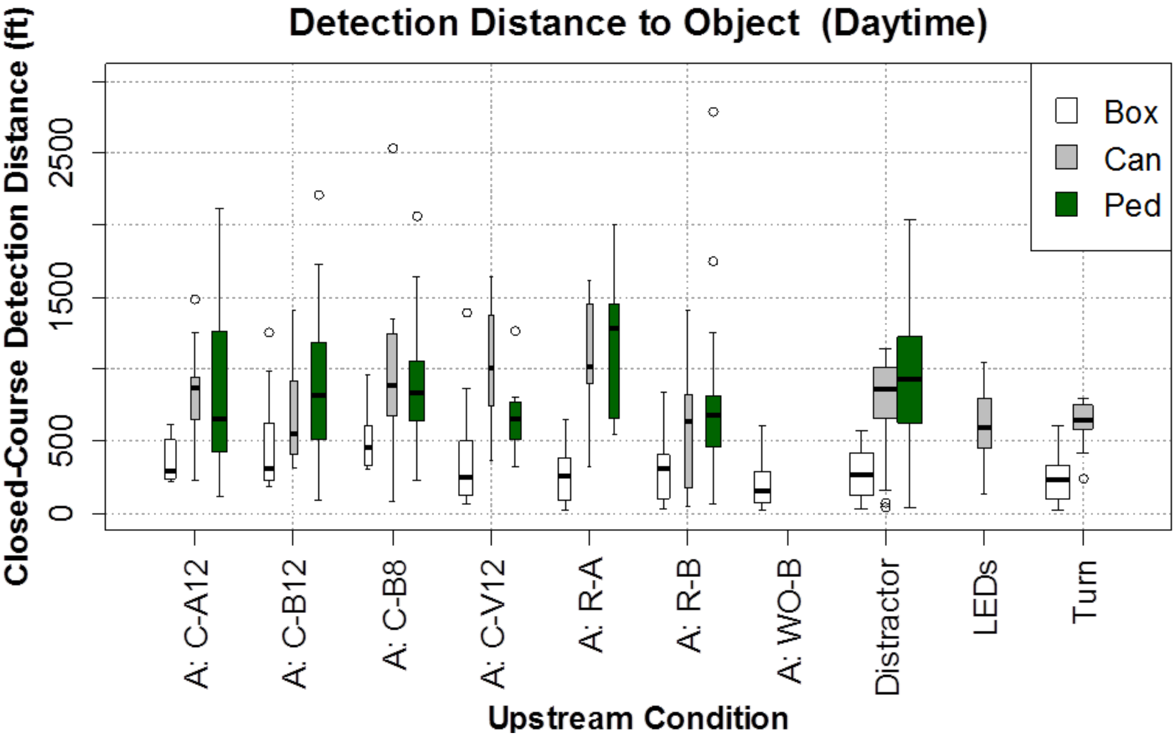


Figure 62. Graph. Box plot of daytime object detection distance by upstream condition.

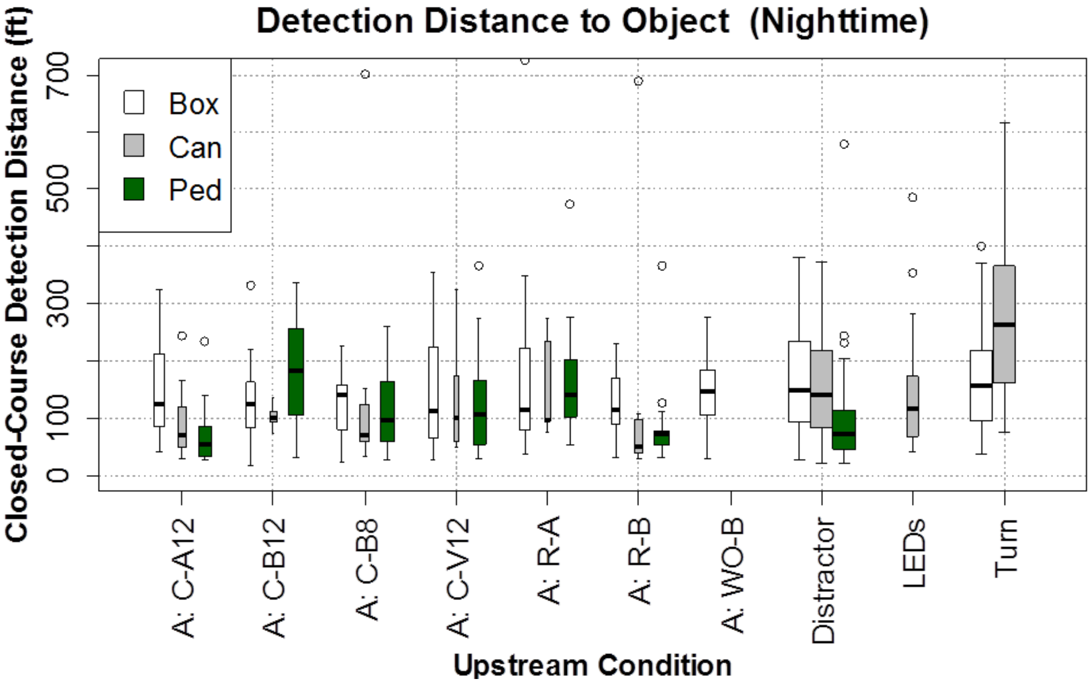


Figure 63. Graph. Box plot of nighttime object detection distance by upstream condition.

Daytime Object Detection Distance

Table 116 shows the LMM, and table 117 shows the ANOVA for daytime object detection distance with upstream conditions (i.e., this evaluation includes objects located behind distractor signs and after turns). All variables considered were significant: type of object (box, trash can, or pedestrian), age group (young or old), and upstream conditions. Finding upstream conditions significant indicates that the presence of a sign assembly and the characteristics of that sign assembly affect a participant's ability to detect an object.

Table 116. Model for daytime object detection distance considering upstream condition.[a]

Variable	Value	Std. error	DF	*t*-value	*p*-value
Reference Level[b]	485.3553	35.77571	418	13.566617	0.0000
Object: box	-287.9107	33.86529	418	-8.501646	0.0000
Object: can	-68.0271	39.98690	418	-1.701234	0.0896
O.Y: young	317.8674	57.58077	33	5.520374	0.0000
Upstream2: Distractor	-45.9384	22.90688	418	-2.005440	0.0456
Upstream2: Turn	-119.9760	34.51648	418	-3.475905	0.0006
Object: box X O.Y: young	-254.9557	54.31000	418	-4.694452	0.0000
Object: can X O.Y: young	-35.7910	72.27445	418	-0.495210	0.6207

[a] Notes:

1. Linear mixed-effects model fit by REML.
2. Fixed effects: Adj_Dis ~ Object * O.Y + Upstream2.

[b] Reference level in the model has the following conditions:

- Object = pedestrian.
- O.Y. (age: old or young) = older driver.
- Upstream2 = assembly.

Table 117. ANOVA results using upstream conditions daytime object detection distance.

Variable	numDF	denDF	*F*-value	*p*-value
(Intercept)	1	418	276.53328	< .0001
Object	2	418	149.20799	< .0001
O.Y	1	33	16.42528	0.0003
Upstream 2	2	418	5.64380	0.0038
Object X O.Y.	2	418	13.87962	< .0001

Table 118 shows the results when focusing on objects near study assemblies (i.e., this evaluation does not include objects located behind the distractor signs or after turns). Table 119 shows the ANOVA results. These evaluations found that object type, age group, and previous sign assembly affect daytime object detection distance.

Table 118. Model for daytime object detection distance focusing on upstream assembly.[a]

Variable	Value	Std. error	DF	*t*-value	*p*-value
Reference Level[b]	404.6981	56.24747	220	7.194955	0.0000
Object: box	-323.8748	50.61636	220	-6.398619	0.0000
Object: can	-23.9229	53.96064	220	-0.443339	0.6580
O. Y: young	296.6900	71.83064	33	4.130410	0.0002
Prev. Assembly: C-A12	133.9378	62.79891	220	2.132804	0.0340
Prev. Assembly: C-B12	154.7027	54.44614	220	2.841389	0.0049
Prev. Assembly: C-B8	166.9417	62.84257	220	2.656507	0.0085
Prev. Assembly: C-V12	77.9409	52.84642	220	1.474857	0.1417
Prev. Assembly: R-A	156.6303	51.24030	220	3.056779	0.0025
Prev. Assembly: LEDs	-25.3392	72.64733	220	-0.348798	0.7276
Sign.Fam: Other Common	120.6914	61.33491	220	1.967744	0.0504
Sign.Fam: Uncommon	-28.8649	49.59985	220	-0.581956	0.5612
Object: box X O.Y: young	-197.6446	70.31444	220	-2.810868	0.0054
Object:can X O.Y: young	64.3989	84.82628	220	0.759186	0.4486

[a] Notes:

1. Linear mixed-effects model fit by REML.
2. Fixed effects: Adj_Dis ~ Object * O.Y + Prev.Assembly + Sign.Fam.

[b] Reference levels in the model has the following conditions:

- Object = pedestrian.
- O.Y. (age: old or young) = older driver.
- Prev. Assembly = R-B.
- Sign.Fam (sign family) = common signs.

Table 119. ANOVA results for daytime detection distance focusing on upstream assembly.

Variable	numDF	denDF	*F*-value	*p*-value
(Intercept)	1	220	254.85467	< .0001
Object	2	220	77.19983	< .0001
O.Y	1	33	14.81887	0.0005
Prev.Assembly	6	220	4.03653	0.0007
Sign.Fam	2	220	2.62041	0.0750
Object X O.Y	2	220	6.56765	0.0017

Because the interaction between age and object type was significant (as shown in table 118), the pair comparisons shown in table 120 include all the possible combinations of object type and age. As expected, detection distances are significantly shorter for detecting a box. Older drivers detected a pedestrian 324 ft upstream compared with seeing a box behind the assembly, and an additional 300 ft for a trash can. Similarly, young drivers recognized a pedestrian 522 ft earlier than a box, and a can 562 ft earlier than a box. There is not sufficient evidence to suggest the detection distance for pedestrians and trash cans differed, either among old drivers (*p*-value of 0.997) or among young drivers (*p*-value of 0.993). However, detection distances by older drivers were significantly shorter compared with younger drivers, except when detecting boxes. Young drivers detected a box further upstream of the object compared with older drivers; however, the finding was not statistically significant. Young drivers outperformed old drivers by 300 ft when detecting a pedestrian and by 361 ft when detecting a trash can.

Table 120. Daytime object detection distance, multiple comparisons by object type and age group.

Linear hypotheses[a]	Estimate	Std. error	*z*-value	Pr(>|*z*|) [b]
Box (Old) - Ped (Old) = 0	-323.87	50.62	-6.399	< 0.001***
Can (Old) - Ped (Old) = 0	-23.92	53.96	-0.443	0.997
Can (Old) - Box (Old) = 0	299.95	59.24	5.064	< 0.001***
Box (Young) - Ped (Young) = 0	-521.52	55.00	-9.482	< 0.001***
Can (Young) - Ped (Young) = 0	40.48	75.61	0.535	0.993
Can (Young) - Box (Young) = 0	562.00	69.61	8.074	< 0.001***
Young (Ped) - Old (Ped) = 0	296.69	71.83	4.130	< 0.001***
Young (Box) - Old (Box) = 0	99.05	67.69	1.463	0.624
Young (Can) - Old (Can) = 0	361.09	82.18	4.394	< 0.001***

[a] Simultaneous tests for general linear hypotheses.

[b] Significance values are as follows: $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$. Adjusted p-values reported single-step method.

For daytime object detection distance, the legend on the sign was not significant. As shown in table 121, no significant differences were identified in the comparison of the Ped X-ing sign face with other common signs or to uncommon signs.

Table 121. Daytime object detection distance, multiple comparisons by sign family.

Linear hypotheses[a]	Estimate	Std. error	*z*-value	Pr(>|*z*|) [b]
(Ped X-ing) – (Other Common) = 0	-120.69	61.33	-1.968	0.112
(Ped X-ing) – (Uncommon) = 0	28.86	49.60	0.582	0.820
(Uncommon) – (Other Common) = 0	-149.56	79.94	-1.871	0.138

[a]Simultaneous tests for general linear hypotheses.

[b]Significance values are as follows: $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$. Adjusted *p*-values reported single-step method.

The characteristics of the beacons/LEDs did influence some of the object detection distances as shown in table 122 and table 123. Objects were detected at a greater distance upstream when located beyond the C-B12, C-B8, and R-A assemblies compared with R-B. During daytime conditions, the object detection distance was between 155 to 167 ft longer for the C-B12, C-B8, and R-A assemblies compared with the R-B assembly.

Table 122. Daytime object detection distance, multiple comparisons to reference assembly by assembly type.

Linear Hypotheses[a]	Estimate	Std. error	*z*-value	Pr(>|*z*|) [b]
(C-A12) - (R-B) = 0	133.94	62.80	2.133	0.1656
(C-B12) - (R-B) = 0	154.70	54.45	2.841	0.0253*
(C-B8) - (R-B) = 0	166.94	62.84	2.657	0.0435*
(C-V12) - (R-B) = 0	77.94	52.85	1.475	0.5467
(R-A) - (R-B) = 0	156.63	51.24	3.057	0.0129*
(LEDs) - (R-B) = 0	-25.34	72.65	-0.349	0.9993

[a]Simultaneous tests for general linear hypotheses.

[b]Significance values are as follows: $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$. Adjusted *p*-values reported single-step method.

Table 123. Daytime object detection distance, other multiple comparisons by assembly type.

Linear Hypotheses[a]	Estimate	Std. error	z-value	Pr(>|z|) [b]
(C-B12) - (C-A12) = 0	20.765	58.518	0.355	0.999
(C-B8) - (C-A12) = 0	33.004	81.692	0.404	0.999
(C-V12) - (C-A12) = 0	-55.997	75.149	-0.745	0.975
(R-A) - (C-A12) = 0	22.692	62.378	0.364	0.999
(LEDs) - (C-A12) = 0	-159.277	83.685	-1.903	0.389
(C-B8) - (C-B12) = 0	12.239	72.839	0.168	1.000
(C-V12) - (C-B12) = 0	-76.762	66.221	-1.159	0.850
(R-A) - (C-B12) = 0	1.928	57.779	0.033	1.000
(LEDs) - (C-B12) = 0	-180.042	79.316	-2.270	0.199
(C-V12) - (C-B8) = 0	-89.001	60.333	-1.475	0.670
(R-A) - (C-B8) = 0	-10.311	73.408	-0.140	1.000
(LEDs) - (C-B8) = 0	-192.281	82.307	-2.336	0.173
(R-A) - (C-V12) = 0	78.689	61.727	1.275	0.791
(LEDs) - (C-V12) = 0	-103.280	81.212	-1.272	0.792
(LEDs) - (R-A) = 0	-181.969	78.915	-2.306	0.184

[a] Simultaneous tests for general linear hypotheses.
[b] Adjusted p-values reported – single-step method.

Table 124 shows the comparisons regarding beacon shape and placement with none being significant. The daytime distance to detect an object located beyond a study assembly was similar for the circular and rectangular beacon shape. The distances were also similar when the beacons were located above the sign compared with when the beacons were located below the sign. The comparison of the 12-inch beacon to the 8-inch beacon is contained in table 123 with the result being no significant difference in daytime detection distance to the object.

Table 124. Daytime object detection distance for beacon placement.

Linear Hypotheses[a]	Estimate	Std. error	z-value	Pr(>|z|) [b]
(Circular) - (Rectangular) = 0	73.54	39.30	1.871	0.142
(Above) - (Below) [All] = 0	38.08	43.61	0.873	0.679
(Above) - (Below) [Without B8] = 0	67.93	40.24	1.688	0.206

[a] Simultaneous tests for general linear hypotheses.
[b] Adjusted p-values reported – single-step method.

Nighttime Object Detection Distance

Table 125 and table 126 show the results regarding nighttime object detection distance when considering upstream conditions (i.e., this evaluation includes objects located behind distractor signs and after turns). Unlike daytime conditions, there was not sufficient evidence to suggest a difference in detection distance between younger and older drivers. Similar to daytime conditions, detection distance differences exist for the object type and for upstream conditions. Even though they were statistically significant, the detection distance differences at night were smaller and may not be of practical meaningfulness.

The box was detected 23 ft prior to the pedestrian (statistically significant), and the trash can was detected 9 ft prior to the pedestrian (not statistically significant). A significant difference was not identified between the detection distance for the objects beyond the distractor signs and the objects beyond the signs with beacons or LEDs. A difference was identified for the distance to the object after a turn (i.e., when no sign is present) and objects following a sign with beacons or LEDs. When participants did not have to identify a sign's presence and to read the sign face, they were able to detect objects an additional 31 ft upstream.

Table 125. Model for nighttime object detection distance considering upstream condition.[a]

Variable	Value	Std. error	DF	*t*-value	*p*-value
Reference Level[b]	63.08422	6.492316	505	9.716751	0.0000
Object: box	22.53531	5.550685	505	4.059915	0.0001
Object: can	9.47397	5.274080	505	1.796327	0.0730
O.Y: young	0.84664	7.654252	34	0.110610	0.9126
Upstream2: Distractor	-2.70914	4.609055	505	-0.587787	0.5569
Upstream2: Turn	31.02125	8.375902	505	3.703631	0.0002

[a]Notes:

1. Linear mixed-effects model fit by REML.
2. Fixed effects: Adj_Dis ~ Object + O.Y + Upstream2.

[b]Reference level in the model has the following conditions:

- Object = pedestrian.
- O.Y. (age: old or young) = older driver.
- Upstream2 = assembly.

Table 126. ANOVA results for nighttime object detection distance considering upstream. condition.

Variable	numDF	denDF	*F*-value	*p*-value
(Intercept)	1	505	388.7771	< .0001
Object	2	505	15.4687	< .0001
O.Y	1	34	0.0004	0.9832
Upstream2	2	505	8.1229	0.0003

Table 127 and table 128 show the results when focusing on the type of beacon/LED of the previous assembly. The base condition is older participant, with the object being a pedestrian located beyond an R-B with a Ped X-ing sign. As shown in table 127 and confirmed with the simultaneous tests shown in table 129, age was not a significant variable regarding object detection distance at night. The results in table 127 imply significant differences in detection distance by type of object; however, the pair comparisons in table 130 demonstrate that the only significant difference was between the trash can and the box with an estimated distance difference of 24 ft.

Table 127. Model for nighttime object detection distance considering upstream assembly.[a]

Variable	Value	Std. error	DF	*t*-value	*p*-value
Reference Level[b]	64.68411	10.206352	194	6.337632	0.0000
Object: box	10.54916	7.423142	194	1.421118	0.1569
Object: can	-13.00810	7.951071	194	-1.636019	0.1035
O.Y: young	13.46431	9.203264	34	1.462993	0.1527
Prev.Assembly: C-A12	17.79469	10.677269	194	1.666596	0.0972
Prev.Assembly: C-B12	35.22210	11.293281	194	3.118854	0.0021
Prev.Assembly: C-B8	23.19978	12.498281	194	1.856238	0.0649
Prev.Assembly: C-V12	22.16982	12.481922	194	1.776154	0.0773
Prev.Assembly: R-A	23.26325	11.247088	194	2.068380	0.0399
Prev.Assembly: LEDs	24.52451	15.412787	194	1.591179	0.1132
Sign.Fam: Other Common	-31.77985	11.438550	194	-2.778311	0.0060
Sign.Fam: Uncommon	-22.72245	9.561413	194	-2.376474	0.0185

[a] Notes:

1. Linear mixed-effects model fit by REML.
2. Fixed effects: Adj_Dis ~ Object + O.Y + Prev.Assembly + Sign.Fam.

[b] Reference level in the model has the following conditions:

- Object = pedestrian.
- O.Y. (age: old or young) = older driver.
- Prev.Assembly = R-B.
- Sign.Fam (sign family) = common signs.

Table 128. ANOVA results using for nighttime object detection distance considering upstream assembly.

Variable	numDF	denDF	*F*-value	*p*-value
(Intercept)	1	194	257.49711	< .0001
Object	2	194	3.61435	0.0288
O.Y	1	34	1.47261	0.2333
Prev.Assembly	6	194	2.46570	0.0254
Sign.Fam	2	194	6.27471	0.0023

Table 129. Nighttime object detection distance, multiple comparisons by age group.

Linear hypotheses[a]	Estimate	Std. error	*z* value	Pr(>|*z*|) [b]
Young - Old = 0	13.464	9.203	1.463	0.143

[a] Simultaneous tests for general linear hypotheses.

[b] Adjusted p values reported single-step method.

Table 130. Nighttime object detection distance, multiple comparisons by object type.

Linear hypotheses[a]	Estimate	Std. error	*z* value	Pr(>|*z*|) [b]
(Ped X-ing) - (Other Common) = 0	31.780	11.439	2.778	0.0143*
(Ped X-ing) - (Uncommon) = 0	22.722	9.561	2.376	0.0437*
(Uncommon) - (Other Common) = 0	9.057	14.416	0.628	0.7976

[a] Simultaneous tests for general linear hypotheses.

[b] Significance values are as follows: $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$. Adjusted *p* values reported single-step method.

Detecting the object occurred at slightly greater distances when beyond the signs showing Ped X-ing compared with uncommon signs (23 ft) or other common signs (32 ft) as shown in table 131.

Table 131. Nighttime object detection distance, multiple comparisons by sign family.

Linear hypotheses[a]	Estimate	Std. error	*z*-value	Pr(>|*z*|) [b]
(Ped X-ing) - (Other Common) = 0	31.780	11.439	2.778	0.0143*
(Ped X-ing) - (Uncommon) = 0	22.722	9.561	2.376	0.0437*
(Uncommon) - (Other Common) = 0	9.057	14.416	0.628	0.7976

[a] Simultaneous tests for general linear hypotheses.

[b] Significance values are as follows: $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$. Adjusted p values reported single-step method.

Table 132 and table 133 are pair comparisons between different beacon/LED types. Only one paired comparison had a statistically significant result (C-B12 to R-B). In all other cases, the detection distance to the object was not significantly different among the various beacon/LED assemblies. During nighttime conditions, objects were detected 35 ft farther upstream with the C-B12 than with the R-B. The objects were also detected at a greater distance upstream during the daytime with C-B12 compared with R-B (155 ft).

Table 134 shows the comparisons regarding beacon shape and placement with none being significant. The distance to detect an object located beyond a study assembly was similar for the circular and rectangular beacon shape. The distances were also similar when the beacons were located above the sign compared with when the beacons were located below the sign. The comparison of the 12-inch beacon to the 8-inch beacon is contained in table 133 with the result being no significant difference in detection distance to the object.

Table 132. Nighttime object detection distance, multiple comparisons to reference assembly by assembly type.

Linear hypotheses[a]	Estimate	Std. error	*z*-value	Pr(>|*z*|) [b]
(C-A12) - (R-B) = 0	17.79	10.68	1.667	0.4148
(C-B12) - (R-B) = 0	35.22	11.29	3.119	0.0106*
(C-B8) - (R-B) = 0	23.20	12.50	1.856	0.2969
(C-V12) - (R-B) = 0	22.17	12.48	1.776	0.3440
(R-A) - (R-B) = 0	23.26	11.25	2.068	0.1928
(LEDs) - (R-B) = 0	24.52	15.41	1.591	0.4672

[a] Simultaneous tests for general linear hypotheses.

[b] Significance values are as follows: $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$. Adjusted *p* values reported single-step method.

Table 133. Nighttime object detection distance, other multiple comparisons by assembly type.

Linear hypotheses[a]	Estimate	Std. error	z-value	Pr(>|z|)[b]
(C-B12) - (C-A12) = 0	17.42741	12.66434	1.376	0.732
(C-B8) - (C-A12) = 0	5.40509	15.39298	0.351	0.999
(C-V12) - (C-A12) = 0	4.37513	15.21513	0.288	1.000
(R-A) - (C-A12) = 0	5.46856	12.06913	0.453	0.997
(LEDs) - (C-A12) = 0	6.72982	17.24016	0.390	0.999
(C-B8) - (C-B12) = 0	-12.02232	14.80255	-0.812	0.964
(C-V12) - (C-B12) = 0	-13.05228	14.21682	-0.918	0.939
(R-A) - (C-B12) = 0	-11.95885	13.09877	-0.913	0.940
(LEDs) - (C-B12) = 0	-10.69759	17.28384	-0.619	0.989
(C-V12) - (C-B8) = 0	-1.02996	11.39493	-0.090	1.000
(R-A) - (C-B8) = 0	0.06347	15.31347	0.004	1.000
(LEDs) - (C-B8) = 0	1.32473	16.81555	0.079	1.000
(R-A) - (C-V12) = 0	1.09343	14.83082	0.074	1.000
(LEDs) - (C-V12) = 0	2.35469	17.25943	0.136	1.000
(LEDs) - (R-A) = 0	1.26126	17.64379	0.071	1.000

[a] Simultaneous tests for general linear hypotheses.

[b] Significance values are as follows: $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$. Adjusted p values reported single-step method.

Table 134. Nighttime object detection distance for beacon placement.

Linear hypotheses[a]	Estimate	Std. error	z-value	Pr(>|z|)
(Circular) - (Rectangular) = 0	13.773	7.624	1.807	0.156
(Above) - (Below) [All] = 0	1.057	9.038	0.117	0.998
(Above) - (Below) [Without B8] = 0	2.918	8.650	0.337	0.960

[a] Simultaneous tests for general linear hypotheses.

Key Findings Regarding Object Detection Distance

For the analysis focusing on object detection distance, which is the distance between the object and the participant when the participant says "ped", "can," or "box," results indicate the following:

- As expected, there is a significant difference between daytime and nighttime object detection distance. As an example, the daytime detection distance to a pedestrian had a mean of 911 ft and a standard deviation of 539 ft. In contrast, during the night, the detection distance to a pedestrian had a mean of only 116 and a standard deviation of 93 ft.

- Similar to legibility distance, there was a statistically significant difference owing to age during the daytime; surprisingly, the same finding did not occur at night. The nighttime condition itself seems to impede detection to a point that the effects of several variables are too small to detect in the experiment.

- The detection distance to a pedestrian or to a trash can was similar for both daytime and nighttime conditions. While the pedestrians were a few feet taller than the can cans and had a similar width, they were much larger than the small box. As expected, the detection distance to a box compared with the pedestrian was shorter during the daytime by 324 ft (older drivers) or 522 ft (younger drivers). Surprisingly, the nighttime detection distance to the box was slightly longer (by about 24 ft) compared with the can.

- Certain assemblies were associated with shorter object detection distances. For daytime conditions, the detection distance to an object was shorter for the R-B than with the C-B12, C-B8, or the R-A (statistically significant). During the nighttime, the detection distance to an object was statistically significantly shorter with the R-B than with the C-B12. These findings indicate that characteristics of the R-B, such as the light intensity or the location of the beacon beneath the sign, may negatively affect driver's ability to see an object beyond the assembly.
- For both daytime and nighttime conditions, similar object detection distance results regardless of the shape of the beacons (circular or rectangular) or the placement of the beacons (above or below).
- Based on the above results and similar to legibility distance recommendation, the suggested alternative for testing in the on-road study is the C-B12 assembly.

Accuracy of Detecting an Object

The previous section discussed the detection distance to an object that was identified. The analysis did not consider when a participant missed the object; in other words, situations where the participant did not say "box," "ped," or "can" when that object was present. This section identifies factors that contribute to drivers missing an object and examines the influence of the preceding assembly on whether an object was missed.

The evaluation of the accuracy of detecting an object considered whether the presence of a sign affected a participant missing an object. Similar to the evaluation on object detection distance, for this evaluation, the following variables were considered:

- Time (day or night).
- Age (young or old).
- Object type (box, trash can, or pedestrian).
- Upstream2 (grouped by signs with Beacon-LED, distractor signs, and turn. The turn group represents the situation when the object was not located beyond a sign. This variable does not include the WO-B device because it only had one object—the box—that followed the sign.).

The evaluation then continued with focusing on those situations when an object followed a sign that had some type of beacon or LED. For this evaluation, the following variables were considered:

- Time (day or night).
- Age (young or old).
- Object type (box, can, or ped).
- Previous device (C-A12, C-B12, C-B8, C-V12, R-B, R-A, or LED).
- Previous sign family (Ped X-ing, common signs, and uncommon signs).

To provide an appreciation of the results, table 135 and table 136 show the frequency (count) of objects detected and missed along with the percent missed. The results in table 135 show differences in percent missed by object type, by upstream condition, and by light level. More objects were missed during nighttime conditions: 21 percent of the boxes, 21 percent of the trash cans, and 21 percent of the pedestrians. Said in another way, about one in five objects were missed at night. During the daytime, fewer pedestrians and trash cans were missed; however, more boxes were missed. Table 136 shows similar data with a focus on age of the participant. Older drivers missed more of the objects (26 percent overall) compared with younger drivers (12 percent overall). Because other factors are known to affect the results of detection distances, the following statistical evaluation indicates whether these preliminary observations are statistically significant.

Table 135. Object percent missed by previous device group, object type, and light condition.

Action	Previous device group	Day				Night				Total
		Box	Can	Ped	Total	Box	Can	Ped	Total	
Miss	Sign with Beacon-LED	27	11	2	40	19	28	29	76	116
	Distractor	41	7	0	48	30	23	15	68	116
	Turn	44	1	0	45	24	7	0	31	76
	WO-B	7	0	0	7	3	0	0	3	10
	Total	119	19	2	140	76	58	44	178	318
Saw	Sign with Beacon-LED	80	92	138	310	89	75	111	275	585
	Distractor	62	97	69	228	77	81	55	213	441
	Turn	56	69	0	125	81	65	0	146	271
	WO-B	27	0	0	27	33	0	0	33	60
	Total	225	258	207	690	280	221	166	667	1357
Percent	Sign with Beacon-LED	25%	11%	1%	11%	18%	27%	21%	22%	17%
	Distractor	40%	7%	0%	17%	28%	22%	21%	24%	21%
	Turn	44%	1%	NA	26%	23%	10%	NA	18%	22%
	WO-B	21%	NA	NA	21%	8%	NA	NA	8%	14%
	All	**35%**	**7%**	**1%**	**17%**	**21%**	**21%**	**21%**	**21%**	**19%**

Ped = Pedestrian.
NA = percentage not calculated because no events with those properties occurred.

Table 136. Object percent missed by age group, object type, and light condition.

Action	Age	Day				Night				Total
		Box	Can	Ped	Total	Box	Can	Ped	Total	
Miss	Old	78	15	2	95	56	38	25	119	214
	Young	41	4	0	45	20	20	19	59	104
	Both	119	19	2	140	76	58	44	178	318
Saw	Old	95	126	106	327	111	93	71	275	602
	Young	130	132	101	363	169	128	95	392	755
	Both	225	258	207	690	280	221	166	667	1357
Percent	Old	45%	11%	2%	23%	34%	29%	26%	30%	26%
	Young	24%	3%	0%	11%	11%	14%	17%	13%	12%
	Both	35%	7%	1%	17%	21%	21%	21%	21%	19%

NA = percentage not calculated because no events with those properties occurred.

Because the data structure is the same for the percent miss and object detection distance variables, the blocking structure for this analysis was preserved (i.e., light condition/driver/lap number). The data were then split by daytime and nighttime conditions so that each set could be analyzed using Generalized Linear Mixed Effects Models (GLMM). These kinds of models are very similar to LMMs in that they treat random effects as blocking factors, and the fixed effects as parameter estimates. The key difference is that because the response variable is binary (1 if the object was missed, 0 otherwise), the estimation requires specifying a link function (logistic function in this case) as Generalized Linear Models also do. Weights were not applied in this case.

Daytime Object Detection Accuracy

Table 137 shows the results regarding detecting objects during the daytime when considering upstream conditions (i.e., this evaluation includes objects located behind distractor signs and after turns). The probability of detecting an object was statistically significantly different for the age groups (older drivers were more likely to miss the object) and object type (participants were more likely to miss a box or a trash can than the pedestrian). The upstream condition was not statistically significant. In other words, it did not matter whether the object was beyond a sign with beacons or LEDs or beyond one of the detector signs or not beyond a sign (i.e., following a turn). The probability of missing an object was similar regardless of the upstream condition.

Table 138 shows the results when focusing on the type of beacon/LED of the previous assembly. The base condition is older participant, with the object being a pedestrian located beyond an R-B with a Ped X-ing sign. Similar to the findings in table 137, age group and object type were significant. The findings in table 138 also show that the probability of missing an object is sensitive to the type of beacons/LED when compared with the base condition of R-B. R-A was the only previous assembly that was not significantly different.

Table 137. Model for daytime object detection accuracy considering upstream condition.[a]

Variables	Value	Std. error	DF	*t*-value	*p*-value
Reference Level[b]	-5.065441	0.6706133	721	-7.553446	0.0000
O.Y: young	-1.040132	0.4196777	33	-2.478406	0.0185
Object: box	4.621094	0.6284863	721	7.352736	0.0000
Object: can	2.105317	0.6404133	721	3.287434	0.0011
Upstream2: Distractor	0.450288	0.2384175	721	1.888652	0.0593
Upstream2: Turn	0.303752	0.2534788	721	1.198334	0.2312

[a] Notes:

1. Linear mixed-effects model fit by maximum likelihood.
2. Fixed effects: Miss ~ O.Y + Object + Upstream2.

[b] Reference level in the model has the following conditions:

- O.Y. (age: old or young) = older driver.
- Object = pedestrian.
- Upstream2 = assembly.

Simultaneous tests were conducted to determine whether differences exist for selected comparisons. Results are shown in table 138 to table 142.

The model results confirm a statistically significant difference by object type (see table 138), with both box and trash can being more likely to be missed than a pedestrian. In addition, the box was more likely to be missed than the trash can. These results are expected because the box is a much smaller target than either the trash can or the pedestrian. Young drivers were less likely to miss objects than old drivers as shown in table 139.

After controlling for other factors, there was no evidence of different probability of missing an object following the Ped X-ing and other common signs. Strong evidence is present for the odds of missing objects after uncommon signs as shown in table 140; the added challenge of reading and interpreting uncommon signs may have resulted in more drivers missing objects behind them.

Table 141 shows the results for the multiple assembly comparisons when each assembly is compared with the R-B. Table 142 provides the results between the different assemblies. The results indicate several pairs of devices that were associated with the participants being more likely to miss an object during the daytime. Recall, as shown in table 135, the object most likely missed was the small box.

Table 144 shows the results when examining the effects of beacon shape and placement. The shape of the beacons did not result in statistically significant differences; a similar probability of missing the object was present whether the beacons were circular or rectangular. If the beacons were located above or below the sign did matter; when beacons were above the sign, the participants were less likely to miss the object. The same results were found whether the below group included all beneath beacons (i.e., R-B, C-B12, and C-B8) or only those beacons beneath the sign that had a direct match with above beacons (i.e., R-B and C-B12 compared with R-A and C-A12).

The size of the circular beacon did not have an effect of the probability of missing an object. As shown in table 143, the difference between C-B8 and C-B12 was not statistically significant.

Table 138. Model for daytime object detection accuracy considering upstream assembly.[a]

Variables	Value	Std. error	DF	*t*-value	*p*-value
Reference Level[b]	-31.036509	.429661	270	-9.049439	0.0000
O.Y: young	-7.604175	3.355508	33	-2.266177	0.0301
Object: box	22.528656	2.060295	270	10.934673	0.0000
Object: can	12.075817	1.600502	270	7.545019	0.0000
Prev.Assembly: C-A12	-5.471284	1.604065	270	-3.410887	0.0007
Prev.Assembly: C-B12	3.308869	1.139095	270	2.904824	0.0040
Prev.Assembly: C-B8	7.405977	1.412711	270	5.242386	0.0000
Prev.Assembly: C-V12	1.985354	0.896321	270	2.215004	0.0276
Prev.Assembly: R-A	1.363892	1.116743	270	1.221312	0.2230
Prev.Assembly: LEDs	13.164725	1.781986	270	7.387669	0.0000
Sign.Fam: Other Common	-1.117426	1.433653	270	-0.779426	0.4364
Sign.Fam: Uncommon	17.846180	1.817777	270	9.817586	0.0000

[a] Notes:

1. Linear mixed-effects model fit by maximum likelihood.
2. Fixed effects: Miss ~ O.Y + Object + Prev.Assembly + Sign.Fam.

[b] Reference level in the model has the following conditions:

- O.Y. = older driver.
- Object = pedestrian.
- Prev.Assembly = R-B.
- Sign.Fam = common.

Table 139. Daytime object detection accuracy, multiple comparisons by object type.

Linear hypotheses[a]	Estimate	Std. error	*z*-value	Pr(>|*z*|) [b]
Box - Ped = 0	22.529	2.025	11.127	< 1e-10***
Can - Ped = 0	12.076	1.573	7.678	< 1e-10***
Can - Box = 0	-10.453	1.385	-7.545	< 1e-10***

[a] Simultaneous tests for general linear hypotheses.

[b] Significance values are as follows: $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$. Adjusted *p* values reported single-step method.

Table 140. Daytime object detection accuracy, multiple comparisons by age group.

Linear hypotheses[a]	Estimate	Std. error	*z*-value	Pr(>|*z*|) [b]
Young - Old = 0	-7.604	3.297	-2.306	0.0211 *

[a] Simultaneous tests for general linear hypotheses.

[b] Significance values are as follows: $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$. Adjusted *p* values reported single-step method.

Table 141. Daytime object detection accuracy, multiple comparisons by sign family.

Linear hypotheses[a]	Estimate	Std. error	*z*-value	Pr(>|*z*|) [b]
(Ped X-ing) - (Other Common) = 0	1.117	1.409	0.793	0.681
(Ped X-ing) - (Uncommon) = 0	-17.846	1.786	-9.990	< 1e-04***
(Uncommon) - (Other Common) = 0	18.964	2.498	7.591	< 1e-04***

[a] Simultaneous tests for general linear hypotheses.

[b] Significance values are as follows: $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$. Adjusted *p* values reported single-step method.

Table 142. Daytime object detection accuracy, multiple comparisons to reference assembly by assembly type.

Linear hypotheses[a]	Estimate	Std. error	*z*-value	Pr(>|*z*|) [b]
(C-A12) - (R-B) = 0	-5.4713	1.5763	-3.471	0.00277**
(C-B12) - (R-B) = 0	3.3089	1.1194	2.956	0.01564 *
(C-B8) - (R-B) = 0	7.4060	1.3883	5.335	< 0.001***
(C-V12) - (R-B) = 0	1.9854	0.8808	2.254	0.10620
(R-A) - (R-B) = 0	1.3639	1.0974	1.243	0.63116
(LEDs) - (R-B) = 0	13.1647	1.7512	7.518	< 0.001***

[a]Simultaneous tests for general linear hypotheses.

[b]Significance values are as follows: $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$. Adjusted *p* values reported single-step method.

Table 143. Daytime object detection accuracy, other multiple comparisons by assembly type.

Linear hypotheses[a]	Estimate	Std. error	*z*-value	Pr(>|*z*|) [b]
(C-B12) - (C-A12) = 0	8.7802	1.2159	7.221	< 0.001***
(C-B8) - (C-A12) = 0	12.8773	2.0258	6.356	< 0.001***
(C-V12) - (C-A12) = 0	7.4566	1.7470	4.268	< 0.001***
(R-A) - (C-A12) = 0	6.8352	1.1431	5.980	< 0.001***
(LEDs) - (C-A12) = 0	18.6360	1.8148	10.269	< 0.001***
(C-B8) - (C-B12) = 0	4.0971	1.7388	2.356	0.14048
(C-V12) - (C-B12) = 0	-1.3235	1.3524	-0.979	0.89861
(R-A) - (C-B12) = 0	-1.9450	0.5526	-3.520	0.00437**
(LEDs) - (C-B12) = 0	9.8559	1.5051	6.548	< 0.001***
(C-V12) - (C-B8) = 0	-5.4206	1.1426	-4.744	< 0.001***
(R-A) - (C-B8) = 0	-6.0421	1.7680	-3.417	0.00664**
(LEDs) - (C-B8) = 0	5.7587	1.2991	4.433	< 0.001***
(R-A) - (C-V12) = 0	-0.6215	1.3740	-0.452	0.99638
(LEDs) - (C-V12) = 0	11.1794	1.6652	6.714	< 0.001***
(LEDs) - (R-A) = 0	11.8008	1.4812	7.967	< 0.001***

[a]Simultaneous tests for general linear hypotheses.

[b]Significance values are as follows: $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$. Adjusted *p* values reported single-step method.

Table 144. Daytime object detection accuracy for beacon placement.

Linear hypotheses[a]	Estimate	Std. error	*z*-value	Pr(>|*z*|) [b]
(Circular) - (Rectangular) = 0	1.0659	0.6903	1.544	0.257
(Above) - (Below) [All] = 0	-5.6250	1.0494	-5.360	< 0.001***
(Above) - (Below) [Without B8] = 0	-3.7081	0.8534	-4.345	< 0.001***

[a]Simultaneous tests for general linear hypotheses.

[b]Significance values are as follows: $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$. Adjusted *p* values reported single-step method.

Nighttime Object Detection Accuracy

Table 145 shows the results regarding detecting objects during the nighttime when considering upstream conditions (i.e., this evaluation includes objects located behind distractor signs and after turns). The probability of detecting an object was statistically significantly different for age groups (older drivers were more likely to miss the object). While object type was statistically different during the daytime, it was not during the nighttime. In other words, the probability of missing any of the different objects was similar at night.

Similar to daytime conditions, the upstream condition was not significant. In other words, it did not matter whether the object was beyond a sign with beacons or LEDs or beyond one of the detector signs or not beyond a sign (i.e., following a turn). The probability of missing the object was similar regardless of the upstream condition.

Table 146 shows the results when focusing on the type of beacon/LED of the previous assembly. The base condition is older participant, with the object being a pedestrian located beyond an R-B with a Ped X-ing sign. Similar to the findings in table 145, age group was significant while object type was not. The pair comparison shown in table 147 confirms that the probability of missing an object at night was similar for the three objects. Table 148 confirms the findings that age does affect the probability of missing an object. No statistical difference was identified between the different sign families (Ped X-ing, other common signs, and uncommon signs) as shown in table 149.

Table 150 and table 151are pair comparisons between different beacon/LED types. The only comparisons with a statistical difference involved the sign with the embedded LEDs. Care should be taken with this finding because only one object type was present beyond the LED-embedded signs (the trash can) and the LED-embedded signs were not rotated to other positions on the course because of study limitations.

The comparison between the beacon shape (circular or rectangular) revealed no difference in the probability of missing an object (see table 152). The comparisons regarding beacon placement (above or below the sign) also showed no difference. In other words, the shape and location of the beacon within the sign assembly did not affect the probability of missing an object. Recall that the probability of missing any of the objects at night is higher than during the day.

Table 145. Model for nighttime object detection accuracy considering upstream condition.[a]

Variables	Value	Std. error	DF	*t*-value	*p*-value
Reference Level[b]	-1.19514	0.3381	732	-3.535173	0.0004
O.Y: young	-1.20987	0.4271	34	-2.83279	0.0077
Object: box	0.269929	0.2202	732	1.22575	0.2207
Object: can	0.086253	0.2247	732	0.383848	0.7012
Upstream2: Distractor	0.178722	0.1867	732	0.957376	0.3387
Upstream2: Turn	-0.40148	0.2404	732	-1.669795	0.0954

[a]Notes:

1. Linear mixed-effects model fit by maximum likelihood.
2. Fixed effects: Miss ~ O.Y + Object + Upstream2.

[b]Reference level in the model have the following conditions:

- O.Y. = older driver.
- Object = pedestrian.
- Upstream2 = assembly.

Table 146. Model for nighttime object detection accuracy considering upstream assembly.[a]

Variables	Value	Std. error	DF	*t*-value	*p*-value
Reference Level[b]	-2.04057	0.53165	269	-3.83818	0.0002
O.Y: young	-1.14365	0.460748	34	-2.48216	0.0182
Object: can	0.547958	0.417624	269	1.312085	0.1906
Object: ped	0.396126	0.334421	269	1.184514	0.2373
Prev.Assembly: C-A12	-0.063	0.539061	269	-0.11686	0.9071
Prev.Assembly: C-B12	0.402231	0.477727	269	0.841968	0.4006
Prev.Assembly: C-B8	0.212159	0.58904	269	0.360178	0.7190
Prev.Assembly: C-V12	0.499291	0.569511	269	0.876701	0.3814
Prev.Assembly: R-A	0.955322	0.469532	269	2.034627	0.0429
Prev.Assembly: LEDs	1.888127	0.554063	269	3.407785	0.0008
Sign.Fam: Other Common	-0.51713	0.639166	269	-0.80907	0.4192
Sign.Fam: Uncommon	0.558717	0.403549	269	1.384508	0.1674

[a] Notes:

1. Linear mixed-effects model fit by maximum likelihood.
2. Fixed effects: Miss ~ O.Y + Object + Prev.Assembly + Sign.Fam

[b] Reference level in the model have the following conditions:

- O.Y. = older driver.
- Object = pedestrian.
- Prev.Assembly = R-B.
- Sign.Fam = common.

Table 147. Nighttime object detection accuracy, multiple comparisons by object type.

Linear hypotheses[a]	Estimate	Std. error	*z*-value	Pr(>|*z*|)
Box - Ped = 0	-0.3961	0.3287	-1.205	0.447
Can - Ped = 0	0.1518	0.3724	0.408	0.912
Can - Box = 0	0.548	0.4104	1.335	0.373

[a] Simultaneous tests for general linear hypotheses.

Table 148. Nighttime object detection accuracy, multiple comparisons by age group.

Linear hypotheses[a]	Estimate	Std. error	*z*-value	Pr(>|*z*|) [b]
Young - Old = 0	-1.1437	0.4528	-2.526	0.0115*

[a] Simultaneous tests for general linear hypotheses.

[b] Significance values are as follows: $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$. Adjusted *p* values reported—single-step method.

Table 149. Nighttime object detection accuracy, multiple comparisons by sign family.

Linear hypotheses[a]	Estimate	Std. error	*z*-value	Pr(>|*z*|)
(Ped X-ing) - (Other Common) = 0	0.5171	0.6281	0.823	0.671
(Ped X-ing) - (Uncommon) = 0	-0.5587	0.3966	-1.409	0.317
(Uncommon) - (Other Common) = 0	1.0758	0.7619	1.412	0.315

[a] Simultaneous tests for general linear hypotheses.

Table 150. Nighttime object detection accuracy, multiple comparisons to reference assembly by assembly type.

Linear hypotheses[a]	Estimate	Std. error	*z*-value	Pr(>|*z*|) [b]
(C-A12) - (R-B) = 0	-0.063	0.5298	-0.119	1.0000
(C-B12) - (R-B) = 0	0.4022	0.4695	0.857	0.9132
(C-B8) - (R-B) = 0	0.2122	0.5789	0.366	0.99877
(C-V12) - (R-B) = 0	0.4993	0.5597	0.892	0.89772
(R-A) - (R-B) = 0	0.9553	0.4614	2.07	0.17552
(LEDs) - (R-B) = 0	1.8881	0.5445	3.468	0.00298**

[a]Simultaneous tests for general linear hypotheses.
[b]Significance values are as follows: $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$. Adjusted p values reported single-step method.

Table 151. Nighttime object detection accuracy, other multiple comparisons by assembly type.

Linear hypotheses[a]	Estimate	Std. error	*z*-value	Pr(>|*z*|) [b]
(C-B12) - (C-A12) = 0	0.46523	0.47666	0.976	0.9225
(C-B8) - (C-A12) = 0	0.27515	0.6768	0.407	0.9985
(C-V12) - (C-A12) = 0	0.56229	0.66282	0.848	0.9564
(R-A) - (C-A12) = 0	1.01832	0.4899	2.079	0.2904
(LEDs) - (C-A12) = 0	1.95112	0.59876	3.259	0.0136*
(C-B8) - (C-B12) = 0	-0.19007	0.6011	-0.316	0.9996
(C-V12) - (C-B12) = 0	0.09706	0.57848	0.168	1.0000
(R-A) - (C-B12) = 0	0.55309	0.44805	1.234	0.8137
(LEDs) - (C-B12) = 0	1.4859	0.54986	2.702	0.0721
(C-V12) - (C-B8) = 0	0.28713	0.5532	0.519	0.9952
(R-A) - (C-B8) = 0	0.74316	0.60602	1.226	0.8179
(LEDs) - (C-B8) = 0	1.67597	0.60419	2.774	0.0595
(R-A) - (C-V12) = 0	0.45603	0.56416	0.808	0.9645
(LEDs) - (C-V12) = 0	1.38884	0.61456	2.26	0.2045
(LEDs) - (R-A) = 0	0.93281	0.54366	1.716	0.5117

[a]Simultaneous tests for general linear hypotheses.
[b]Significance values are as follows: $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$. Adjusted p values reported single-step method.

Table 152. Nighttime object detection accuracy for beacon placement.

Linear hypotheses[a]	Estimate	Std. error	*z*-value	Pr(>|*z*|)
(Circular) - (Rectangular) = 0	-0.2939	0.3233	-0.909	0.657
(Above) - (Below)[All] = 0	0.2414	0.3595	0.671	0.810
(Above) - (Below)[Without B8] = 0	0.2450	0.3395	0.722	0.779

[a]Simultaneous tests for general linear hypotheses.

Speed When Object Was Detected or Missed

During reviews of the previous finding, a question was asked on whether the drivers who missed the pedestrians and the trash cans were driving faster compared with the drivers who detected the objects. The speed when the participant detected the object was readily available. The speed when a participant missed the object was not as readily available. The research team searched the data stream to identify the speed when the driver who missed an object was near the location of the missed object. Table 153 provides the average speeds. When speed was included in the statistical evaluation, it was found to be not significant. The drivers who missed the pedestrian or the trash can during the study were operating the vehicle at similar speeds as the drivers who detected the pedestrian or trash can, both in the daytime and the nighttime.

Table 153. Average speed of vehicle when object was detected or missed.

Day or night	Object	Object missed Average speed (mi/h)	Object missed Standard deviation of speed (mi/h)	Object missed Count	Object detected Average speed (mi/h)	Object detected Standard deviation of speed (mi/h)	Object detected Count
Day	Can	35	5.4	19	33	8.2	263
Day	Ped	37	3.1	2	38	5.9	210
Day	Either	36	5.2	21	35	7.7	473
Night	Can	32	6.4	58	33	5.7	227
Night	Ped	35	4.3	44	34	6.4	167
Night	Either	34	5.8	102	34	6.0	394

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:

- As expected, 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, 1 in 23 pedestrians/trash cans were missed while at night 1 in 5 pedestrians/trash cans were missed.

- 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 drivers who missed the pedestrian or the trash can during the study were operating the vehicle at speeds similar to the drivers who detected the pedestrian or trash can, both in the daytime and the nighttime. For this study, the speed the participant was driving did not affect whether an object was missed.

- 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.

Discomfort Glare

Raw Data

Raw data for the discomfort glare study are shown in figure 64 for C-B8 at position 1, figure 65 for C-B8 at position 2, figure 66 for LED at position 1, and figure 67 for LED at position 2. The abbreviations for these figures include the following:

- P1 = position 1 or 250 ft in advance of assembly.

- P2 = position 2 or 150 ft in advance of assembly.

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

The data show that for all devices at all distances, the percentage of participants indicating the brightness of the lights from the beacons/LEDS was comfortable decreased as brightness increased and the percentage of participants indicating the discomfort glare was unbearable increased as brightness increased. In addition, the data show that almost 50 percent of all participants indicated the discomfort glare was unbearable at a setting number 6 for all devices.

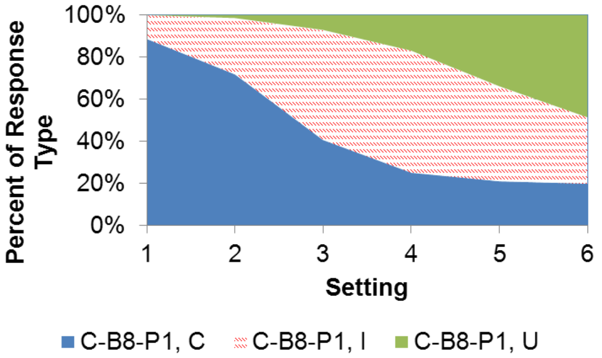


Figure 64. Graph. Percent of response for discomfort glare study—C-B8 at position 1.

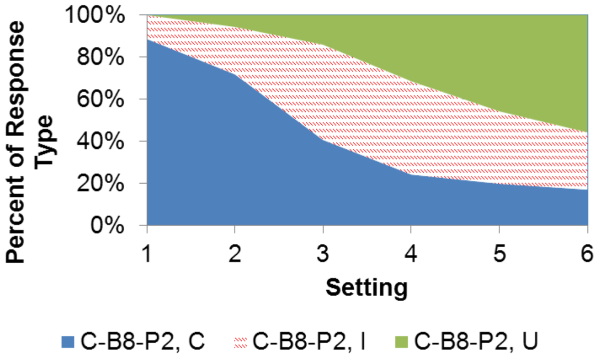


Figure 65. Graph. Percent of response for discomfort glare study—C-B8 at position 2.

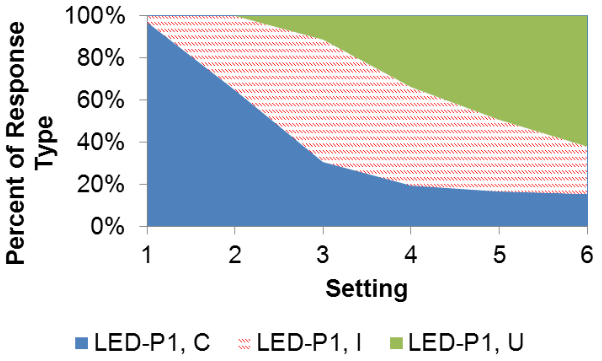


Figure 66. Graph. Percent of response for discomfort glare study—LED at position 1.

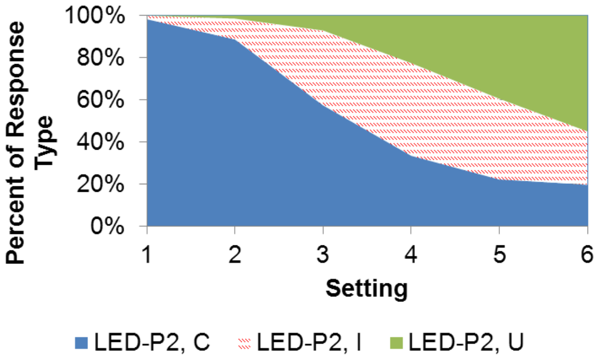


Figure 67. Graph. Percent of response for discomfort glare study—LED at position 2.

Statistical Method

The statistics program R was used to develop cumulative logistic regression models to evaluate participant's ratings of discomfort glare. Cumulative logistic regression models are a method for calculating the probability of a response less than or equal to a specific value for ordinal data; the discomfort ratings in this study (comfortable, irritating, and unbearable) are ordinal data. The basic form of the Cumulative Logit models in this study is shown in figure 68 (32):

$$\text{Logit}(\ P(I\_ciu \leq j)\ ) = \alpha_j + \beta_i X_i$$

Figure 68. Equation. Basic form of the Cumulative Logit model.

Where:
$\text{Logit}(p) = \text{odds}(p) = \ln(p) - \ln(1-p)$.
$P = P(I\_ciu \leq j)$.
I_ciu = discomfort level, such that $I_ciu \in \{1,2,3\} \rightarrow \langle$comfortable, irritating, unbearable$\rangle$
Ln = the natural log function.
$P(I\_ciu \leq j)$ = probability of I_ciu not exceeding threshold j, such that $j \in \{1,2,3\}$.
α_j = intercept value (for comfortable j = 1, for irritating j = 2).
$\beta_i = i^{th}$ parameter value.
$X_i = i^{th}$ variable.

To calculate the probability of event I_ciu = 3 (unbearable brightness), the equation in figure 69 is valid.

$$P(I\_ciu = 3) = 1 - P(I\_ciu \leq 2) = 1 / [\ \exp(\alpha_2 + \beta_i X_i) + 1\ ]$$

Figure 69. Equation. Probability of unbearable brightness.

Where:
$P(I\_ciu = 3)$ = probability of I_ciu equal 3 (unbearable).
$P(I\_ciu \leq 2)$ = probability of I_ciu ≤ 2 (comfortable or irritating).
α_2 = intercept value for $P(I\_ciu \leq 2)$.
β_i = i^{th} parameter value.
X_i = i^{th} variable value.
Exp = the exponential function.

For variables only taking two values, exp (β_i) is the odds ratio, which is the probability of event A occurring divided by the probability of event B occurring. Mathematically, the odds ratio is as shown in figure 70:

$$\text{Odds ratio} = [P_a/(1-P_a)] / [P_b/(1-P_b)]$$

Figure 70. Equation. Basic form of the odds ratio for events A and B.

Where:
P_a = probability of event A occurring.
P_b = probability of event B occurring.

Model Selection

The variables considered for inclusion in the statistical models are defined in table 154. To select statistically significant cumulative logistic regression models, researchers used the Akaike's Information Criterion (AIC) to assess the value of adding a parameter to the model. First, researchers tested the three measures of brightness (C_Level, INT_One, and OP_One) to determine which parameter had the lowest AIC. Next, researchers tested the non-brightness measures for inclusion in the model, adding one parameter at a time, adding the parameter with the lowest AIC. Models with lower AIC values fit the data better than models with higher AIC values while limiting the number of parameters in the model. To say it another way, the selected models maximize log-likelihood while minimizing the number of parameters in the model. Researchers did not investigate the inclusion of cross terms in this study.

Table 154. Discomfort glare variable names and descriptions.

Variable name	Description
I_ciu	Indicates whether the participant felt the device was comfortable, irritating, or unbearable to look at for a given combination of variables; equals 1 if comfortable, 2 if irritating, and 3 if unbearable.
INT_One	95th percentile intensity measured at a vertical angle of zero and a horizontal angle of zero.
OP_One	Optical power measured at a vertical angle of zero and a horizontal angle of zero.
C_Level	Setting on the controller for a given observation; equals 1 through 6 as categorical variables.
M_Num	Measurement number representing the order measurements were taken (0 = 250 ft for sign 1, 1 = 150 ft for sign 1, 2 = 250 ft for sign 2, 3 = 250 ft for sign 2)
I_Age	Indicator value for age of participant; equals 1 for participants 55 years or older, 0 otherwise.
I_Dist	Indicator value for distance from assembly where measurements were taken; 1 if 250 ft, 0 otherwise.
I_Device	Indicator value for device where measurements were taken; 1 if sign 1, 0 if sign 2.
I_Day	Indicator value for day or night; 1 if day, 0 if night.

After selecting an appropriate cumulative logistic regression model with C_Level as the measure of brightness, researchers generated two additional models using OP_One and INT_One as the parameters representing the brightness of the device; these models allow researchers to compare participants' rating of discomfort glare with measures of brightness found in SAE standard J595. The models evaluated as part of this process and associated AIC values are shown in table 155. Note that the only difference between the three selected models is the parameter used to represent the brightness of the device.

Table 155. Model specification and selection using Akaike Information Criterion (AIC).

Model[a]	Number of parameters	Log-likelihood	AIC	Model selected for further analysis
INT_One	3	-1,696	3,398	No
OP_One	3	-1,563	3,131	No
C_Level	7	-1,421	2,856	Yes
C_Level+M_Num	10	-1,409	2,838	No
C_Level+I_Age	8	-1,418	2,846	No
C_Level+I_Dist	8	-1,415	2,854	No
C_Level+I_Device	8	-1,421	2,857	No
C_Level+I_Day	8	-1,173	2,363	Yes
C_Level+I_Day+M_Num	11	-1,158	2,339	Yes
C_Level+I_Day+I_Age	9	-1,169	2,356	No
C_Level+I_Day+I_Dist	9	-1,172	2,361	No
C_Level+I_Day+I_Device	9	-1,173	2,364	No
C_Level+I_Day+M_Num+I_Age	12	-1,154	2,332	Yes
Selected Models				
C_Level+I_Day+M_Num+I_Age	12	-1,154	2,332	Yes
OP_One+I_Day+M_Num+I_Age	8	-1169	2,352	Yes
INT_One+I_Day+M_Num+I_Age	8	-1216	2,448	Yes

[a] Models including M_Num are not full rank (cannot be evaluated) with either I_Dist or I_Device.

Selected Cumulative Logit Regression Models

The parameter estimates, standard error, odds ratio, and 95-percent confidence interval for the odds ratio for the selected Cumulative Logit Regression Models are provided in table 156 through table 158. The models show that as brightness increases, the odds of a participant indicating the brightness is less than or equal to a rating of irritating decreases, which means that as brightness increases the odds of a participant indicating the discomfort glare is unbearable increases. In addition, the models show the participant's odds of indicating unbearable discomfort is about 13 times greater at night than during the day. An atypical finding in this study is that the odds of a younger participant indicating unbearable discomfort are about 1.4 times more likely than older participant's odds of indicating unbearable discomfort. In the next section, researchers use the models in table 157 and table 158 to develop equations predicting the probability of a participant indicating a light source has unbearable discomfort.

Table 156. Cumulative logit model with C_Level as a measure of brightness.

Parameter	Estimate	Standard error	95-percent confidence interval[a]		
			Lower bounds	Odds ratio[b]	Upper bounds
Intercept (j = 1)	1.5207	0.2655	NA	NA	NA
Intercept (j = 2)	4.1643	0.2808	NA	NA	NA
C_Level = 2	-1.7627	0.2897	0.0972	0.1716	0.3027
C_Level = 3	-3.4831	0.2844	0.0176	0.0307	0.0536
C_Level = 4	-4.6302	0.2878	0.0055	0.0098	0.0171
C_Level = 5	-5.3249	0.2938	0.0027	0.0049	0.0087
C_Level = 6	-5.9668	0.3036	0.0014	0.0026	0.0046
I_Day = 1	2.6209	0.1319	10.6161	13.7481	17.8040
M_Num = 2	0.7791	0.1580	1.5991	2.1796	2.9708
M_Num = 3	0.4887	0.1563	1.2000	1.6302	2.2145
M_Num = 4	0.1285	0.1552	0.8389	1.1371	1.5414
I_Age = 1	0.3302	0.1109	1.1194	1.3912	1.7290

[a] If the odds ratio confidence interval includes the value 1.000 (which M_Num = 4 does), the difference is not statistically significant with 95-percent confidence.

[b] For C_Level = z, the odds ratio is odds(C_Level = z)/odds(C_Level = 1). For M_Num = z, the odds ratio is odds(M_Num = z)/odds(M_Num = 1).

NA = Not Applicable.

Table 157. Cumulative logit model with OP_One as a measure of brightness.

Parameter	Estimate	Standard error	95-percent confidence interval[a]		
			Lower bounds	Odds ratio[b]	Upper bounds
Intercept (j = 1)	4.0117	0.2602	NA	NA	NA
Intercept (j = 2)	6.6042	0.2984	NA	NA	NA
OP_One[c]	-0.0001534	0.000006193	NA	NA	NA
I_Day = 1	2.5577	0.1287	10.0287	16.6091	12.9061
M_Num = 2	0.8730	0.1661	1.7288	3.3153	2.3941
M_Num = 3	-2.1270	0.1875	0.0825	0.1721	0.1192
M_Num = 4	-2.4520	0.1903	0.0593	0.1251	0.0861
I_Age = 1	0.3313	0.1105	1.1216	1.7296	1.3928

[a] If the odds ratio confidence interval includes the value 1.000, the difference is not statistically significant with 95-percent confidence.

[b] For M_Num = z, the odds ratio is odds(M_Num = z)/odds(M_Num = 1).

[c] It is not appropriate to interpret the parameter estimate of OP_One as an odds ratio because it is a continuous variable.

NA = Not Applicable.

Table 158. Cumulative logit model with INT_One as a measure of brightness.

Parameter	Estimate	Standard error	95-percent confidence interval[a]		
			Lower bounds	Odds ratio[b]	Upper bounds
Intercept (j = 1)	5.5347	0.3490	NA	NA	NA
Intercept (j = 2)	7.9764	0.3819	NA	NA	NA
INT_One[c]	-0.003781	0.0001693	NA	NA	NA
I_Day = 1	2.4113	0.1238	8.7465	11.1484	14.2100
M_Num = 2	0.8889	0.1689	1.7469	2.4325	3.3870
M_Num = 3	-4.7285	0.2840	0.0051	0.0088	0.0154
M_Num = 4	-5.0237	0.2871	0.0037	0.0066	0.0116
I_Age = 1	0.3205	0.1085	1.1139	1.3778	1.7043

[a] If the odds ratio confidence interval includes the value 1.000, the difference is not statistically significant with 95-percent confidence.

[b] For M_Num = z, the odds ratio is odds(M_Num = z)/odds(M_Num = 1).

[c] It is not appropriate to interpret the parameter estimate of INT_One as an odds ratio because it is a continuous variable.

NA = Not Applicable.

Prediction Equations

To assist in evaluating the relationship between unbearable discomfort glare, optical power, and 95th percentile peak intensity, researchers developed prediction equations. These equations predict the probability of a participant indicating beacons in this study had unbearable discomfort glare. The prediction equations are shown in figure 71 and figure 72.

$$p(\text{I\_ciu} = 3)_{\text{OP}} = 1 / [1 + \exp(6.6042 - 0.0001534\times\text{OP\_one} + 2.5577\times\text{I\_Day} + 0.3313\times\text{I\_Age} + f_{M\_Num(OP)})]$$

Figure 71. Equation. Probability of unbearable discomfort glare based on optical power.

$$p(\text{I\_ciu} = 3)_{\text{INT}} = 1 / [1 + \exp(7.9764 - 0.003781\times\text{INT\_One} + 2.4113\times\text{I\_Day} + 0.3205\times\text{I\_Age} + f_{M\_Num(INT)})]$$

Figure 72. Equation. Probability of unbearable discomfort glare based on intensity.

Where:
$p(\text{I\_ciu} = 3)_{\text{OP}}$ = Probability of participant indicating the light level is unbearable with optical power as the measure of brightness.
$p(\text{I\_ciu} = 3)_{\text{INT}}$ = Probability of participant indicating the light level is unbearable with 95^{th} percentile intensity as the measure of brightness.
exp( ) = Exponential function.
OP_one = Optical power of the device measured at a vertical and horizontal angle of zero.
INT_one = 95th percentile intensity of the device measured at a vertical and horizontal angle of zero.
I_Day = Indicator variable for daytime; equals 1 if daytime and 0 if nighttime.
I_Age = Indicator variable for age group; equals 1 if 55 years or older, 0 otherwise.
$f_{M\_Num(OP)}$ = Factor associated with the measurement number (M_Num); equals 0 if M_Num = 1, 0.0.8730 if M_Num = 2, -2.1270 if M_Num = 3, and -2.4520 if M_Num = 4.
$f_{M\_Num(INT)}$ = Factor associated with the measurement number (M_Num); equals 0 if M_Num = 1, 0.8889 if M_Num = 2, -4.7285 if M_Num = 3, and -5.0237 if M_Num = 4.

Using these prediction equations, researchers produced the curves shown in figure 73 and figure 74; these curves show the probability of an older driver (55 years or more) indicating the discomfort glare of LED embedded sign is unbearable using the flash pattern from the right beacon of an RRFB for daytime and nighttime conditions. In addition to the discomfort glare curves, the graphs also indicate the SAE minimum for test point and three times the SAE minimum for the test point. Specific values for the optical power and 95th percentile intensity when 10 percent, 15 percent, and 50 percent of the older driver population would indicate the discomfort is unbearable are provided in table 159; in addition, the percentiles at the SAE minimum and three times the SAE minimum are shown in table 160.

Key Findings for Discomfort Glare Study

The data show that for all devices at all distances, the percentage of participants indicating the brightness of the lights from the beacons/LEDs is comfortable decreases as brightness increases, and the percentage of participants indicating the discomfort glare is unbearable increases as brightness increases.

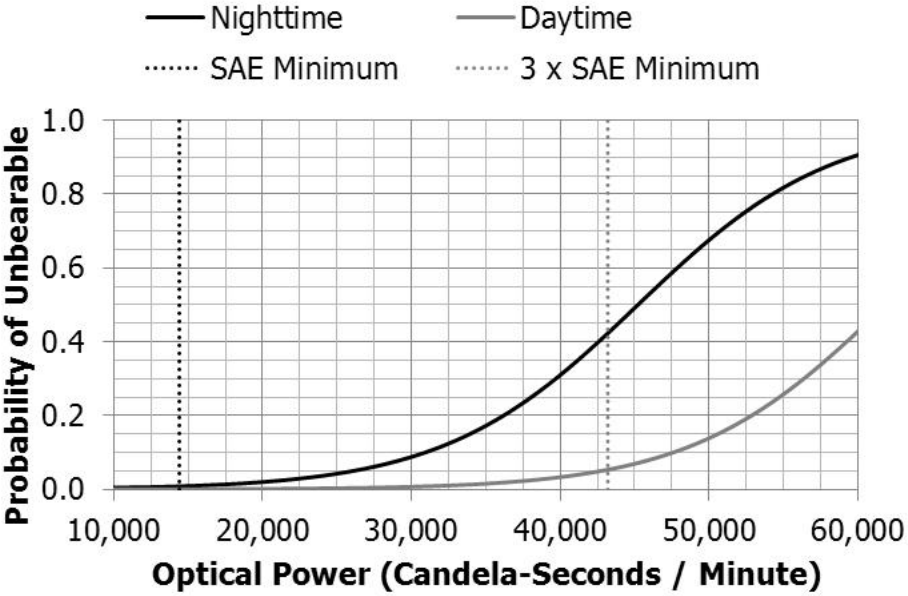


Figure 73. Graph. Older drivers' probability of unbearable discomfort glare by optical power and time of day for LED-embedded signs at 250 ft.

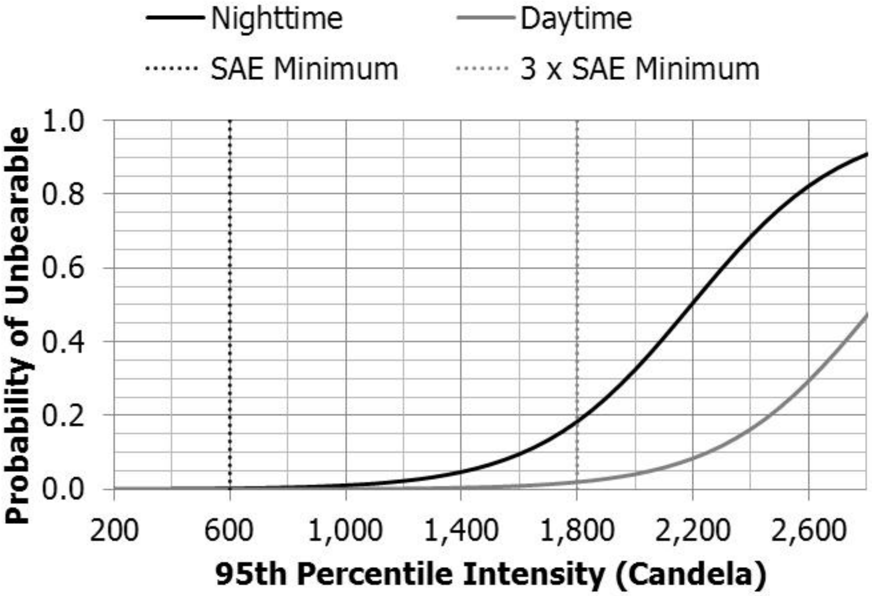


Figure 74. Graph. Older drivers' probability of unbearable discomfort glare by 95th percentile intensity and time of day for LED-embedded signs at 250 ft.

Table 159. Unbearable discomfort glare for 10th, 15th, and 50th percentiles for LED-embedded signs at 250 ft.

Brightness variable	I_Day	10th percentile	15th percentile	50th percentile	SAE minimum[a]	3 times SAE minimum[b]
OP_One	Day	48,190	51,246	62,703	14,400	43,200
	Night	31,296	34,352	45,809	14,400	43,200
INT_One	Day	2,251	2,373	2,832	600	1,800
	Night	1,613	1,736	2,194	600	1,800

[a] This is the minimum measured at a vertical angle of zero and horizontal angle of zero.

[b] This is a potential maximum brightness; the Institute of Transportation Engineers specifies a maximum peak luminous intensity on traffic signals of three times the minimum intensity value.

Table 160. Unbearable discomfort glare percentiles at SAE minimum and three times the SAE minimum for LED-embedded signs at 250 ft.

Brightness variable	I_Day	SAE minimum[a]	Probability unbearable (percent)	3 times SAE minimum[b]	Probability unbearable (percent)
OP_One	Day	14,400	0.07	43,200	4.96
	Night	14,400	0.85	43,200	40.25
INT_One	Day	600	0.02	1,800	1.98
	Night	600	0.24	1,800	18.38

[a] This is the minimum measured at a vertical angle of zero and horizontal angle of zero.

[b] This is a potential maximum brightness; the Institute of Transportation Engineers specifies a maximum peak luminous intensity on traffic signals of three times the minimum intensity value.

Observations From Discomfort Glare Study

The data indicate agencies should focus on meeting the SAE minimum intensity and place less emphasis on obtaining the brightest devices possible. When devices have intensities and optical powers close to the SAE minima, the probability of unbearable discomfort glare is less than 1 percent.

The profession needs maximum brightness for RRFB beacons. As the brightness of the beacons on a traffic control device increases, the probability of a driver indicating 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 may result in drivers missing hazards located near the glare source.

When setting maximum brightness for RRFB beacons, decision makers should consider a variety of distances from the glare source. As the distance from the glare source varies, drivers perceive increases and decreases in discomfort glare. A policy on maximum brightness should limit the discomfort glare along the length of the approach with a focus on critical distances such a decision sight distance, stopping sight distance, and sign legibility distance.

Setting different nighttime and daytime maximum brightness values might be appropriate. The data indicate that under daytime conditions, participants are 13 times more likely to indicate the brightness is either comfortable or irritating compared with their responses in nighttime conditions (when they were more likely to indicate unbearable instead). This suggests that daytime settings could be higher than nighttime settings.

The discomfort glare results support the concept of dimming traffic control devices during low light conditions; however, this study did not investigate the ability of devices below the SAE minima to draw a driver’s attention, which means dimmed devices should still meet SAE minimum values.

Brightness specifications for RRFBs should consider alternative measures of brightness, such as optical power. Peak intensity is not the only measure of brightness, and in some instances, it may not be the best measure of brightness. When quantifying the brightness of traffic control devices, researchers should consider alternative measures of brightness in their studies and use statistics to determine which measure is the most appropriate.

This study found controller setting (which is highly correlated with intensity and optical power) as the measure of brightness that resulted in the model with the best fit of data. This indicates participants may have been responding to the setting of the controller at measurement locations two, three, and four rather than the brightness of the traffic control device.

CHAPTER 6. OPEN-ROAD STUDY

STUDY DEVELOPMENT

Study Sites

Toward the conclusion of the closed-course study, the researchers talked with city representatives and made requests during professional society meetings, seeking cities that would be willing to participate in the open-road research. Four cities volunteered: Milwaukee, WI; Flagstaff, AZ; Austin, TX; and College Station, TX. As a minimum, the cities were asked to identify at least two locations that allowed the treatments to be installed in one location and then rotated to the other location after the initial data collection. Table 161 lists the sites included in the study.

Table 161. Study site characteristics.

Site	Posted speed limit (mi/h)	Total crossing distance (ft)	Crossing distance to refuge (ft)	Calculated daily traffic (vehicles/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

The calculated daily traffic (CDT) was determined based on 1-hour counts made from the video recordings. The values for hourly percentage of ADT were determined using hourly traffic distributions available in the *2011 Urban Mobility Report*.(34) The distributions for non-freeway, a.m. and p.m. peak periods for both no/low congestion and moderate congestion were considered to obtain typical weekday values. These volume distributions were combined to generate an overall representative distribution for use in this project. Figure 75 shows the hourly distribution used to adjust the 1-h counts into CDT values. For example, the 1-h count at MK-05 was 382 vehicles and was done from 11 a.m. to noon. That hour represents 5.55 percent of the daily traffic, so 382/0.0555 = 6,883 vehicles/day.

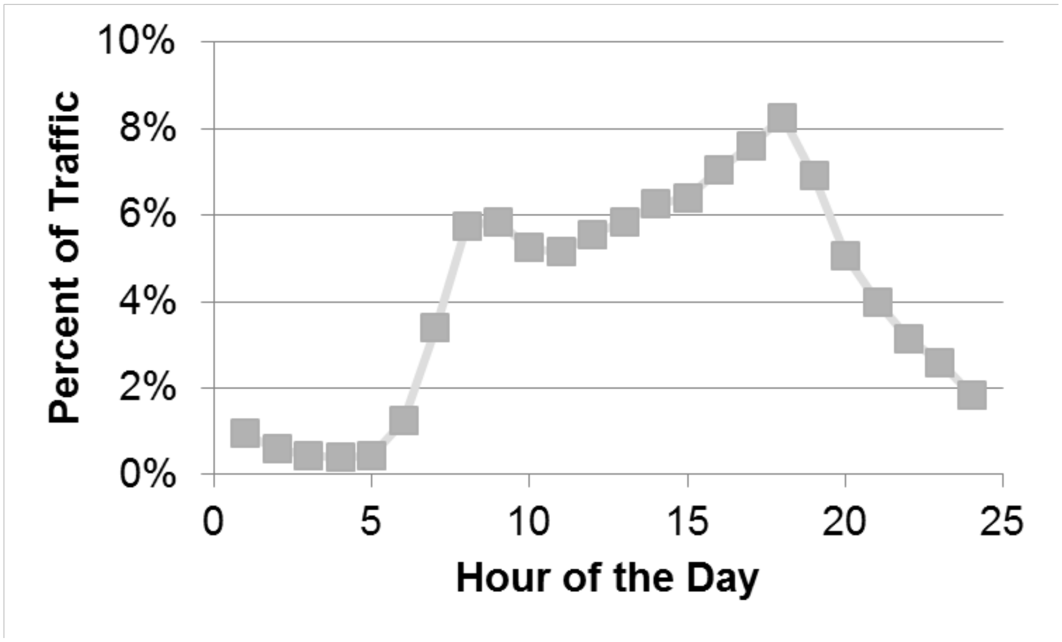


Figure 75. Graph. Typical hourly distribution used to convert 1-h volume into CDT.

Study Assemblies

Examples of the study assemblies are shown in figure 76 through figure 87. The beacons were mounted on a roadside pole to supplement a W11-2 (pedestrian) crossing warning sign with a diagonal downward arrow (W16-7P) plaque, and located at or immediately adjacent to a marked crosswalk. The RRFBs were mounted and operated as detailed in the FHWA Interim Approval and/or the subsequent official interpretations issued by FHWA on RRFB installations. The circular beacons used high-intensity LED-based indications (meeting Class 1 requirements), and used the rapid-flashing pattern used by the RRFB. The 12-inch circular beacons were mounted beneath the pedestrian crossing sign.

The flash pattern used at the sites was the 2-5 pattern currently used with the RRFBs. In the 2-5 pattern, one side of the beacon pulses twice followed by the other side pulsing five times. Table 162 provides information on installation order along with the dates of the data collection.

Rotation

To account for the potential that device installation order could affect the results, the RRFB was installed first in some locations and second in other locations. For the 12 study sites, the RRFB was installed first in half of the sites while the CRFB was installed first in the other half of the sites.

Brightness of Beacons

Because preliminary findings from another closed-course study indicated that brightness of the beacons can influence how quickly a participant can detect a pedestrian within a crosswalk, efforts were made to measure the brightness of the beacons included in this study.(34) Because of limited funds, only one trip was made to each city to measure brightness. When knowledge was available regarding the new location of a measured beacon after rotation, the brightness level of that beacon in the new location was assumed to be the same as was measured in the previous location.

Figure 76. Photo. Rectangular beacons used at CS-01.

Figure 77. Photo. Circular beacons used at CS-02.

Figure 78. Photo. Circular beacons used at AU-01.

Figure 79. Photo. Rectangular beacons used at AU-02.

Figure 80. Photo. Circular beacons used at MK-04.

Figure 81. Photo. Circular beacons used at MK-05.

Figure 82. Photo. Circular beacons used at MK-06.

Figure 83. Photo. Rectangular beacons used at MK-07.

Figure 84. Photo. Rectangular beacons used at MK-08.

Figure 85. Photo. Circular beacons used at FG-01.

Figure 86. Photo. Circular beacons used at FG-02.

Figure 87. Photo. Rectangular beacons used at FG-03.

Table 162. Installation dates and dates of data collection.

Site	Existing beacon on assembly[a]	Date of before data collection	Initial assembly	Date CRFB installed	Date of CRFB data collection	Date RRFB installed	Date of RRFB data collection
AU-01	24/7	8/29/2013	CRFB	2/3/2014	3/26/2014	4/10/2014	4/24/2014
AU-02	Activated	8/28/2013	RRFB	4/10/2014	4/23/2014	3/7/2014	3/25/2014
CS-01	24/7	11/15/2012	RRFB	3/6/2014	4/2/2014	11/27/2014	2/14/2014
CS-02	None	1/28/2013	CRFB	11/27/2014	2/5/2014	3/6/2014	4/1/2014
FG-01	Activated	5/21/2013	RRFB	1/9/2014	3/5/2014	9/2/2013	10/23/2013
FG-02	RRFB	NA[b]	RRFB	1/9/2014	3/5/2014	7/11/2013	10/22/2013
FG-03	None	5/21/2013 5/22/2013	CRFB	9/7/2013	10/23/2013	12/4/2013	3/5/2014 3/6/2014
MK-04	None	6/18/2013	CRFB	8/1/2013	9/24/2013	10/21/2013	12/5/2013
MK-05	None	6/19/2013	CRFB	8/1/2013	9/23/2013	10/21/2013	12/5/2013
MK-06	None	NA[c]	CRFB	8/5/2013	9/23/2013	10/21/2013	12/5/2013
MK-07	RRFB	NA[b]	RRFB	10/21/2013	12/6/2013	Existing condition	6/19/2013
MK-08	RRFB	NA[b]	RRFB	10/21/2013	12/4/2013	Existing condition	6/20/2013

[a] 24/7 = continuously active yellow flashing beacons; Activated = pedestrian-activated yellow flashing beacons.
[b] No before data collected because the RRFBs were already installed at the site.
[c] Road work was being conducted near the site during the data collection trip; therefore, no before data were collected.
NA = Not Available.

DATA COLLECTION

Study Periods

The study was conducted between November 2012 and April 2014. The before data were collected between November 2012 and August 2013. Once the before data were obtained, the research team requested the city to install the initial device—at approximately half the sites, the initial device was the RRFB; at the other half of the sites, it was the CRFB. Following installation of the initial device (and a minimum period of 1 month for drivers to get acclimated to the new device), the research team collected "after data." Once the after data were obtained, the research team requested the city to install the second device (thus, RRFBs were replaced with CRFBs and vice versa). Once again, following a minimum period of 1 month for drivers to get acclimated to the second device, the research team collected after data for the second device. The CRFB and RRFB data were collected between June 2013 and April 2014.

Data were collected primarily during the daytime when vehicles were free-flowing. Because few, if any, studies have collected data at night, the research team wanted to obtain some data for nighttime conditions. The characteristics of the beacon and the site might have different impacts on driver yielding during night conditions compared with daytime conditions. Therefore, nighttime data were collected for one of the sites in each city.

Staged Pedestrian Protocol

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. Under this protocol, a member of the research team acted as a pedestrian using the crosswalk, to stage the conditions under which driver yielding would be observed. Each staged pedestrian wore similar clothing (gray t-shirt, blue jeans, and gray tennis shoes) and followed specific instructions in crossing the roadway. The staged pedestrian was accompanied by a second researcher, who observed and recorded the yielding data on pre-printed datasheets. Additional information on the staged pedestrian protocol followed is available in a recent paper.(12) For this study, data for a minimum of 60 staged pedestrian crossings were collected at each site in each time period during daytime. Because of the length of time needed to collect the crossing data, data for a minimum of 40 staged pedestrians were collected at night with one exception. Because of the very low yielding and the frequency of the staged pedestrian being stranded in the TWLTL, data collection was stopped at one of the sites.

Video

The team also video-recorded the sites for approximately 4 to 6 hours for each study period. The video data provided the opportunity to confirm characteristics of a crossing, including whether the pedestrian pushed the pushbutton to activate the beacons. Volume counts were reduced for a sample of the video recorded at the RRFB sites.

Brightness of Beacons

Background

Formal definitions of luminance intensity, brightness, optical power, and other photometric measurement terms are listed in table 163. While the term optical power is more traditionally associated with optical convergence or divergence of a lens, in this memo, the SAE definition is used.(35)

Equipment

The equipment responsible for the light measurements includes a photometer with a cosine-corrected photometric sensor and an oscilloscope with high-speed photodetector. The cosine-corrected photometric sensor is rated to capture light with wavelengths between 400 and 700 nanometers, which is also the spectrum of visual light. The high-speed photodetector is rated for capturing light with wavelengths between 400 and 1,100 nanometers, which includes infrared light in addition to the visual spectrum of light.(36) All of the equipment used and purpose of the equipment are listed in table 164.

Table 163. Photometric terminology.

Term	Definition
Brightness	"Attribute of a visual perception according to which an area appears to emit, or reflect, more or less light."(37)
Illuminate energy (lux-seconds)	Quantity of light falling on a sensor from a light source.
Luminous Intensity (candela)	"The luminous flux per unit solid angle in a given direction expressed in candela (cd)."(38) (p. 1)
Luminous energy (candela-seconds)	Luminous flux per unit solid angle in a given direction for a duration of time.
Optical Power (candela-seconds/minute)	"The integration of the luminous intensity of the flashing light source for a time of 60 seconds."(35) (p. 3)
Light Pulse	"A single, visually continuous emission of optical energy. High frequency modulation is permitted."(35) (p. 3)
Flash	"A flash is a light pulse or a train of light pulses, where a dark interval of at least 160 ms separates the light pulse or the last pulse of the train of light pulses from the next pulse or the first pulse of the next train of light pulses."(35) (p. 3)

Table 164. Equipment list and purpose.

Equipment	Purpose
Photometer with cosine-corrected photometric sensor(39)	Illuminating energy measurement (lux-seconds)
Oscilloscope with high-speed photodetector	Capturing flash pattern (time) Determining relative beacon intensity
Tripod and mounting equipment	Positioning the photometric sensor and photodetector in front of the beacons
Laptop computer	Recording the illuminate energy and capturing the flash pattern
Portable generator	Powering the photometer and oscilloscope
Electric measuring tape	Measuring the distance between the cosine-corrected photometric sensor and the light source

Brightness Data Collection

Researchers collected illuminate energy and flash pattern digital images of beacons in cities participating in the CRFB/RRFB open-road study. The dates of the data collection by site are listed in table 165. All of the data were collected at night because ambient light from the sun would overwhelm the sensors if researchers used the same methods during the day.

Table 165. Data collection dates by site and city.

Site ID	Beacon shape	City	Night(s)
AU-01	Circular	Austin	March 6 to 7, 2014
AU-02	Rectangular	Austin	March 6 to 7, 2014
CS-01	Rectangular	College Station	January 21, 2014
CS-02	Circular	College Station	January 21, 2014
FL-01	Circular	Flagstaff	March 3 to 5, 2014
FL-02	Circular	Flagstaff	March 3 to 5, 2014
FL-03	Rectangular	Flagstaff	March 3 to 5, 2014
MI-04	Circular	Milwaukee	September 22 to 24, 2013
MI-05	Circular	Milwaukee	September 22 to 24, 2013
MI-06	Circular	Milwaukee	September 22 to 24, 2013
MI-07	Rectangular	Milwaukee	September 22 to 24, 2013
MI-08	Rectangular	Milwaukee	September 22 to 24, 2013

Upon arriving at the data collection location, researchers would mount the photometric sensor and high-speed photodetector to the tripod. Then, to the best of their ability, the researchers positioned the cosine-corrected photometric sensor in front of the yellow warning beacons such that measurements were taken at a horizontal (left/right) angle of zero degrees and a vertical (up/down) angle of zero degrees. In addition, researchers positioned the photometric sensor between 3 and 12 ft away from the beacons. In this study, the beacons were either 12-inch circular beacons mounted below the sign or rectangular beacons mounted below the sign.

After positioning the sensors, the research team confirmed the equipment was working properly before taking measurements. The researcher responsible for taking measurements took five measurements of background illuminate energy. During data reduction, researchers used these measurements to quantify and remove background illuminate energy from the calculated values of luminance energy and luminance intensity for the beacons. Background illuminate energy often came from streetlights. The duration of the illuminate energy readings was between 1 and 2 s depending on the distance from the light source and volume of illuminate energy. (The photometer was unable to record illuminate energy values greater than 500 lx-s.)

After taking the background illuminate energy readings, the research team activated the beacons and took digital images of the flash pattern using the high-speed photodetector and digital oscilloscope. Each digital image consisted of 4 s worth of data recorded as 4,000 individual energy readings. (The high-speed photodetector and oscilloscope documented the flash pattern in terms of voltage.) Each digital image was saved to the computer in a spreadsheet.

Once the digital images of the flash patterns were recorded, the researcher responsible for taking measurements took five illuminate energy readings while the beacons were activated (flashing). The duration for each reading was the same as the duration of the background readings.

Before moving the sensors to the next set of beacons at the site, the research team recorded the distance from the cosine-corrected photometric sensor to the light source in meters. During data reduction, researcher used this value to convert illuminate energy (lx-s) to luminance energy (cd-s). In addition, the research team documented which beacon (left or right) in the set had two pulses and which beacon had more than two pulses.

After confirming all of the necessary data were collected, the research team then moved to the next set of beacons at the site. It took the research team between 90 and 180 min to collect all of the illuminate energy readings and flash pattern images required for sites with four sets of beacons to measure.

DATA REDUCTION

Driver Yielding

After completing the data collection, researchers entered the crossing data and the site characteristics data from the field worksheets into an electronic database. The average yielding rate for a site was calculated as shown in figure 88; however, data for individual crossings were used in the statistical evaluation.

$$Yielding\ rate = \frac{number\ of\ yielding\ vehicles}{number\ of\ yielding\ vehicles + number\ of\ non\text{-}yielding\ vehicles}$$

Figure 88. Equation. Yielding rate for a single crossing and average yielding rate for a site.

Brightness

Determine Luminance Energy and Optical Power for Each Set of Beacons

The first step in determining the luminance intensity and luminance energy for each set of beacons and individual lamps was to average the illuminate energy background measurements and illuminate energy readings when the beacons were active. Researchers then subtracted the average background illuminate energy from the average illuminate energy with activated beacons to determine the average beacon illuminate energy. Average beacon illuminate energy is then converted to luminance energy using the equation in figure 89.

$$\text{lum\_energy} = \text{ill\_energy} \times \text{m\_dist}^2$$

Figure 89. Equation. Average luminance energy.

Where:
lum_energy = average beacon luminance energy (cd-s).
ill_energy = average beacon illuminate energy (lx-s).
m_dist = distance between the cosine-corrected photometric sensor and the beacons (m).

After determining the average luminance energy, researchers converted luminance energy to optical power, which is luminance energy per minute. For this memo, optical power is calculated using the equation in figure 90:

$$\text{OP\_both} = \text{lum\_energy} * 60 / \text{m\_dur}$$

Figure 90. Equation. Optical power.

Where:
lum_energy = average beacon luminance energy (cd-s).
m_dur = duration of the illuminate energy reading used to calculate luminance energy (s).
OP_both = optical power of the beacon set (cd-s/min).

Determine on Time and Cycle Length for Each Beacon Set

After determining the optical power for each set of beacons, the next step in the process of determining the luminous intensity for individual beacons is to determine the total on time, individual lamp on time, and cycle length for each beacon. To determine these values, researchers used the digital images of the flash patterns captured using the oscilloscope and high-speed photodetector.

The first step in the process of determining on time and cycle length is to convert the voltage values in the digital images to percent maximum voltage; then, to determine which values count as on and which values count as off, researchers used a trigger level of 10 percent of the maximum voltage. This means that if the percent maximum voltage was under 10 percent, then the lamp was considered to be off and that time was assigned a percent maximum voltage of zero. Sometimes, owing to background illuminate energy, researchers adjusted up to 20 percent of the maximum voltage, but this rarely occurred.

Next, researchers used a computer macro to sort the data into four separate flash cycles of about 800 ms. A researcher then graphed each flash cycle and reviewed these graphs to make sure the image was captured correctly before performing calculations. An example of a graphed flash cycle that was captured correctly is shown in figure 91.

Each data point in figure 91 represents 1 ms of data. Therefore, to determine cycle length, researchers counted the number of data points in each correctly captured flash cycle and averaged these values to determine the cycle length in milliseconds. To determine on time, researchers counted the number of data points that were greater than zero and averaged these values to determine the on time in milliseconds. Owing to background lighting, some points that were greater than zero would be filtered to zero during the data analysis. This ensured that readings that were greater than zero based on the background light and not the beacon being active were accounted for properly.

After determining the total on time and cycle length, researchers then determined the on time for the beacon with five flashes (the first five flashes in figure 91) and the on time for the beacon with two flashes (the sixth and seventh flashes in figure 91).

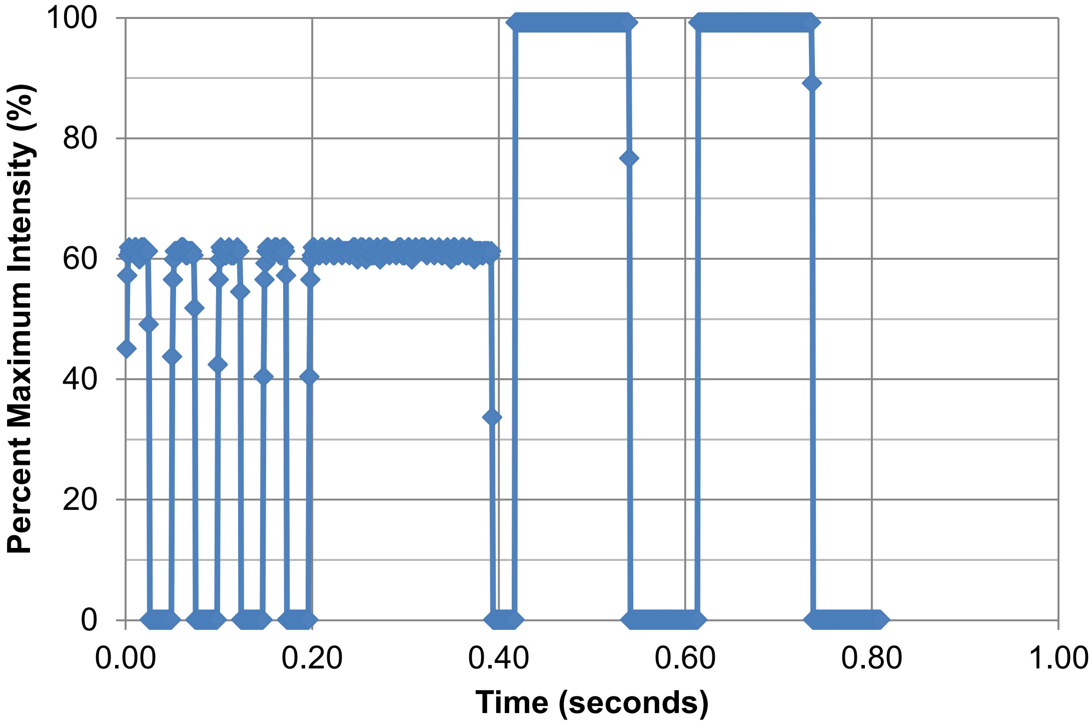


Figure 91. Graph. Example of correctly captured and graphed flash cycle showing five pulses of light (0.0 to 0.4 time) followed by two pulses of light (0.4 to 0.8 time).

FINDINGS

Driver Yielding Findings

Table 166 shows the driver yielding results for each site and assembly along with the number of nonstaged and staged pedestrian crossings for the daytime data collection periods. During the daytime, driver yielding to staged pedestrians averaged 63 percent for the CRFB and 59 percent for the RRFB assemblies. The range of driver yielding to staged pedestrians at yellow, rapid-flashing beacons ranged from a low of 22 percent to a high of 98 percent.

Table 167 lists the driver yielding rates for the nighttime data collection periods. Driver yielding to staged pedestrians at night averaged 72 percent for the RRFB assemblies and 49 percent for the CRFB assemblies; however, the 49 percent figure includes data for a site that had a beacon that did not meet the Class 1 requirement for brightness. Without that site, the average yielding for the CRFB was 69 percent.

Table 166 and table 167 also contain the driver yielding rates in the before condition (i.e., before the installation of the rapid-flashing beacon) for those sites where data were available. An evaluation of whether a statistically significant increase was present between the before conditions (slow flashing beacon or no flashing treatment) and the rapid-flashing beacon condition could not be completed because of the limited number of sites with a before treatment.

Table 166. Daytime driver yielding rate by site and assembly.

Assembly	Site	Nonstaged count	Nonstaged driver yielding	Staged count	Staged driver yielding
CRFB	AU-01	28	90%	60	62%
	AU-02	13	54%	60	57%
	CS-01	41	97%	39	89%
	CS-02	11	48%	60	36%
	FG-01	131	83%	81	94%
	FG-02	73	93%	69	95%
	FG-03	37	90%	66	95%
	MK-04	109	12%	62	58%
	MK-05	104	13%	78	44%
	MK-06	130	22%	56	67%
	MK-07	62	58%	62	39%
	MK-08	30	30%	60	58%
All CRFB		**769**	**46%**	**753**	**63%**
All CRFB (without site CS-02)		**717**	**44%**	**654**	**67%**
RRFB	AU-01	26	71%	60	71%
	AU-02	82	43%	60	59%
	CS-01	58	97%	60	56%
	CS-02	17	49%	60	44%
	FG-01	95	77%	69	84%
	FG-02	77	92%	61	98%
	FG-03	25	98%	80	98%
	MK-04	79	25%	61	43%
	MK-05	40	24%	59	22%
	MK-06	36	23%	61	57%
	MK-07	114	48%	61	31%
	MK-08	128	37%	82	36%
All RRFB		**777**	**57%**	**774**	**59%**
Slow	AU-01	83	22	60	12
	AU-02	33	26	61	51
	CS-01	77	100	42	66
	FG-01	89	79	100	85
All Slow Flashing		**282**	**58**	**263**	**54**
None	CS-02	10	10	40	9
	FG-03	37	87	80	62
	MK-04	121	18	96	19
	MK-05	88	12	89	9
All No Flashing		**256**	**26**	**305**	**24**

Table 167. Nighttime driver yielding rate by site and assembly.

Assembly	Site	Nonstaged count	Nonstaged driver yielding	Staged count	Staged driver yielding
CRFB	AU-02	0	NA	40	67%
	CS-02	0	NA	19[a]	5%[a]
	FG-01	23	85%	52	89%
	MK-08	6	56%	60	52%
All CRFB (without site CS-02)		**29**	**78%**	**152**	**69%**
RRFB	AU-02	0	NA	40	88%
	CS-02	0	NA	40	53%
	FG-01	21	100%	50	95%
	MK-08	9	20%	50	54%
All RRFB		**30**	**84%**	**180**	**72%**
Slow	FG-01	7	100%	58	63%

[a] Data should not be considered because beacon brightness did not satisfy the Class 1 requirement.
NA = Not Applicable (no nonstaged pedestrians were observed at night at these sites).

Brightness Findings

Determine Average Intensity

After determining the cycle length, total on time, on time for the five-flash beacon, and on time for the two-flash beacon, it is possible to determine the average luminance intensity for each beacon set and individual beacons. The equation for determining the average intensity for each beacon set is shown in figure 92:

$$\text{int\_both} = \text{OP\_both} \times \text{cycle} / [\ 60 \times \text{on\_both}\ ]$$

Figure 92. Equation. Average intensity.

Where:
int_both = the average luminance intensity for both beacons (cd).
cycle = cycle length for the beacon set (ms).
on_both = total on time for both beacons (ms).
OP_both = optical power of the beacon set (cd-s/min).

Determine Optical Power and Average Luminance Intensity by Approach

The optical power by approach can be calculated using the equation in figure 93.

$$\text{op\_approach} = \text{op\_left} + \text{op\_right}$$

Figure 93. Equation. Optical power by approach.

Where:
op_approach = optical power for a vehicle traveling in a given direction (cd-s/min).
op_left = optical power for a set of beacons on the left side of the roadway (cd-s/min).
op_right = optical power for a set of beacon on the right side of the roadway (cd-s/min).

The average intensity by approach can be calculated using the equation in figure 94.

$$\text{int\_approach} = (\text{int\_left} \times \text{on\_left} + \text{int\_right} \times \text{on\_right}) / (\text{on\_left} + \text{on\_right})$$

Figure 94. Equation. Average intensity by approach.

Where:
int_approach = average intensity for an approach (cd)
int_left = intensity for a set of beacons on the left side of the roadway (cd).
on_left = on time for the set of beacons on the left side of the roadway (s).
int_right = intensity for a set of beacons on the right side of the roadway (cd).
on_right = on time for the set of beacons on the right side of the roadway (s).

Determine Optical Power and Average Luminance Intensity by Site

Because motorist yielding calculations are done for a site rather by an approach, a value is needed to reflect the site. The average optical power for a site would be the average of the two directions or approaches. The optical power for an approach is the sum of the optical power for the assembly on the left and the assembly on the right because a driver would have both assemblies in view. For a site, the driver would only have the assemblies on approach A or on approach B in view; therefore, an average the optical power for the two approaches is needed. It can be calculated using the equation in figure 95.

$$\text{op\_site} = (\text{op\_approach-A} + \text{op\_approach-B})/2$$

Figure 95. Equation. Optical power for a site.

Where:
op_site = average optical power for site (cd-s/min).
op_approach-A = optical power for a vehicle traveling in a given direction (cd-s/min).
op_approach-B = optical power for a vehicle traveling in the opposing direction (cd-s/min).

To provide an appreciation of how long a beacon is on, the average intensity for a site should be a weighted average. It can be calculated using the equation in figure 96:

$$\text{int\_site} = (\text{int\_left\_A} \times \text{on\_left\_A} + \text{int\_right\_A} \times \text{on\_right\_A} + \text{int\_left\_B} \times \text{on\_left\_B} + \text{int\_right\_B} \times \text{on\_right\_B}) / (\text{on\_left\_A} + \text{on\_right\_A} + \text{on\_left\_B} + \text{on\_right\_B})$$

Figure 96. Equation. Average intensity for a site.

Where:
int_site = average intensity for a site (cd).
int_left_A = intensity for left-side beacons on approach A (cd).
int_right_A = intensity for right-side beacons on approach A (cd).
int_left_B = intensity for left-side beacons on approach B (cd).
int_right_B = intensity for right-side beacons on approach B (cd).
on_left_A = on time for left-side beacons on approach A (s).
on_right_A = on time for right-side beacons on approach A (s).
on_left_B = on time for left-side beacons on approach B (s).
on_right_B = on time for right-side beacons on approach B (s).

The measured average optical power and average intensity by site are provided in table 168 and table 169, respectively. Figure 97 shows a plot of the optical power values while figure 98 shows average intensity per site. In most cases, the research team was able to track where the beacons were moved after a rotation.

Table 168. Average optical power and intensity by crossing.

Shape	Site	Average intensity (cd), rounded to hundreds	Average optical power (cd-s/min), rounded to thousands
CRFB	AU-01	500	37,000
RRFB	AU-02	3,000	226,000
RRFB	CS-01	1,400	117,000
CRFB	CS-02	100	8,000
CRFB	FG-01	1,800	156,000
CRFB	FG-02	1,100	80,000
RRFB	FG-03	1,200	93,000
CRFB	MK-04	1,100	87,000
CRFB	MK-05	2,100	162,000
CRFB	MK-06	1,900	150,000
RRFB	MK-07	1,100	84,000
RRFB	MK-08	800	66,000

Table 169. Device brightness at each site.

Site	CRFB-intensity (cd)	CRFB-optical power (cd-s/min)	RRFB-intensity (cd)	RRFB-optical power (cd-s/min)
AU-01	600	37,000	3,100	220,000
AU-02	600	37,000	3,100	220,000
CS-01	100	8,000	1,500	117,000
CS-02	100	8,000	1,500	117,000
FG-01	1,900	165,000	NA	NA
FG-02	1,200	83,000	NA	NA
FG-03	NA	NA	1,200	95,000
MK-04	1,100	87,000	1,200	91,000
MK-05	2,100	162,000	1,000	77,000
MK-06	1,900	150,000	800	66,000
MK-07	1,600	124,000	1,100	84,000
MK-08	1,900	150,000	800	66,000

NA = Not Available.

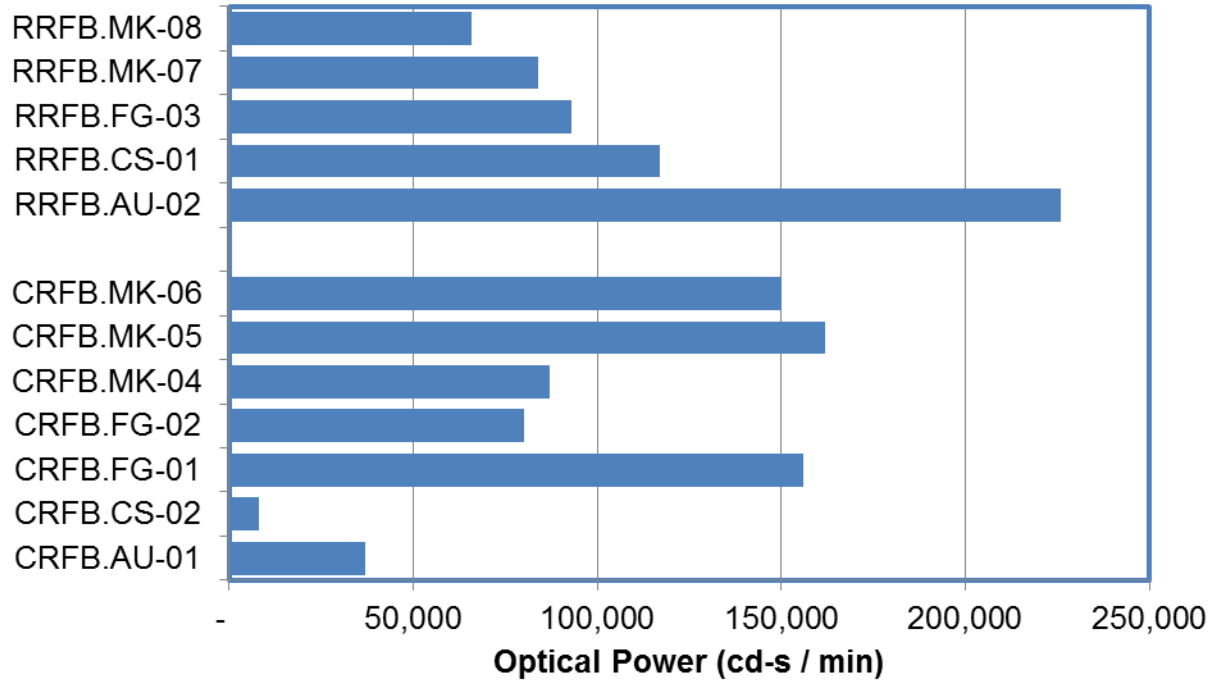


Figure 97. Graph. Plot of average optical power by beacon shape and site.

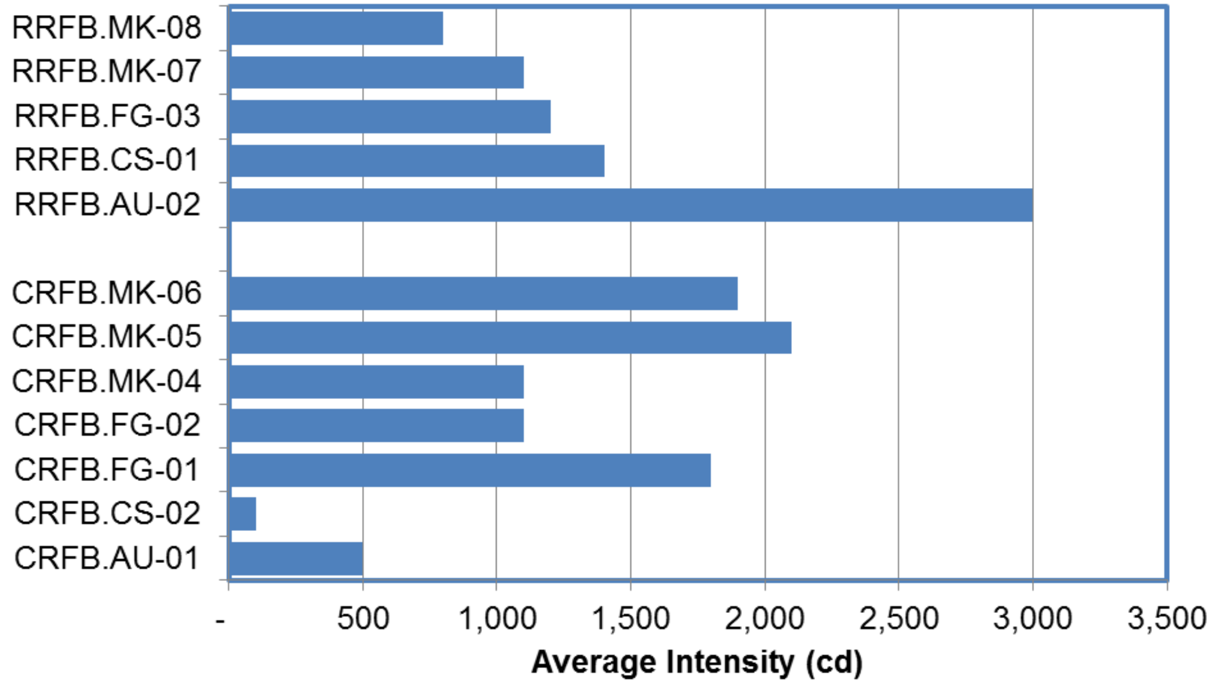


Figure 98. Graph. Plot of average intensity by beacon shape and site.

RESULTS

When a driver approaches a pedestrian crossing, the driver either yields and stops (or slows) the vehicle or does not yield to the waiting pedestrian. This binary behavior (yield or no yield) can be modeled using logistic regression. A significant advantage of using logistic regression is it permits consideration of individual crossing data rather than reducing all the data at a site to only one value. For the dataset available in this study, that means more than 2,500 data points could be available (i.e., all the unique staged crossings recorded) rather than only 41 data points (i.e., the number of study sites by number of assemblies and by day or night). For the analyses that focused on comparing the CRFB to the RRFB, that means 1,878 data points rather than 32 data points are available. When examining both staged and nonstaged data, there are 3,483 crossings available. These larger sample sizes could result in finding significant relationships that would not be apparent with a smaller dataset. In addition, it is possible to use random effects to account for site-specific differences because such differences induce a correlation structure in the dataset.

Using logistic regression to model the relationships assumes that the logit transformation of the outcome variable (i.e., yielding rate) has a linear relationship with the predictor variables, which results in challenges in interpreting the regression coefficients. The interpretation of such coefficients is not based on the yield rate changes directly, but a change in the odds of motorists yielding. (The odds are defined as the ratio of the number of yielding motorists to the number of non-yielding motorists.) The regression coefficients can be transformed and interpreted as odds ratios of different levels of the corresponding independent variable. In other words, a unit change of the independent variable corresponds to a change in the odds of motorists yielding, which is an alternative way to express a change in yielding rate. More details on these types of models can be found in the statistical literature.(40) All the statistical analyses were performed using R, an open-source statistical language and environment and two open-source packages for fitting GLMMs.(41,42,27)

Comparison of CRFB to RRFB

Because a previous study that included RRFBs found that posted speed limit, crossing distance, and city influenced driver yielding, the initial analyses were also conducted with those variables.(12) In addition, a measure of the rotation was also recorded, to potentially account for a learning curve in the driver yielding rates, as was indicated in the TxDOT study.(12) Therefore, the variable “order” was added as a nested random effect in each site.

Preliminary modeling revealed a correlation between crossing distance and speed limit present in the dataset; therefore, only crossing distance was included in the final model. Attempts were made to conduct the analysis separately for nighttime and daytime conditions; however, insufficient data were available for the nighttime analysis. To determine whether nighttime results were significantly different from daytime results, an indicator variable for nighttime conditions was included in the final model. The model specification was a quasi-binomial regression because the dataset exhibited significantly more dispersion than it would be expected for binomially distributed data. This type of model adjusts maximum likelihood standard errors using an estimate of overdispersion to reduce risk of type-I error in the analysis.

From the preliminary review of the results in table 166, it appears that there are only minor, if any, differences between the CRFB and the RRFB. The results from the GLMM are shown in table 170, and these results support that observation. These results indicate that there are no significant differences between the two beacon shapes (*p*-value = 0.4792). The day/night variable was not significant (*p*-value = 0.5152), which indicates that there is not enough nighttime data to differentiate from daytime rates as a flat effect, after accounting for the rest of the variables in the analysis. Preliminarily, it appears that the city of Flagstaff has notably higher driver yielding compared with the base city of Austin (an adjusted *p*-value for multiple comparisons is required to make a formal assessment) while College Station and Milwaukee are clearly not different from Austin. The model also showed that calculated daily traffic was not a significant variable (*p*-value = 0.3157). The results also revealed that the correlation in the data structure and order of installation are rather weak effects, judging by the intraclass correlation coefficient, which is a measure of how similar data points are within groups when aggregated by site and by order of installation.

Table 170. GLMM results comparing CRFB to RRFB.

Variable[a,b]	Estimate	Standard error	DF	*t*-value	*p*-value
Reference Level[c]	1.94372	0.706795	1,837	2.750049	0.006
City: College Station	-0.24829	0.700020	6	-0.354687	0.735[d]
City: Flagstaff	2.37791	0.512182	6	4.642705	0.0035[d]
City: Milwaukee	-0.80018	0.439072	6	-1.822435	0.1182[d]
CrossDis	-0.02137	0.021964	6	-0.973127	0.3681
Treatment: RRFB	-0.15289	0.205130	11	-0.745352	0.4717
Day.Night: Night	0.07484	0.113837	1,837	0.657453	0.511
Calculated Daily Traffic	-0.00004	0.000037	6	-1.094477	0.3157

[a] Column headings are defined as follows:

- Variable: Fixed Effects variables included in model.
- Estimate: natural logarithm of the ratio: Odds(coefficient level)/Odds(reference level). In the case of reference level, Estimate is the log-odds of the average yielding rate at the reference level.
- Standard Error = Standard error of value.
- DF = degrees of freedom.
- *t*-value = conservative estimate of the z-value, which is the standard normal score for estimate, given the hypothesis that the actual odds ratio equals one.
- *p*-value: Probability that the observed log-odds ratio be at least as extreme as estimate, given the hypothesis that the actual odds ratio equals one.

[b] Random effects variables: Site (intraclass correlation coefficient = +0.045) and Site X Order (intraclass correlation coefficient = +0.169).

[c] Reference Level Yielding in the model is estimated at 78.02 percent for the following conditions:

- City = Austin.
- Day.Night = Day.
- Treatment = CRFB.

[d] These *p*-values require an adjustment for multiple comparisons if inferences about different yielding rates among cities are intended.

Comparison of CRFB to RRFB Considering Beacon Brightness

For a subset of the sites, the brightness of the beacons was measured. The results for the analysis that included intensity as a measure of brightness are shown in table 171. Again, the findings illustrate, preliminarily, that driver yielding in Flagstaff is higher than in Austin. This analysis included a separate account of intensity under those conditions because the effects of beacons might differ between daytime and nighttime.

Figure 99 for daytime and figure 100 for nighttime show graphs of average driver yielding per site versus intensity that illustrate a trend of increasing driver yielding associated with increases in intensity. Furthermore, the statistical analysis results also demonstrated an increasing yielding rate with increasing intensity; however, only at night (*p*-value < 0.0001 from the quasi-binomial regression model, see Intensity:Night in table 171). Still, the trend is in the same direction during the day but with a smaller magnitude that the analysis found statistically insignificant. It is estimated that the odds of yielding at night increase by a multiplicative factor of 1.0008 per additional candela of intensity.

Including brightness in the analysis does not modify the findings for treatment. Without brightness, the results (as shown in table 170) are that there was no difference between the circular and rectangular shaped beacons. When considering brightness, the circular beacons still do not have significantly different yielding rates compared with rectangular beacons (as shown in table 171). Table 172 and table 173 show the estimated daytime and nighttime effects on a theoretical site for the range of intensity in this study (100 to 3,100 cd). For reference, column 5 of these tables shows the raw data averages. The sixth column shows how many crossings are available to compute the raw data estimates. The results demonstrate the strong effect for intensity at night that is also evident in the raw data averages.

Table 171. GLMM results comparing CRFB to RRFB when beacon brightness data are available.

Variable[a,b]	**Estimate**	**Standard error**	**DF**	***t*-value**	***p*-value**
Reference Level[c]	1.2670	0.7413	1,593	1.7091	0.0876
City: College Station	0.2310	0.6303	7	0.3669	0.7245[d]
City: Flagstaff	2.2340	0.4830	7	4.6261	0.0024[d]
City: Milwaukee	-0.5060	0.4006	7	-1.2620	0.2474[d]
CrossDis	-0.0260	0.0197	7	-1.3330	0.2243
Treatment: RRFB	-0.2430	0.1567	7	-1.5528	0.1644
Intensity	0.0002	0.0001	7	1.5855	0.1569
Day.Night: Night	-0.8910	0.2320	1,593	-3.8412	0.0001
Intensity X Day.Night	0.0007	0.0002	1,593	4.4355	< 0.0001

[a] Column headings are defined as follows:

- Variable: Fixed Effects variables included in model.
- Estimate: natural logarithm of the ratio: Odds(coefficient level)/Odds(reference level). In the case of reference level, Estimate is the log-odds of the average yielding rate at the reference level.
- Standard Error = Standard error of value.
- DF = degrees of freedom.
- *t*-value = conservative estimate of the z-value, which is the standard normal score for estimate, given the hypothesis that the actual odds ratio equals one.
- *p*-value: Probability that the observed log-odds ratio be at least as extreme as estimate, given the hypothesis that the actual odds ratio equals one.

[b] Random effects variables: Site (intraclass correlation coefficient = +0.093) and Site X Order (intraclass correlation coefficient = +0.138).

[c] Reference Level Yielding in the model is estimated at 78.02 percent for the following conditions:

- City = Austin.
- Day.Night = Day.
- Treatment = CRFB.

[d] These *p*-values require an adjustment for multiple comparisons if inferences about different yielding rates among cities are intended.

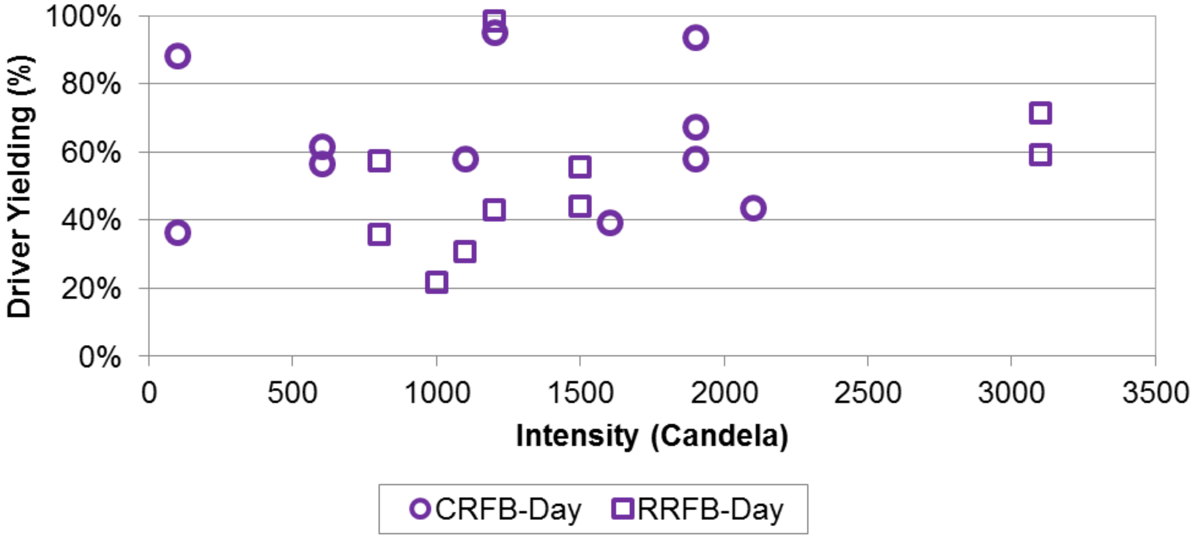


Figure 99. Graph. Driver yielding compared with beacon brightness intensity for day.

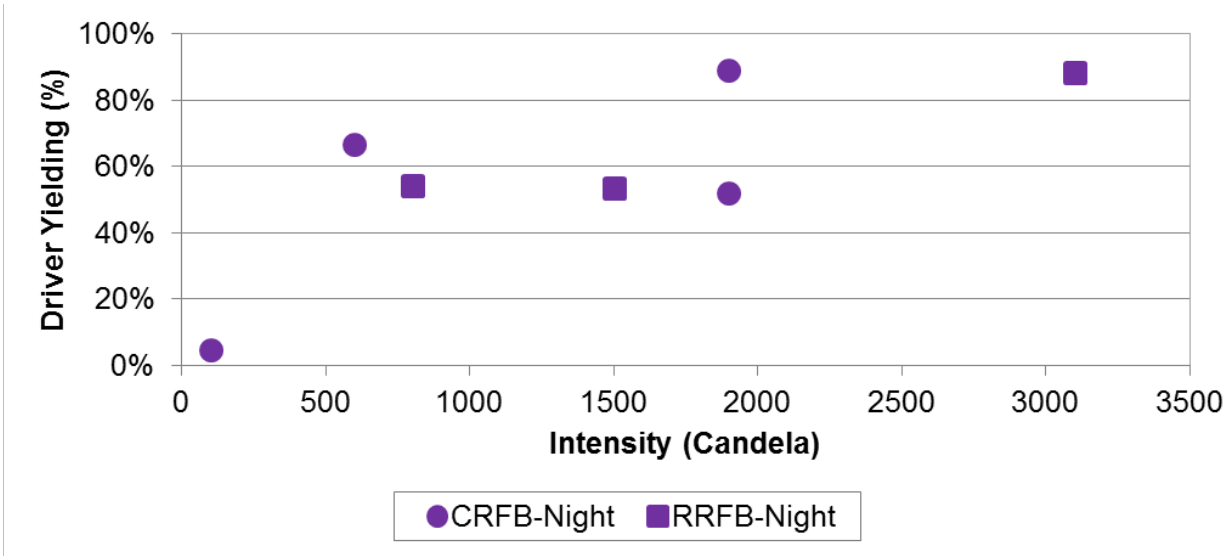


Figure 100. Graph. Driver yielding compared with beacon brightness intensity for night.

Table 172. Daytime effect of intensity on driver yielding for a theoretical site and for the raw data averages.

Intensity (cd)	Odds ratio	Initial YR = 50 percent (percent)	Initial YR = 60 percent (percent)	Initial YR = 70 percent (percent)	Raw data average (percent)	Number of crossings
100	1.02	50.0	60.0	70.0	58.8	91
800	1.14	53.4	63.2	72.8	54.8	143
1,900	1.38	58.0	67.4	76.3	78.6	197
3,100	1.69	62.8	71.7	79.8	71.2	120

YR = Yielding Rate.

Table 173. Nighttime effect of intensity on driver yielding for a theoretical site and for the raw data averages.

Intensity (cd)	Odds Ratio	Initial YR = 50 percent (percent)	Initial YR = 60 percent (percent)	Initial YR = 70 percent (percent)	Raw data average	Number of crossings
100	1.09	50.0	60.0	70.0	6.3	19
800	1.97	66.3	74.7	82.1	66.7	50
1,900	4.98	83.3	88.2	92.1	78.3	112
3,100	13.73	93.2	95.4	97.0	92.9	40

YR = Yielding Rate.

When considered together, analysis of results from table 172 and table 173 indicate that the difference in yielding rate associated with the day or night varies depending on the beacon intensity level, as shown in table 174. This table shows that nighttime driver yielding was significantly lower than daytime when the intensity was 800 cd or less. If a 0.10 significance level is used, daytime yielding is significantly higher than nighttime for intensities larger than 1,800 cd.

Table 174. Multiple comparisons for natural light effect on driver yielding by intensity.

Odds ratio (OR) compared to 1.0	OR	Ln(OR)	Standard error	*z*-value	*p*-value	Significant[a]
Night/Day (0 cd)	0.41	-0.89142	0.23142	-3.852	<0.001	***
Night/Day (800 cd)	0.70	-0.35079	0.14502	-2.419	0.0401	*
Night/Day (1,400 cd)	1.06	0.05468	0.12660	0.432	0.8983	—
Night/Day (1,800 cd)	1.38	0.32499	0.14807	2.195	0.0698	—

[a] Significance values are as follows: — = *p*-value > 0.05, * = p-value ≤ 0.05, ** = *p*-value < 0.01 *** = *p*-value < 0.001.

Comparison of Driver Yielding When Beacon Activated to Beacon Not Activated

The purpose of a rapid-flashing beacon—whether it is circular or rectangular—is to draw drivers' attention to a pedestrian waiting to cross the roadway and, thus, encourage drivers to yield to that pedestrian. Therefore, a key question to be answered in the research was to what extent did the presence of an actively flashing beacon influence driver yielding. To address this question, driver yielding rates were compared between the pedestrian crossings when a beacon was activated and the pedestrian crossings when a beacon was not activated.

The analysis included RRFBs and CRFBs and focused on crossings during daytime study periods. An initial comparison of staged pedestrian crossings (Note: staged pedestrians activated the beacon every time they crossed the roadway) and those nonstaged pedestrian crossings for which the beacon was activated showed no statistically significant difference in driver yielding. Therefore, the analysis included both staged and nonstaged pedestrian crossings.

The data consisted of a total of 1,970 activated and 476 non-activated crossings, for a total of 2,446 crossings used in the analysis. The distribution of activated and non-activated crossings in each city and site is shown in table 175.

Table 175. Number of activated and non-activated crossings by city and site.

City	Site	Beacon activation Yes	Beacon activation No	Total
Austin	AU-01	149	9	158
	AU-02	134	44	178
College Station	CS-01	126	5	131
	CS-02	136	4	140
Flagstaff	FG-01	266	71	337
	FG-02	255	16	271
	FG-03	192	4	196
Milwaukee	MK-04	130	95	225
	MK-05	147	39	186
	MK-06	132	98	230
	MK-07	147	46	193
	MK-08	156	45	201
Total		1,970	476	2,446

A GLMM with a binomial distribution and logit link was used to model the probability of yielding as a function of the following variables:

- Beacon activation (Yes/No).
- City (4 levels).
- Interaction between beacon activation and city (8 levels).
- CDT (continuous; ranging from approximately 2,130 to 23,008 vehicles/day).
- Crossing distance (continuous; ranging from 21 to 60 ft).

The data collection site within each city was included in the model as a random effect to account for differences among sites. Model estimation was done using PROC GLIMMIX in SAS. Stepwise backward-elimination was used to identify which factors and interaction were statistically significant at the 5-percent level. At each step, the factor, or interaction, with the highest *p*-value above 0.05 from a type 3 analysis *F*-test was excluded and the model rerun. A Type 3 analysis *F*-test determines the significance of each variable in the model individually. The results of this approach to obtain the final model, including beacon activation, city, and CDT as significant variables at the 0.05 level, are summarized in table 176.

Table 176. Stepwise elimination procedure results.

Step in ANOVA	Type 3 *p*-value for each factor in the ANOVA model: Beacon activation	City	Beacon activation times city interaction	CDT (vehicles/day)	Crossing distance
Step 1	< .0001	< .0001	0.40	0.15	0.94
Step 2	< .0001	< .0001	0.40	0.08	—
Step 3	< .0001	< .0001	—	0.07	—
Final	< .0001	< .0001	—	—	—

p-values above 0.05 are not significant.
— Not Applicable.

Those variables significant at the 0.05 level—beacon activation and city—were included in the GLMM evaluation. The ANOVA results of the reduced model, containing beacon activation and city as statistically significant factors, are shown in table 177. The logistic regression results, on a logit scale, as well as the results of the type 3 analysis, are shown. The probability associated with the *t*-value (columns 6 and 7) indicates whether the corresponding coefficient is statistically significantly different from zero. The reference level (baseline) for this analysis was defined as non-activated beacons (of either type) in Milwaukee, WI.

Table 177. GLMM results comparing driver yielding rates between activated and non-activated beacons.

Effect	Level	Coefficient estimate	Standard error	DF	*t*-value	Pr > |t|	Type 3 analysis *F*-value	Type 3 analysis Pr > F
Intercept	Intercept	-1.51	0.26	8	-5.72	0.0004	—	—
Beacon activation	Yes	1.30	0.08	2,433	15.79	< .0001	249.2	< .0001
	No[a]	0.00	—	—	—	—		
City	Austin	0.87	0.48	2,433	1.798	0.0723	16.07	< .0001
	College Station	0.68	0.49	2,433	1.395	0.1630		
	Flagstaff	2.96	0.43	2,433	6.890	< .0001		
	Milwaukee[a]	0.00	—	—	—	—		

[a]Reference Level: City = Milwaukee; Beacon Activation = No.
— Not Applicable

Table 177 shows that, overall, more drivers yielded when the beacon was activated (coefficient on logit scale = 1.30) than when it was not activated (coefficient = 0). The table also shows that, overall, the percentage of drivers yielding was lowest in Milwaukee (coefficient = 0) and highest in Flagstaff (coefficient = 2.96).

The predicted yielding rates and their 95-percent confidence limits are shown in table 178 for each site in each city, separately when the beacon was activated or not activated, all other factors held constant. At each site, table 177 shows that the yielding rate is higher when the beacon was activated than when it was not activated (i.e., significant beacon activation effect shown in table 177). Table 178 clearly shows that yielding rates in Flagstaff are considerably higher than in all other cities studied, regardless of whether or not pedestrians activated the device.

From the logistic model, the odds ratio for beacon activation was estimated. Because the interaction between beacon activation and city was not statistically significant, the odds ratio is the same for all cities (and sites in cities). The odds ratios and their 95-percent confidence limits are shown in table 179. In summary, drivers were, overall, 3.68 times more likely to yield when the beacon was activated than when it was not activated.

Table 178. Predicted driver yielding rates by city and site.

City, State	Site	Beacon activation	Driver yielding rate (percent) Predicted	Lower 95-percent confidence limit	Upper 95-percent confidence limit
Austin, TX	AU-01	Yes	70	66	74
		No	39	33	45
	AU-02	Yes	61	56	66
		No	30	25	35
College Station, TX	CS-01	Yes	78	71	83
		No	49	39	58
	CS-02	Yes	42	38	46
		No	16	14	20
Flagstaff, AZ	FG-01	Yes	89	86	90
		No	68	63	72
	FG-02	Yes	95	93	97
		No	84	78	89
	FG-03	Yes	96	94	98
		No	87	81	92
Milwaukee, WI	MK-04	Yes	45	40	49
		No	18	15	21
	MK-05	Yes	34	29	38
		No	12	10	15
	MK-06	Yes	53	49	57
		No	24	20	27
	MK-07	Yes	45	41	50
		No	18	15	22
	MK-08	Yes	47	43	52
		No	20	16	24

Table 179. Odds ratio results for beacon activation.

Factor	Comparison	Odds ratio	Lower 95-percent confidence limit	Upper 95-percent confidence limit	Significantly different from 1 at Alpha = 0.05?
Beacon Activation	Yes versus No	3.68	3.13	4.32	Yes

Influence of Traffic Volume on Driver Yielding

During data collection at pedestrian crossings in the research, data collectors observed that some drivers appeared to make a last-minute decision to yield when a driver in the adjacent lane was yielding, and other drivers appeared to make a last-minute decision not to yield when a driver in the adjacent lane was not yielding. This behavior suggests that driver yielding might be influenced by other vehicles in the traffic stream. It has also been suggested that drivers might be less likely to slow down or stop to yield when there is traffic behind them; that is, when they feel "pushed" from behind. An analysis was conducted to explore whether the presence of other vehicles influenced driver yielding.

The objective of the analysis was to evaluate the relationship between traffic volume and driver yielding rate. To estimate traffic volume for a particular pedestrian crossing, 1-min traffic volume counts were obtained from the videos for a sample of the daytime data collection periods at RRFB sites. The 1-min counts were then aggregated into 5-min averages, but still expressed on a 1-min basis. For example, the 5-min average for a particular minute was the average of the actual count for that minute and the actual counts for the preceding 4 min. Statistics (sample size, minimum, and maximum) for 1-min volume counts at each site are shown in table 180.

Table 180. One-min volume count statistics at crossings with RRFBs.

City	Site	Number of lanes	Number of crossing events with traffic present	Average of five 1-min volume counts	
				Minimum	Maximum
Austin	AU-01	2	37	12.0	18.8
	AU-02	1	74	5.4	14.2
College Station	CS-01	1	32	1.4	5.0
	CS-02	2	48	13.0	28.0
Flagstaff	FG-01	2	134	17.0	36.0
	FG-02	1	45	13.0	25.6
	FG-03	2	32	8.8	15.8
Milwaukee	MK-04	2	87	4.2	10.6
	MK-05	2	72	2.0	9.2
	MK-06	3	63	10.4	18.6
	MK-07	3	41	6.2	15.4
	MK-08	2	76	4.0	12.0

The analysis was based on daytime study periods for which traffic counts were obtained (note that only RRFB study sites were considered), at both staged and nonstaged pedestrian crossings. A GLMM with a binomial distribution and logit link was used to model the probability of driver yielding as a function of 1-min traffic volume count (representing the average 1-min count for the nearest 5-min period) and data collection site (to account for potential differences in traffic volume ranges and driver yielding rates between sites). Model estimation was done using PROC GLIMMIX in SAS.

The model showed that percentage yielding decreased as volume increased (slope estimate on the logit scale was -0.02278) but that relationship is not statistically significant (*p*-value = 0.30) using a type 3 *F*-test. In other words, there is not enough evidence to conclude that traffic volume influences driver yielding behavior at sites with RRFBs in a positive or negative manner. This is also reflected in figure 101, which presents the plot of predicted driver yielding percentage versus average 1-min volume counts in a 5-min time period, separately for each site; the data points are color-coded by city; different symbols are used for the different sites in a city.

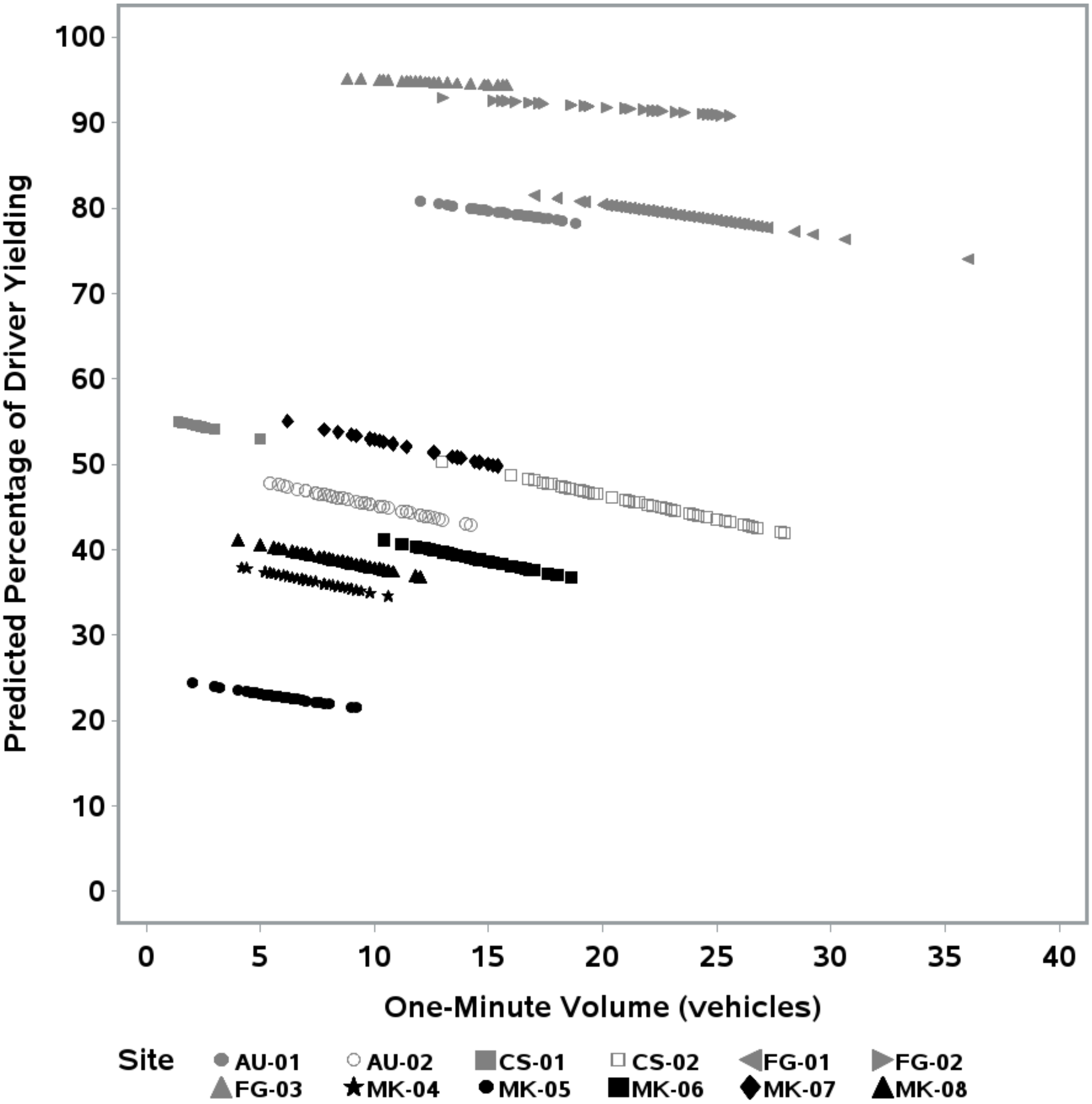


Figure 101. Graph. Predicted percent of driver yielding by 1-min volume counts.

CHAPTER 7. SUMMARY/CONCLUSIONS, DISCUSSION, AND FUTURE RESEARCH NEEDS

OVERVIEW

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 RRFB. The RRFB has received extensive national attention because of high yielding rates observed at several installations. Several studies have found increased driver yielding after installing this device as summarized in table 181. The findings from this FHWA study are also provided in table 181.

SUMMARY OF PHASE I FINDINGS

Findings From Literature Review

Efforts in the initial phase of this project included a comprehensive literature review of pedestrian treatments being used at unsignalized intersections. The appendix to this report contains the entirety of the literature review of these treatments. Certain parts of the literature review were updated or additional literature reviews were conducted as needed to support work done in later tasks in this project.

Review of Pedestrian Crash Data

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. The following datasets were reviewed:

- NHTSA FARS.
- NHTSA GES.
- FHWA HSIS—included a review of data from the States of California, Minnesota, North Carolina, Ohio, Texas, and Washington.

FARS crash data were reviewed for the years 2005 through 2009, inclusive. During this period, 22,892 pedestrian fatalities occurred in the United States, and 73.0 percent of the pedestrian fatalities occurred at midblock locations. The following statistics apply to the pedestrian fatalities that occurred at midblock locations:

- 1.3 percent occurred at marked midblock crosswalks.
- 30.7 percent occurred not in, but near, a marked midblock crosswalk.
- 68.0 percent occurred at locations that were not near marked midblock crosswalks.

Table 181. Overview of driver yielding results from several RRFB studies.

Study	Number of sites	Driver yielding[a]	Unique characteristics of study
2010 FHWA(3)	22 (most in St. Petersburg, FL)	72 to 96 percent (staged[b])	Original study that included data for multiple years
2009 FHWA(4)	2 (Miami, FL)	55 to 60 percent day (staged) 66 to 70 percent night (staged)	Day and night
2009 Florida(5)	1 (St. Petersburg, FL)	35 percent overall 54 percent activated[c]	Trail crossing
2011 Texas(6)	1 (Garland, TX)	80 percent (staged)	School, overhead
2011 Oregon(7)	3 (Bend, OR)	74 to 83 percent (staged)	Two sites had 45 mi/h posted speed limit
2013 California(8)	2 (Santa Monica, CA)	See table 182	Two sites where the RRFB and CRFB were alternately used. Data available for a third observation period where back plates were changed
2013 Calgary(9)	6 (Calgary, AB)	98 percent (staged)	Before installing RRFB, the yielding was 83 percent—type of before treatment not provided
2014 Michigan(10)	1 (South Lyon Township, MI)	69 percent (staged)	Comparison with no signs (20 percent), gateway in-street signs (80 percent), combination of gateway and RRFB (85 percent)
2014 Texas(11,12)	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): RRFB: 22 to 98 percent CRFB: 36 to 95 percent	Study compared yielding with beacons with circular and rectangular shapes
		Nighttime (staged): RRFB: 53 to 95 percent CRFB: 52 to 89 percent	Data were collected at night.

[a] Range provided shows the average driver yielding for the sites included in the study as reported by the authors. See study reference for details regarding study methodology and whether the findings are significant.
[b] Staged pedestrian was used to collect the data.
[c] Findings reported for when the device was activated (i.e., pedestrian pushed the pushbutton).

Table 182. Findings for 2013 Santa Monica, CA study.(8)

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

[a] Staged pedestrian was used to collect the data.
[b] Findings reported for when the device was activated (i.e., pedestrian pushed the pushbutton).

In a review of a nationwide sample of crash data for all crash severity levels from GES, the database includes 10,079 crashes involving a pedestrian from 2005 to 2009, inclusive. Nearly half of the pedestrian crashes occurred at midblock locations. However, only 2.5 percent of the midblock pedestrian crashes were explicitly identified as midblock crossing crashes.

HSIS data for California include crash data only for the State highway system, consisting of approximately 15,520 mi of highways. Data analyzed for this report included the years from 2006 to 2008, inclusive. During the study period, 3,944 pedestrian crashes occurred on the California State highway system. Nearly 70 percent of the pedestrian crashes occurred at midblock locations. Only 2.6 percent of the midblock crashes were classified as occurring at midblock crosswalks.

HSIS data for Minnesota crash data include nearly all crashes statewide; including both State-maintained and local-agency-maintained road systems. Data analyzed for this report included the years 2003 to 2007, inclusive. During the study period, 8,271 pedestrian crashes occurred in Minnesota. Approximately 29 percent of the pedestrian crashes occurred at midblock locations. Only 3.0 percent of the midblock crashes were classified as occurring at midblock crosswalks.

HSIS data for North Carolina include crash data for approximately 62,000 mi of the 77,000 mi of roadway on the State-maintained highway system. Data analyzed for this report included the years from 2005 to 2008, inclusive. During the study period, 3,847 pedestrian crashes occurred on the North Carolina State highway system. Nearly 85 percent of these pedestrian crashes occurred at midblock locations. Only 2.7 percent of the midblock crashes were classified as occurring at midblock crosswalks.

HSIS data for Ohio include crash data only for the State highway system, consisting of approximately 19,500 mi of highways. Data analyzed for this report included the years from 2005 to 2008, inclusive. During the study period, 4,127 pedestrian crashes occurred on the Ohio State highway system. Approximately 45 percent of these pedestrian crashes occurred at midblock locations. Only 1.2 percent of the midblock crashes were classified as occurring at midblock crosswalks.

Data for Texas include crash data for both on and off the State highway system. Data analyzed for this report included the years 2003 to 2009, inclusive. During the study period, 3,134,365 crashes were included in the Texas crash database. Of these, 39,993 (1.3 percent) were pedestrian crashes. Nearly 50 percent of the pedestrian crashes occurred at midblock locations. Only 136 crashes (0.7 percent of the midblock crashes) were classified as occurring at midblock crosswalks.

HSIS data for Washington include crash data only for the State highway system, consisting of approximately 7,193 mi of highways. Data analyzed for this report included the years from 2005 to 2008, inclusive. During the study period, 1,573 pedestrian crashes occurred on the Washington State highway system. Nearly 40 percent of these pedestrian crashes occurred at midblock locations. Only 5.0 percent of the midblock crashes were classified as occurring at midblock crosswalks.

Local Field Observations

The research team made observations at selected midblock pedestrian crossings with a range of traffic control treatments. Ten midblock pedestrian crossings in 5 States were observed, including sites in 8 different cities. These observations were intended as a source of ideas about how particular crossing types could potentially be evaluated later in the study. The crossings observed were not selected as candidates for evaluation; indeed, many of the observed locations had already been treated in particular ways. The observation periods were typically brief (15 to 30 min), and insights and assessments gained from these observations, by intention, should be regarded as anecdotal rather than definitive.

The limited field observations indicated that the inclusion of flashing lights on pedestrian crosswalk signs rather than just in the pavement surface appeared to substantially increase driver compliance with the law requiring yielding to pedestrians.

Selection of Studies for Phase II

The research team used the information gathered during the literature review and the crash evaluation and combined it with information provided by members of the Technical Advisory Panel to generate a list of five proposed crossing countermeasures that could be evaluated in phase II of this FHWA project. The final selection of the phase II studies was made by the panel and representatives of FHWA during a face-to-face panel meeting and a later conference call. Refinements were made to the study plans during follow-on telephone calls with the panel and FHWA. The following two phase II studies were selected:

- Closed-course study with the following goal: identify the impacts of beacon shape, size, and placement on object detection in a closed-course setting.
- Open-road study with the following goal: identify driver yielding behavior to installed assemblies identified at the conclusion of the closed-course study.

SUMMARY AND CONCLUSIONS FROM CLOSED-COURSE STUDY

Traffic control options for a pedestrian crossing include numerous combinations of signs and flashing beacons/LEDs. To investigate the influence of beacon characteristics on drivers, participants drove on a closed course at the Texas A&M Riverside campus. During each lap, the participants viewed 8 study assemblies, 9 distractor signs, and up to 11 objects. The types of objects were a pedestrian (dressed in blue scrubs), a trash can, and a small gray box. The study assemblies included the following:

- Two circular 12-inch beacons located above the sign (named C-A12 in the study).
- Two circular 12-inch beacons located below the sign (C-B12).
- Two circular 8-inch beacons located below the sign (C-B8).
- One circular 12-inch beacon located above the sign and one circular 12-inch beacon located below the sign (C-V12).
- Two rectangular beacons located above the sign (R-A).
- Two rectangular beacons located below the sign (R-B), the format currently being used for the RRFB device.

- Sign with LEDs embedded into the border (LED).

- Diamond-shaped sign with no beacons or LEDs (WO-B).

Specific research objectives for this closed-course study were the following:

- Determine whether the shape, size, and placement of flashing beacon/LEDs affect the following:

    - Sign legibility and symbol identification distances.
    - Object detection.

- Determine driver ratings of disability glare for 8-inch circular beacons and LED-embedded signs using a rapid flash pattern.

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

Driving Portion

Each participant drove the course twice with a pause between laps for the field crew to switch the signs and objects for the second lap. 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 do the following:

- See warning lights.
- See road signs.
- Read the words or identify the symbol on the road signs.
- See objects.

As soon as the driver said "lights," "sign," "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 detection. Each sign on the course had two to three marks in the data file: one for detection distance of the sign, one for legibility distance, and (if lights were included on the sign or sign assembly) one for detection distance of the lights. Each object had one mark in the file.

Discomfort Glare Portion

At the beginning of the discomfort glare study, researchers asked the participants to park 250 ft away from sign 1. After the participant parked the vehicle, researchers turned on the beacon and asked the participant to indicate whether the brightness of the light was comfortable, irritating, or unbearable, which were defined as follows:

- Comfortable—when the glare is not annoying and the device is easy to look at.

- Irritating—when the glare is uncomfortable; however, the participant is still able to look at it without the urge to look away.

- Unbearable—when 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 controller setting to level two. This process continued until the participant indicated the brightness was unbearable or the technician reached level six on the controller, 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.

Participants

The study recruited a group of 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, 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 was sought. These divisions resulted in 16 participant categories. The research goal was to have 4 participants in each of the 16 categories, resulting in 64 participants. The study included 71 participants because participants were added to 1) replace participants whose data were not recorded successfully and 2) provide additional data to offset missing data points not collected because signs were temporarily disabled or objects were not appropriately placed.

Results

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 with each having six different levels of intensity.

Key Findings Regarding Legibility Distance

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

- As expected, 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. Finding age to be significant indicates future studies need to consider older participants.

- The type of assembly was significant at night and nearly not significant during the day. This indicates that the effects of the beacons/LEDs on reading the message on the sign are more influential during nighttime conditions, an expected finding.

Key Findings Regarding Object Detection Distance

For the analysis focusing on object detection distance, which is the distance between the object and the participant when the participant said “ped,” “can,” or “box,” results indicated the following:

- As expected, there is a significant difference between day and night object detection distances. For example, the daytime detection distance to a pedestrian was on average 911 ft with a standard deviation of 539 ft. During the night, the pedestrian detection distance had very different statistics: mean distance of 116 ft and standard deviation of 93 ft.

- Similar to legibility distance, there was a statistically significant difference owing to age during the daytime; surprisingly, the same finding did not occur at night. The nighttime condition seems to impede detection to a point that the effects of several variables are 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 the R-B than with the C-B12, C-B8, or the R-A (statistically significant). During the nighttime, the detection distance to an object was shorter with the R-B than with the C-B12 (statistically significant). These findings indicate that characteristics of the R-B, such as the light intensity or the location of the beacon beneath the sign, might negatively affect a 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, the results indicate the following:

- As expected, 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, 1 in 23 pedestrians/trash cans were missed while at night 1 in 5 pedestrians/trash cans were missed.

- 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 the brightness of the lights from the beacons/LEDS is comfortable decreases as brightness increases, and the percentage of participants indicating the discomfort glare is unbearable increases as brightness increases.

The discomfort glare data indicate agencies should focus on meeting minimum intensity and place less emphasis on obtaining the brightest devices possible. When devices have intensities and optical powers close to the SAE minima, the probability of unbearable discomfort glare is less than 1 percent.

SUMMARY AND CONCLUSIONS FROM OPEN-ROAD STUDY

The open-road study was conducted to investigate 1) whether drivers yield differently to circular or rectangular beacons when used with a rapid-flashing pattern, 2) 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 3) whether vehicle traffic volume affects driver yielding.

Both rectangular beacons and circular beacons were installed at 12 sites located in 4 cities (Milwaukee, WI; Flagstaff, AZ; Austin, TX; and College Station, TX). At 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 if 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, random effect for rotation order, and the beacon shape variable.(11,12) An indicator variable for nighttime conditions was included in the final model to determine whether nighttime results were significantly different from daytime results. The preliminary review of the findings (average daytime yielding was 63 percent for CRFBs and 59 percent for RRFBs) indicates only minor, if any, differences between the CRFB and the RRFB. The results from the GLMM further revealed that there were no significant differences between the two beacon shapes (*p*-value =0.4717). For a subset of the sites, the brightness of the beacons was measured. For those sites, there is clear 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

An analysis was also conducted to determine the extent to which the presence of an actively flashing beacon influences driver yielding. Driver yielding rates were compared between pedestrian crossings when a beacon was activated and pedestrian crossings when a beacon was not activated. The analysis included RRFBs and CRFBs, staged pedestrians and nonstaged pedestrians, and daytime study periods. The results of the analysis concluded that a driver is 3.68 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 analysis focused on a 1-min vehicle count. To estimate the traffic volume present when a particular pedestrian was attempting to cross, 1-min traffic volume counts were obtained from the videos for a sample of the daytime data collection periods at RRFB sites. The 5-min period nearest to when the pedestrian was crossing was averaged. 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.

Results

In conclusion, traffic volume and the shape of a yellow rapid-flashing beacon do not have an impact on whether a driver yields to a pedestrian. However, while the shape of a beacon does not influence driver yielding, a driver is more than three 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 study).

DISCUSSION

The STC of the NCUTCD is interested in research findings that could assist in crafting language regarding this device that would result in material suitably generic for the MUTCD. For example, as studied in this research project, do the beacons need to be rectangular or could they be circular?

In this study, the presence of beacons or LEDs was associated with shorter nighttime sign legibility distances. One interpretation of this finding could be to question the use of beacons because they affect the ability of a driver to read a sign. Even if flashing beacons limit the ability to read a sign, their presence can warn drivers to take additional care at the location. The presence of a yellow flashing beacon communicates warning to a driver and, perhaps, the need to look for unexpected entries onto the roadway. Unfortunately, the extensive and continuous use of the flashing yellow beacon on roadways might not effectively communicate to drivers the needed action of slowing down or searching for a potential roadway entry. The use of a specific flash pattern, however, could offset some of these concerns.

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 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 hazards located near the glare source. The profession needs to identify maximum brightness for RRFBs. The profession also needs guidance on whether to dim these devices during low light conditions, and if so, by how much.

A part of the effort to set brightness levels is the need to investigate how best to measure the brightness of a flashing device. Peak intensity is not the only measure of brightness, and in some instances, it might not be the best measure of brightness. How to measure the impacts of different flash patterns that have unequal bright and dark periods must be considered.

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 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 considered.

The closed-course study also found that when grouping the beacons by shape (i.e., rectangular versus circular), there was no significant difference in object detection accuracy. Therefore, both beacon shapes were selected for study in the open-road portion of the project, and results indicated that there are no significant differences in driver yielding between the two beacon shapes. With the finding from the open-road study that the shape of the yellow rapid-flashing beacon does not affect a driver's decision to yield, agencies could have the flexibility to use either shape with their pedestrian treatment installations, assuming that the appropriate language is included in the MUTCD. Another interpretation is that with both shapes having similar yielding, one shape should be selected and specified in the MUTCD to promote pedestrian treatment consistency.

In the open-road portion of this FHWA study, the brightness of devices installed in the field was also measured. The brightness of LEDs in the field appears to be highly variable; part of the reason could be that current requirements only specify a minimum intensity.

FUTURE RESEARCH NEEDS

In this section, a pedestrian rapid-flashing beacon assembly is assumed to consist of a Pedestrian Crossing (W11-2) or School Crossing (S1-1) sign and a pair of beacons (whether rectangular or circular) that flash in a rapid pattern. The rapid pattern could either be the 2-5 pattern, or the now preferred WW+S pattern as discussed in Official Interpretation #4(09)-41 (I)—Additional Flash Pattern for RRFBs.(43) The rapid-flashing beacon assembly can be located either roadside or overhead.

Based on the research conducted as part of this study, along with discussions held at professional society meetings and with other practitioners, additional research questions regarding rapid-flashing beacons used at pedestrian crossings are discussed in the following sections.

Appropriate Use of Rapid-Flashing Beacon Assemblies on Only One Side of the Roadway Approach

The original Interim Approval for the RRFB requires the following for assembly location:

> For any approach on which RRFBs are used, two W11-2 or S1-1 crossing warning signs (each with RRFB and W16-7P plaque) shall be installed at the crosswalk, one on the right-hand side of the roadway and one on the left-hand side of the roadway.

> On a divided highway, the left-hand side assembly should be installed on the median, if practical, rather than on the far left side of the highway."(1)

There may be street widths where having two assemblies provides limited benefits. If so, the additional cost savings in purchasing and maintaining fewer devices at a site could provide additional resources to treat other locations.

When Rapid-Flashing Beacons Should Be Dimmed, and by How Much

The profession needs guidance on whether to dim these devices during low light conditions, and if so, by how much. A study of disability glare and discomfort glare in both bright and dark conditions can be used to determine appropriate maximum nighttime and daytime brightness for rapid-flashing beacons. The investigation into brightness levels should consider an open-road portion to be able to associate different motorist yielding behavior with the different brightness levels.

Appropriate Brightness Level of Rapid-Flashing Beacons

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. When the discomfort glare is unbearable, drivers are more likely to divert their eyes away from the discomfort, which might result in drivers missing people or objects located near the glare source. The results of this study indicate the profession might want to consider a maximum brightness for beacons used with pedestrian crossing signs—and the maximum brightness should vary between daytime and nighttime conditions.

Appropriate Installation of Rapid-Flashing Beacon Assemblies Overhead Rather Than on the Roadside

FHWA issued an interpretation in 2009 that indicated overhead mounting is appropriate and that, if overhead mounting is used, a minimum of only one sign per approach is required and it should be located over the approximate center of the lanes of the approach.(13) The catalyst for this interpretation was a concern that a frequent bus presence at a near-side bus stop would unacceptably obscure approaching road users' view of the Pedestrian Crossing (W11-2) signs mounted at the normal roadside locations.

When Garland, TX, installed several RRFBs on multilane undivided roadways, city staff were concerned that the left-side roadside assembly would be outside the driver's cone of vision or it could easily be obscured by a truck traveling in the opposite direction. Medians on divided roadways provide a location for a left-side beacon installation adjacent to traffic approaching the crosswalk, but roadways with narrow or no medians do not. Therefore, at crosswalks located on undivided roadways (e.g., four lanes and a TWLTL, multilane one-way roads) or roadways with a median less than 4 ft wide, Garland installed RRFBs and School Crossing signs on a mast arm over the roadway. Garland also decided to supplement its overhead installation with roadside installations as illustrated in figure 2.

Presence of buses and street width are two examples of site conditions where the rapid-flashing beacon could be installed overhead rather than roadside, but there might be other criteria that should be considered when making this decision. In addition to identifying the applicable criteria, developing numeric guidance for these criteria is also needed (e.g., at what roadway width should overhead rather than roadside installation be considered). The guidance might also need to consider additional variables beyond primary characteristics such as roadway width. For example, if the sidewalks at the site are adjacent to the face of curb, then the roadside assembly might need to be located more than 5 ft from the curb, which would place the assembly beyond the driver's cone of vision. Additional research is needed to investigate these questions.

Guidance on Selection of Appropriate Pedestrian Crossing Treatment for a Particular Location

In general, the pedestrian hybrid beacon has higher yielding rates but costs more than rapid-flashing beacon assembly. The rapid-flashing beacon is more effective than many other pedestrian treatments; however, a Texas study found lower compliance for the RRFB for longer crossing distances.(11) This finding indicates that there is a crossing distance width for which a device other than the RRFB should be considered. The dataset included sites with total crossing distances that ranged between 38 and 120 ft.

A research study with an objective of developing guidelines for selecting appropriate pedestrian crossing treatments would help to improve uniformity across the country. The study would also need to identify the site conditions that should be considered (e.g., roadway volume, pedestrian volume, crossing distance, posted speed limit, typical pedestrian walking speed at the site, and/or others). It could start with the methodology developed as part of NCHRP 562/Transit Cooperative Research Program (TCRP) 112, which uses pedestrian delay to make the determination of whether to recommend a device with a red indication (e.g., pedestrian hybrid beacon), a yellow indication (i.e., an active device such as a rapid-flashing beacon), or a crosswalk.(44) The method also includes a step to determine whether a traffic control signal is warranted. Figure 102 shows an illustration of a graph that can be generated from the NCHRP 562/TCRP 112 methodology using an assumed crossing distance and other variables. The user would then use the major road volume and the pedestrian volume to determine the appropriate type of pedestrian treatment for the site. The graph in figure 102 is out of date because the research was done prior to the 2009 MUTCD change in the pedestrian signal warrant, but the concept is applicable.

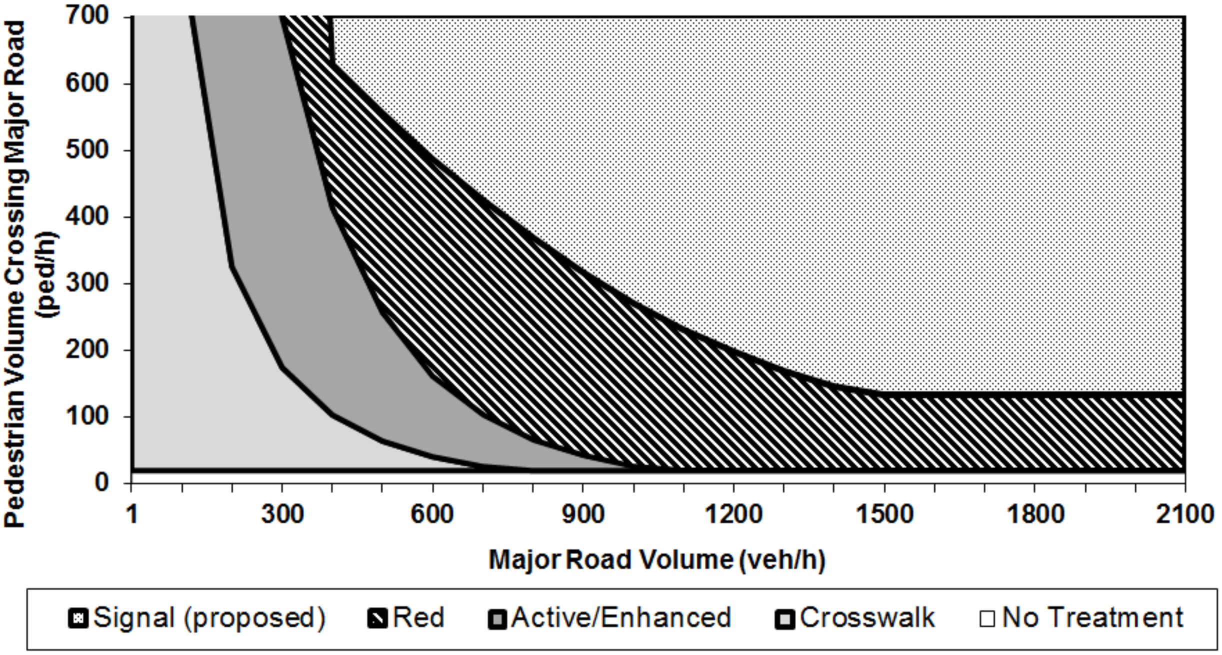


Figure 102. Graph. Example of a graph generated from NCHRP 562/TCRP 112 methodology (function of walking speed, crossing distance, and other variables) that could be used to determine pedestrian treatment.(44)

National Education Campaign on the Rapid-Flashing Beacon

What education campaigns have been used by cities and jurisdictions that have implemented rapid-flashing beacons? Were they successful? Are there common themes that could be used on a national level? The campaigns could also include other considerations of pedestrian behaviors such as the need to activate the pushbutton, cautions against distracted walking, walking during nighttime conditions, blind spots around commercial vehicles, and others. Education campaigns could be directed toward drivers, pedestrians, or both.

Minimum Number of Pedestrians to Warrant a Pedestrian Treatment

There is a growing use of the pedestrian hybrid beacon and the RRFB for pedestrian crossings. Establishing guidance that can be consistently applied would help to facilitate use of these devices in appropriate settings. A particular question is whether there is a minimum number of pedestrians before a device should be considered. The MUTCD contains graphs that illustrate when to consider a pedestrian hybrid beacon, and these graphs include a minimum of 20 pedestrians per h.(2) When deciding to recommend this minimum pedestrian number, the National Committee based its decision on a value developed through engineering judgment during an FHWA study on whether to mark crosswalks.(45)

Research is needed to more fully consider what should be the minimum pedestrian value used for selecting various traffic control devices. For example, should this minimum number be a function of crossing distance or posted speed limit? In addition, should it consider the distance to the nearest crossing? A location that is only a few hundred feet from an established crossing should have a higher minimum number compared with a crossing that is more than 0.25 or 0.5 mi from a signal on a wide high-speed arterial.

Number of Pedestrians Induced as a Result of Installation of Selected Pedestrian Treatments

The primary objective of this study would be to determine reasonable values for estimates of induced pedestrian crossing maneuvers (i.e., estimated number of pedestrians that would now use the site because of the installation of a specific pedestrian treatment). The results of the research could improve the process for selecting pedestrian treatments. The research should make appropriate suggestions for changes to key reference documents, such as design manuals or the MUTCD. Improved guidance should help to improve conditions for pedestrians by identifying appropriate devices for crossings, which should improve pedestrian mobility and reduce the number of pedestrian crashes.

Drivers' Search Patterns Near Flashing Beacons

There was also evidence in this study that the closed-course drivers were more accurate in seeing objects beyond the signs with flashing beacons compared with seeing objects beyond the distractor signs. This could be an artifact of this study or it could be because the flashing beacons attracted the eye to the area. Additional research could focus on drivers' search patterns when a flashing beacon is present to test the theory that the presence of the beacons or LEDs encourages drivers to search a particular area. By varying the brightness of the beacons along with the light source (e.g., beacons or LED-embedded signs), the study could also investigate whether drivers need additional time to search an area because of the brightness of the device.

Pedestrians' Attitude Toward Using Treatments

Observations of pedestrians in the open-road portion of this study (and in other studies) have documented crossing pedestrians that did not activate the beacon when it was provided. Some of those pedestrians were jaywalking and were not within the treated crosswalk to be able to use the beacon, while others crossed at the crosswalk but chose not to activate the beacon. This study would explore pedestrian decision-making and examine why pedestrians who have the opportunity to use a treatment (such as a rapid-flashing beacon) to support their crossing choose not to do so. For example, at crosswalks marked as school crossings, do adult pedestrians think that the treatment is for use only by schoolchildren? Results from this study could feed into the suggested educational campaign mentioned previously, and results could also be used to support guidance on where treatments should be installed and what information (e.g., instructional plaques next to the pushbutton) should be provided to crossing pedestrians.

Influence of Traffic Volume on Driver Yielding

In this research, an analysis was conducted using RRFB sites to evaluate the relationship between traffic volume and driver yielding rate. While the plot in figure 101 suggests that the percentage of driver yielding might decrease as volume increases, that relationship was not statistically significant. In other words, there was not enough evidence to conclude that traffic volume influences driver yielding behavior at sites with RRFBs in a positive or negative direction. However, the percentage of driver yielding varied substantially between cities, and this city-to-city variability might have had a stronger influence on the model than traffic volume. Additional research with larger sample sizes and/or additional cities is needed to look at the relationship between traffic volume and driver yielding more closely.

Estimating Pedestrian Exposure

With average daily vehicle traffic being the key predictor of vehicle crashes, there is a desire to have similar types of data for pedestrians. With limited resources for collecting counts—vehicle, bicycles, or pedestrians—what are the most effective means for obtaining pedestrian exposure?

APPENDIX: PEDESTRIAN TREATMENTS

A variety of engineering (e.g., geometric design, traffic control device) treatments are available with the potential of improving safety at pedestrian crossings. Research studies have been conducted across the United States and in a number of other countries to understand better the effects of these treatments. This appendix contains summaries of a selection of treatments, along with reported results on their effectiveness. The list of treatments considered for this report is provided in table 183.

Table 183. Pedestrian treatments for unsignalized locations.

Treatment	Included in this appendix?	CMF available?
Advance stop or yield line and sign	Yes	None
Barrier—median	Yes	None
Barrier—roadside/sidewalk (railing or fencing)	Yes	None
Bus stop location	Yes	None
Circular beacons	Yes	None
Crosswalk marking patterns	Yes	None
Curb extensions	Yes	None
Flags (pedestrian crossing)	Yes	None
Illumination	Yes	Yes[a,b]
In-roadway warning lights	Yes	None
In-street pedestrian crossing signs	Yes	None
Marked crosswalk	Yes	Yes[b]
Motorist warning signs	Yes	None
Overpasses and underpasses	Yes	None
Pedestrian hybrid beacon (PHB) (also known as HAWK)	Yes	Yes[b]
Puffin crossing	Yes	Yes[b]
Raised crosswalks	Yes	Yes[b]
Rectangular rapid flashing beacon (RRFB)	No—see chapter 2	None
Refuge island	Yes	None
Road diet	Yes	None
Sidewalks	Yes	None
Zigzag lines	Yes	None
Leading pedestrian interval	No—signal treatment	Yes[b]
No right turn on red	No—signal treatment	Yes[a,b]
Pedestrian countdown	No—signal treatment	Yes[b]
Pedestrian scramble	No—signal treatment	Yes[b]
Signal	No—signal treatment	None

[a] Highway Safety Manual.(46)
[b] FHWA CMF Clearinghouse.(47)
Puffin = Pedestrian User-Friendly Intelligent.
CMF = Crash Modification Factor.

ADVANCE STOP OR YIELD LINE AND SIGN

Advance yield lines (i.e., pavement markings) place the traditional stop or yield line 30 to 50 ft upstream of the crosswalk and are often accompanied by YIELD HERE TO PEDESTRIAN signs. Advance yield lines address the issue of multiple-threat crashes on multilane roadways, where one vehicle stops for a pedestrian in the crosswalk but inadvertently screens the pedestrian from the view of vehicles in other lanes. Several studies have documented that advance yield lines decrease pedestrian–vehicle conflicts and increase driver yielding at greater distances from the crosswalk. (See references 48 through 51.)

Studies by Van Houten and others have demonstrated the effectiveness of advance yield lines and YIELD HERE TO PEDESTRIAN signs.(49,50,51) This research found a marked reduction in motor vehicle–pedestrian conflicts and an increase in motorists yielding to pedestrians at multilane crosswalks with an uncontrolled approach. These results have been documented at crosswalks with and without amber flashing beacons. Van Houten and Malenfant also demonstrated that the markings and sign together were more effective than the sign alone.(50) In a 2001 study by Van Houten et al., advance yield lines and YIELD HERE TO PEDESTRIAN signs were shown to reduce vehicle–pedestrian conflicts by 67 to 87 percent.(51) The study also found a large increase in the distance at which motorists yielded to pedestrians. These evaluation results were further replicated at 24 additional study sites located in Canada.(52) Results showed that the advance yield sign and advance yield markings reduced the percentage of motor vehicle–pedestrian conflicts involving evasive action and increased the percentage of motorists yielding to pedestrians and yielding further back from the crosswalk line. Treatments were applied only to streets posted at 30 mi/h.

A 2011 paper reported on the installation of advance yield markings with a YIELD HERE TO PEDESTRIAN sign at two midblock locations in Las Vegas.(53) Results indicated that there was an increase in the proportion of drivers yielding to pedestrians at the location with a five-lane cross section, an ADT of 17,100 vehicles/day, and a posted speed limit of 35 mi/h. The increase in driver yielding was not statistically significant at the location with seven-lane cross section, an ADT of 43,000 vehicles/day, and a posted speed limit of 30 mi/h.

BARRIER—MEDIAN

Placing a barrier in a median is a pedestrian crossing treatment discussed in a review of pedestrian safety research by Campbell et al.(54) The purpose of barriers in the median is to discourage pedestrians from crossing at undesirable locations and encourage them to cross at a crosswalk. As part of a larger test of various pedestrian countermeasures, median fence barriers were installed at two sites: one in Washington, DC, with a 4-ft fence, and one in New York City, with a 6-ft fence.(55) The median fence barrier at one site consisted of two gaps, each located at an intersecting minor street. After installation of the barrier, researchers interviewed pedestrians to gauge their reactions to the treatment. Regarding crosswalk use, a reported 61 percent of the pedestrians identified the barrier as the reason for using the crosswalk. When asked whether the barrier affected the manner in which they crossed the street, 52 percent stated it had no effect, while 48 percent indicated the only effect was to force them to cross at the intersection. Of those who were crossing midblock before the installation, 61 percent did so out of convenience, and about one-third indicated they would use the crosswalk only if midblock traffic volumes were "very heavy." After the fence was installed, 32 percent of the 22 pedestrians interviewed who previously made midblock crossings stated inconvenience as the major factor, with high turning volume at the intersection as a close second (23 percent). In particular, older pedestrians were generally concerned with turning traffic at intersections, and many cited recent crash experience as a concern. Almost one-quarter of those interviewed indicated they had walked along the median to the end of the barrier, or an opening, before completing the crossing. While merchants at a control site indicated they did not anticipate much effect from a median barrier, 58 percent of those at the experimental sites indicated that its major effect was to discourage customers from shopping both sides of the street. Most residents accepted the barrier, only 7 percent wanted it removed, and a few complained about inconvenience and unsightly appearance.

BARRIER—ROADSIDE/SIDEWALK

A recent FHWA International Scan found that pedestrian railings were common in the United Kingdom, where they were used to direct pedestrian movements to preferred crossing locations at intersections and in median islands.(56) They also offered a useful guide to pedestrians with visual disabilities. The railings appeared to be most common in areas with high pedestrian traffic.

Campbell et al. discuss several studies in which chains, fences, guardrails, and other similar devices were proposed as a means of channelizing and protecting pedestrians. (See references 54 and 57 through 60.) Parking meter post barriers were tested at three urban areas sites.(55) All of the tests used chains that connected parking meter posts. The barrier was 3 ft high and incorporated as many as three chains. In Washington, DC, six parking meter post barriers were created on one side of a street, resulting in a series of 12-ft single chain sections. In New York City, 19 posts were used, 9 on one side of the street and 10 on the other. These were 12-ft sections with two chains. The third site was a section of one-way street along which three-chain sections were installed on eight posts. Results of the study were mixed, in part because of vandalism (i.e., stolen chains) that interfered with the experiment. Twenty-six percent of those interviewed who crossed at the intersections after the installation mentioned that a factor in their choice of crossing location was that it was illegal to cross elsewhere. Because only 12 percent of those interviewed had mentioned this before the change, the authors surmised that the barriers may have reminded pedestrians that it was illegal to jaywalk. While 65 percent of merchants perceived no negative effects from the countermeasure, 15 percent noted that the chains interfered with street crossings, and 18 percent cited a problem when loading or unloading goods.

In London, research was conducted on an 1,800-ft road segment with pedestrian barriers on both sides. Access openings on each side of the road were not located directly across from each other.(54,61) Researchers mapped pedestrian crossing movements and compiled crash data from the site. Crashes during the previous 8 years were shown as a ratio to a 4-hr pedestrian volume, which was fewer than 20,000 people. The resulting risk ratio was compared with that for 11 other sites in London that did not have pedestrian barriers. The only significant difference in risk ratio occurred at midblock crossings located within 150 ft of a signalized intersection (these locations had more than twice the risk ratio with the pedestrian barrier) and at other midblock locations within 60 ft of an intersection (where controlled crossings were not present and had approximately 10 times the risk ratio). The overall risk ratio was lower at the test site but was not found to be statistically significant. Researchers also studied the longitudinal path taken by each pedestrian; this path was the distance between barrier openings used to get on and off the roadway, measured parallel to the curb. The results indicated most pedestrians would cross outside of the crosswalk when the longitudinal distance between barrier openings on either side of the street was less than 30 ft. The author suggested that longitudinal distances between the openings on opposite sides of a street should be greater than 30 ft.

Pedestrian barrier fences were installed along 18 sections of roadway in Tokyo.(62) Analysis of crashes before and after the installation revealed that crashes related to crossing pedestrians declined by nearly 20 percent. Researchers observed an overall reduction of 4 percent, including non-pedestrian crashes. It had been thought that even though crashes related to pedestrians crossing out of crosswalks might decrease, crashes related to pedestrians crossing in the crosswalks might increase. However, the results indicated that both types of pedestrian collisions were reduced by an equal percentage.

BUS STOP LOCATION

TCRP Report 125: Guidebook for Mitigating Fixed-Route Bus-and-Pedestrian Collisions provides information on pedestrian–bus crashes and countermeasures and strategies for reducing these crashes.(63) Lack of pedestrian-friendly environments was noted as one of the factors. This includes sidewalk conditions such as broken and uneven sidewalks, narrow sidewalks, sidewalk obstacles, and lack of sidewalks or other positive separation. Lack of lighting was another concern noted.

According to Campbell et al., 2 percent of all pedestrian collisions in urban areas can be classified as pedestrian collisions at bus stops.(54) Most do not involve a pedestrian being struck by a bus, but the bus creates a visual screen between approaching drivers and pedestrians crossing in front of the bus. In rural areas, pedestrian crashes related to school bus stops were identified in 3 percent of all pedestrian crashes. A countermeasure proposed for urban crashes involved relocating bus stops to the far side of intersections to encourage pedestrians to cross behind rather than in front of the bus. This allows the pedestrian to be seen and to see oncoming traffic closest to the bus. To determine the effect of such relocation on pedestrian crossing behavior, two before–after studies evaluated bus stop relocations. One site in Miami, FL, was located on a two-way, four-lane street intersecting with a two-way, two-lane street at an unsignalized location. The other site was located in San Diego, CA, on a two-way, four-lane street intersecting with a one-way, three-lane street at a signalized intersection with pedestrian signals.(54,55) The relocation of the bus stops to the far side eliminated the undesired crossing behavior; previously, half of the riders crossing the street after disembarking crossed in front of the bus.

An analysis of pedestrian crashes in Sweden found school bus stops should be located with greater consideration of pedestrian safety factors.(54,64) Campbell reported that Swedish researchers drew the following conclusions about the location of bus stops:

- Ensure they are not hidden by vegetation or other obstacles.
- Place them away from roadway curves or superelevated locations.
- Provide adequate standing and playing area for the waiting passengers.
- Provide maximum sight distance to all critical elements.

Additional guidance for the location and design of bus stops is provided in TCPR Report 19.(65)

CIRCULAR BEACONS

The use of circular flashing beacons for pedestrian crossings is prevalent in the United States. In some instances, there are concerns that the overuse of flashing beacons or the continuous flashing at specific locations has diluted their effectiveness in warning motorists of a pedestrian crossing. Flashing beacons have been installed in a variety of ways, including the following:

- At the pedestrian crossing, both overhead and side mounted.
- In advance of the pedestrian crossing, both overhead and side mounted.
- In conjunction with or integral within other warning signs.
- In the roadway pavement itself (see section on in-roadway warning lights).

The operations for flashing amber beacons may also vary, including the following:

- Continuous flash mode.
- Pedestrian-activated using manual pushbuttons.
- Passive pedestrian detection using automated sensors (e.g., microwave, video).
- Different flash rates, sequences, or strobe effects.

The experience with flashing beacons has been mixed, as would be expected when they have been installed in numerous ways. Several studies have shown that intermittent (typically activated using a manual pushbutton or automated sensor) flashing beacons provide a more effective response from motorists than continuously flashing beacons.(66,67) These beacons do not flash constantly; thus, when they are flashing, motorists can be reasonably assured that a pedestrian is crossing the street. With pedestrian activation, special signing may be necessary to ensure that pedestrians consistently use the pushbutton activation. Alternatively, automated pedestrian detection has been used with some success but typically requires extra effort in installation and maintenance.

Overhead flashing beacons appear to have the best visibility to motorists, particularly when used both at and in advance of the pedestrian crossing. Many installations have used both overhead and side-mounted beacons. The effectiveness of the flashing beacons in general, however, may be limited on high-speed or high-volume arterial streets. For example, overhead flashing beacons have produced driver yielding behavior that ranges from 30 to 76 percent, with the median values falling in the mid-50 percent range; however, the evaluations did not contain enough information to attribute high or low driver yielding values to specific road characteristics. (See references 48, 66, 67, and 68.) The field studies conducted in a TCRP/NCHRP project (documented in TCRP Report 112/NCHRP Report 562) found a similarly wide range of motorist yielding values (25 to 73 percent), with the average value for all flashing beacons at 58 percent.(44) The analysis of site conditions and traffic variables also found that traffic speeds, traffic volumes, and number of lanes have a statistically significant effect on driver yielding behavior on arterial streets.

Little and Saak evaluated two installations of pedestrian-activated overhead yellow flashing beacons.(69) Both sites consisted of a five-lane cross section and ADTs of either 7,500 or 18,400 vehicles/day. The motorist compliance at the sites was 64 to 65 percent during the day and 68 to 78 percent at night.

Van Winkle and Neal evaluated the use of pedestrian-actuated advance and crosswalk flashers in Chattanooga, TN.(66) The installation of the crosswalk flashers was a compromise solution for a group of senior citizens that demanded a traffic signal so that they could cross a minor arterial street with speed limit of 40 mi/h. City staff conducted a before-and-after study in 1987, with follow-up data collection in 2000. Data were collected on the percentage of drivers yielding or slowing at the pedestrian crosswalk. The original 1987 data showed that driver yielding improved from 11 to 52 percent in the eastbound direction and 6 to 32 percent in the westbound direction. The percentage of drivers yielding at this location has been sustained as a long-term improvement; driver yielding in 2000 was measured to be 55 percent in the eastbound direction and 45 percent in the westbound direction. The authors attribute the success of the flashers to pedestrian actuation. The city of Chattanooga has installed similar flashing crosswalk warning devices at three other locations with what it characterizes as similar results, although no formal studies of their effectiveness have been conducted.

Sparks and Cynecki reported in 1990 on the use of flashing beacons for warning of pedestrian crosswalks in Phoenix, AZ.(70) The city evaluated the application of advance warning flashing beacons at four pedestrian crossing locations. The authors describe the use of several experiments in their evaluation, including before-and-after speed and crash data collection as well as treatment-and-control experiments for traffic speeds. The authors found that the advance warning flashing beacons did not decrease speeds or crashes, and in some cases, the traffic speeds or crashes increased after installation of the flashing beacons. These findings led the authors to conclude the following:

> …[F]lashers offer no benefit for intermittent pedestrian crossings in an urban environment. In addition, the longer the flashers operate the more it becomes part of the scenery and loses any effectiveness.(70) (p. 35)

The authors do concede that actuated warning flashers may be beneficial in a high-speed rural environment with unusual geometrics, high pedestrian crossings, and unfamiliar drivers; however, these conditions were not tested in their study.

CROSSWALK MARKING PATTERNS

In a 2009 FHWA study of crosswalk markings, researchers investigated the relative daytime and nighttime visibility of three crosswalk marking patterns: bar pairs, continental, and transverse lines.(31) In the study, conducted on the campus of Texas A&M University in College Station, TX, information was collected on the distance from the crosswalk at which 78 participant motorists verbally indicated visual recognition of the crosswalk with the different patterns. The participants were about evenly divided in gender between males and females and in age between younger than 55 years old and older than 55.

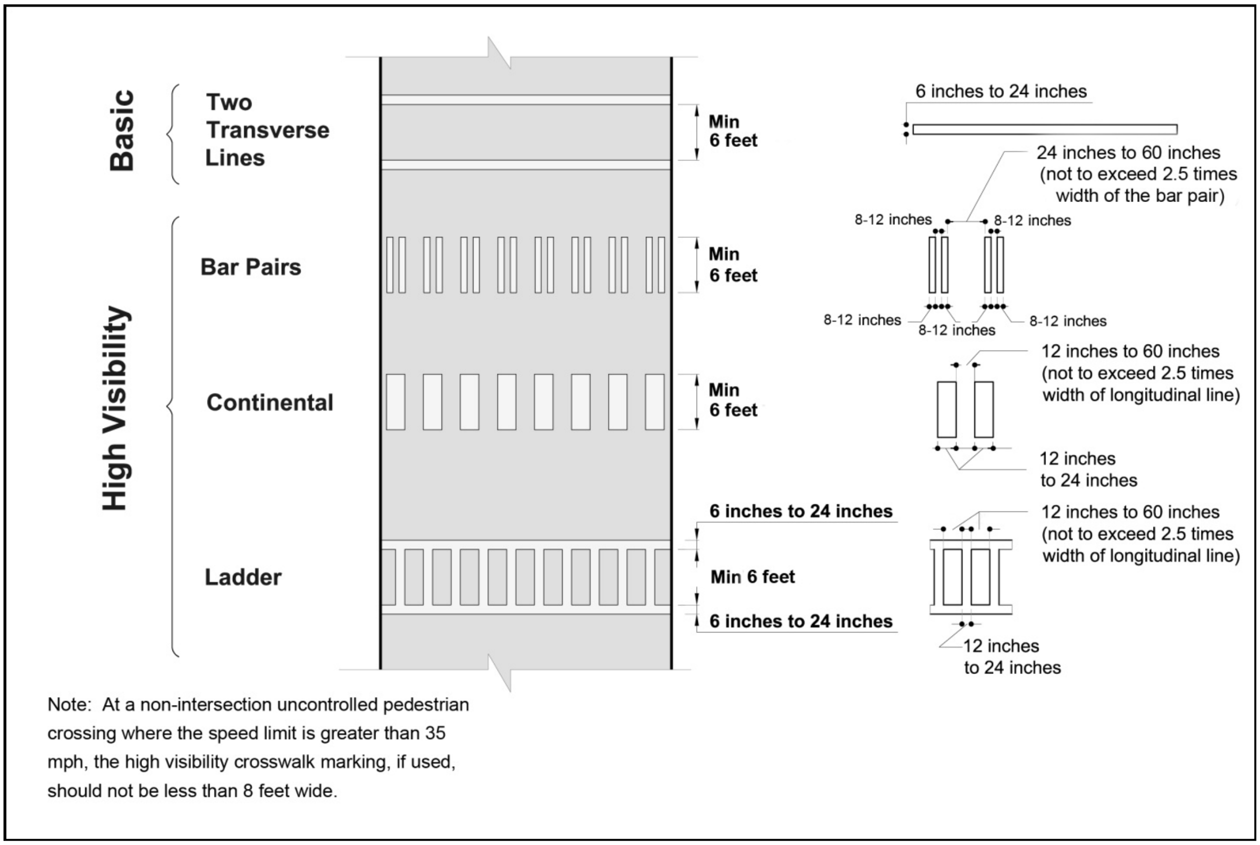
The researchers used instrumented vehicles on a route along open roads on the campus. The research team collected data during two periods: daytime (sunny and clear or partly cloudy) and nighttime (street lighting on). The tests used existing markings (six intersection and two midblock locations) and new markings installed for the study (nine midblock locations).

For the study sites, the findings indicate that the marking type (bar pair, continental, or transverse) was statistically significant. The detection distances to bar pairs and continental markings were statistically similar, and they were statistically longer than the detection distance to the transverse markings, both during the day and at night.

For the existing midblock locations, the drivers detected the continental markings at about twice the distance upstream as the transverse markings during daytime conditions. This increase in distance translates to 8 s of increased awareness of the presence of the crossing at 30-mi/h operating speeds.

The participants also rated the appearance of markings on a letter-grade scale of A to F. The researchers compared those subjective ratings of visibility for all the groups and variables identified in the preceding analysis. The ratings for bar pairs and continental were consistent over various comparison groups, with better ratings for bar pairs and continental markings than for transverse markings. These results mirrored the findings from the evaluation of detection distances. Overall, participants preferred the continental and bar pairs markings over the transverse markings.

The research team worked with the NCUTCD to develop recommendations for incorporating the findings from the study into the MUTCD. The recommendations were endorsed on June 23, 2011. Figure 103 shows the proposed figure for inclusion in the next edition of the MUTCD.



Note: At a non-intersection uncontrolled pedestrian crossing where the speed limit is greater than 35 mph, the high visibility crosswalk marking, if used, should not be less than 8 feet wide.

Figure 103. Diagram. Examples of crosswalk markings (figure proposed to replace existing MUTCD figure 3B-19).[71]

A 2010 paper presented the findings from an empirical Bayes evaluation of high-visibility school (yellow, continental-style) crosswalks in the city of San Francisco, CA.(72) The analysis used data for 54 treated intersections with high-visibility crosswalks and 54 control intersections, each chosen for its geographical proximity to a treated intersection. The study found a statistically significant reduction in crashes of 37 percent for intersections with high-visibility school crosswalks.

CURB EXTENSIONS

The purpose of a curb extension, also known as a choker, curb bulb, or bulbout, is to reduce the width of the vehicle travel way at either an intersection or a midblock pedestrian crossing location. It shortens the street crossing distance for pedestrians, may slow vehicle speeds, and provides pedestrians and motorists with an improved view of one another, thereby reducing the risk of a motor vehicle-pedestrian collision. Campbell et al. identify multiple studies of variations of this treatment in Australia, the Netherlands, and Canada.(54)

In two Australian cities (Keilor, Queensland, and Eltham, Victoria), researchers indicated that "curb blisters" had little effect on reducing vehicle speeds.(54,73) However, in Concord, New South Wales, researchers compared a subarterial street treated with both curb blisters and marked parking lanes to an untreated street; the comparison showed that the crash rate on the treated street was only one-third that of the untreated street. The number of these crashes involving pedestrians was not stated, nor is it known how the streets compared before treatment.

Australia's "wombat" crossings usually consist of a raised platform with a marked crosswalk on top, and a refuge and curb blisters where space permits. Thus, they combine features of both speed tables and bulbouts. They are designed to slow motorists, shorten pedestrian exposure to motor vehicles, and increase pedestrian visibility to motorists. Reports of those studies indicate that wombat crossings have generally reduced 85th percentile vehicle speeds by 40 percent.(54,73)

The Dutch towns of Oosterhout and De Meern installed variations of street-narrowing treatments. The Oosterhout project consisted of installing two bulbouts so as to require motorists to deviate from a straight path. Both the 85th percentile vehicle speed and the degree of pedestrian–motor vehicle conflict fell after the deviation was installed. De Meern's path deviation was created by placing two bulbouts opposite one another to narrow the width of the traveled way. Researchers did not observe a significant reduction in the 85th percentile vehicle speed, and opinions of the treatment were mixed. Residents did not express a strong sense of neighborhood improvement, swerving cars were thought to endanger bicyclists, school teachers thought that children would be confused by the deviation, retailers were concerned about accessibility and parking, and there was some concern about emergency vehicle access.(54,74)

Macbeth reported favorable speed changes seen on five raised and narrowed intersections and seven midblock bulbouts (two raised) in Canada.(54,75) The speed limit was also lowered to 19 mi/h. The results of the speed changes are presented in table 184.

Table 184. Speed changes due to bulbouts.[(54)]

Period	Percent exceeding		
	19 mi/h	25 mi/h	31 mi/h
Before	86	54	13
After	20	3	2

Huang and Cynecki reported in 2001 the effects of bulbouts at various locations to determine their effects on selected pedestrian and motorist behaviors.(76) At four intersections in Cambridge, MA, and Seattle, WA, they found no significant effect on motorists yielding to pedestrians in crosswalks, as shown in table 185.

Table 185. Percentage of motorists yielding to pedestrians at bulbout crosswalks.(76)

Location	Locations	Before[a] (percent)	After[a] (percent)	Significance
Cambridge, MA	2	20.0 (5)	66.7 (6)	Small[b]
Seattle, WA	2	57.9 (342)	52.2 (471)	No[c]

[a] Sample size in parentheses.
[b] Small sample size.
[c] Not significant at 0.10 level.

Huang and Cynecki used a treatment-and-control study approach to evaluate four additional bulbouts in Greensboro, NC, and Richmond, VA. Because of low pedestrian activity in both Greensboro and Richmond, it was necessary to stage pedestrian crossings, using a two-person data collection team. Motorists stopped for fewer than 10 percent of the staged pedestrians in both cities. The differences between the treatment and control sites were not statistically significant at the 0.10 level, as shown in table 186.

Table 186. Percentage of motorists stopping for staged pedestrians at bulbout crosswalks.(76)

Location	Locations	Treatment[a]	Control[a]	Significance
Greensboro, NC	2	5.2 (211)	7.6 (185)	No[b]
Richmond, VA	2	0.0 (66)	0.0 (66)	No[b]

[a] Sample size in parentheses.
[b] Not significant at 0.10 level.

FLAGS

Several cities (e.g., Salt Lake City, UT; Kirkland, WA; Berkeley, CA) use fluorescent orange flags that are carried by crossing pedestrians. The research team found no formal studies in the literature on the effectiveness of crossing flags; however, anecdotal information has indicated that these crossing flags are effective in improving driver yielding behavior. The flags in Salt Lake City are used mostly on streets near the downtown area that have speed limits of 30 mi/h or less. Several of these streets, however, are multilane, high-volume arterials. Field studies conducted in a TCRP/NCHRP project (documented in TCRP Report 112/NCHRP Report 562) found pedestrian crossing flags in Salt Lake City and Kirkland were moderately effective.(44) The study sites with crossing flags had motorist yielding rates that ranged from 46 to 79 percent, with an average of 65 percent compliance. Several of the study sites had four or more lanes with speed limits of 30 mi/h or 35 mi/h.

ILLUMINATION

At certain locations, site characteristics can make a crosswalk difficult for the driver to see at night or in dusk/dawn settings. Trees, shadows, or glare from nearby buildings, and roadway alignment can all affect the ability of approaching drivers to see a crosswalk or pedestrians who use it. Adding illumination can improve the visibility and the safety of such crosswalks. Campbell et al. discuss three studies on illumination in Australia, Israel, and the United States, which are summarized in the following paragraphs.(54)

Pegrum conducted a two-stage study of lighting of pedestrian crossings in Perth, Australia.(54,77) A pilot study showed sufficient success to initiate a broader scale lighting program, in which 63 sites were studied. The illumination consisted of two luminaires (100-watt sodium lamps), one on each side of the roadway at either side of the crosswalk, mounted approximately 12 ft from the crosswalk at a height of 17 ft and aimed at a point 3 ft above the pavement. Campbell states that Pegrum reported the sodium floodlighting resulted in a significant decrease in nighttime pedestrian crashes; a summary of crashes is shown in table 187.

Table 187. Crash effects of providing sodium floodlights at pedestrian crossings in Perth, Australia.(54)

Test	Study Period	Pedestrian crashes (fatalities)			Vehicle-only crashes (fatalities)		
		Day	Night	Total	Day	Night	Total
Pilot Test: 6 crossings	5 years before	19 (1)	7 (1)	26 (2)	5 (0)	1 (0)	6 (0)
	5 years after	21 (1)	2 (0)	23 (1)	9 (0)	0 (0)	9 (0)
Follow-On Test: 57 additional crossings	2 years before	57 (2)	32 (1)	89 (3)	19 (0)	2 (0)	21 (0)
	2 years after	58 (2)	13 (1)	71 (3)	18 (1)	1 (0)	19 (1)

Polus and Katz developed and tested a combined illumination and signing system for pedestrian crosswalks in Israel.(54,78) Reported changes in nighttime crashes at the 99 illuminated study sites and 39 unilluminated control sites are summarized in table 188, which shows a noticeable decrease in nighttime crashes at the study sites compared with increased crashes at the control sites. The authors concluded that crash reductions were primarily the result of the illumination, because daytime crashes were largely unchanged. Campbell also states that the authors studied other possible influences, including changes in pedestrian and vehicle flow, weather differences, and national crash trends, but none showed any effect on the results.

Freedman et al. conducted a study in Philadelphia to assess the impacts of installing improved lighting at seven sites.(54,79) The impacts were evaluated on the basis of behavior as measured for 728 pedestrians and 191 drivers at the 7 study sites and 7 control sites. The researchers reported that the study sites were high-crash locations, while the control sites were low-crash locations. The illumination improvement consisted of 90-watt low-pressure sodium lamps. Each system was controlled by a photocell that energized the circuit at sundown and turned it off at sunrise, with a provision for experimenter override.

Table 188. Effects of crosswalk illumination on nighttime pedestrian crashes in Israel.[54]

Location	Nighttime crashes	
	Before	After
Illuminated Study Sites (99)	28	16
Unilluminated Control Sites (39)	10	16

The Philadelphia evaluation contained a comparison of changes in five pedestrian attributes—search behavior, crossing path, concentration, erratic behavior, and clothing brightness—before and after lighting improvements. According to Campbell's summary of the researchers' report, the comparison showed that "perceived clothing brightness" increased significantly after installing the special illumination.(54) Observers who searched the street in a manner similar to drivers perceived the general appearance of pedestrians as brighter. The researchers also reported significant improvement in the apparent concentration of pedestrians to the crossing task at all signalized locations, and search behavior was found to improve significantly under all conditions. Drivers appeared more aware of approaching crosswalks when the illumination was present. Campbell added a note that changes in the number of crashes at both groups of sites moved toward the mean, consistent with what would be expected because one group consisted of high-crash sites and the other consisted of low-crash sites; however, he reported that the behavioral measures should not have been influenced by regression to the mean.

A recent study in Las Vegas by Nambisan et al, evaluated a midblock crosswalk illumination system with automatic pedestrian detection devices.(80) The "smart lighting" system detected the presence of pedestrians that were using the crosswalk and activated additional lighting during their time within the crosswalk. This strategy was used to address problems related to motorists' failure to yield and the high proportion of nighttime crashes, and it was thought to be more effective in capturing the attention of approaching drivers than the use of continuous high-intensity lighting in the crosswalk.

Using a before-and-after methodology, the researchers studied the results of the "smart lighting" test based on two MOE categories: safety MOEs, including pedestrian and motorist behaviors, and mobility MOEs, consisting of pedestrian and vehicle delay. Results indicated that safety MOEs improved, as shown in table 189 and table 190. The percentage of increase in the diverted pedestrians from the before to the after condition was reported as statistically significant, as was the decrease in the proportion of pedestrians trapped in the roadway and the improvement in motorist yielding behavior.

Table 189. Results for "smart lighting" pedestrian safety MOEs.(80)

Measure of effectiveness	Before (n = 44)		After (n = 84)	
	Number	Percent	Number	Percent
Pedestrians who look for vehicles before beginning to cross	44	100	84	100
Pedestrians who look for vehicles before crossing second half of street	44	100	84	100
Diverted pedestrians	0	0	14	17
Pedestrians trapped in roadway	13	13	12	14

Table 190. Results for "smart lighting" motorist safety MOEs.[80]

Measure of effectiveness		Before (n = 91) Number	Before (n = 91) Percent	After (n = 116) Number	After (n = 116) Percent
Motorists yielding to pedestrians		20	22	41	35
Distance motorist stops/yields before crosswalk (ft)	0–10	8	40	16	39
	10–20	10	50	16	39
	> 20	2	10	9	22

IN-ROADWAY WARNING LIGHTS AT CROSSWALKS

As a specific design case of flashing beacons, in-roadway warning light installations have proliferated since the 1990s. Their use originated in California and Washington State but has spread to numerous other cities in the United States. In-roadway warning lights are mounted in the pavement near the crosswalk markings such that they typically protrude above the pavement less than 0.5 inch. As with flashing beacons, the experience with in-roadway warning lights has been mostly positive but with a few negative results.

Many early and some current equipment designs for the in-roadway warning lights have been problematic. Some of the problems encountered are as follows:

- Snow plows damage the flashing light enclosures.
- Light lenses become dirty from road grit and require regular cleaning.
- Automated pedestrian detection does not operate effectively.

Many of the early problems have been resolved through experience, but some cities continue to be cautious in specifying more in-roadway warning lights until they have long-term experience. Some cities have noted their preference for overhead flashing beacons instead of in-roadway lights because of poor visibility issues when traffic is queued in front of the in-roadway lights.(67,81) Another concern is that in very bright sunlight, the flashing lights are difficult for drivers to see.

In-roadway warning lights have been evaluated in numerous studies with varying results. It appears that the effectiveness of this treatment varies widely depending on the characteristics of the site and existing motorist and pedestrian behavior.

For most of the installations, in-roadway warning lights have increased driver yielding into the 50- to 90-percent range. (See references 68 and 82 through 86.) In addition, the in-roadway warning lights typically increase the distance that motorists first brake for a pedestrian crossing, indicating that motorists recognize the pedestrian crossing and the need to yield sooner. (See reference 82 through 85.) These results have been even more dramatic at night when the in-roadway warning lights are highly visible. For a few installations, driver yielding decreased or did not increase above 35 percent.(68,69,87) The research team did not include in-roadway warning lights in the early 2000 TCRP/NCHRP project's field studies because of the abundance of evaluation results in the literature.(44)

On the walkinginfo.org website, Thomas provided a review of an in-roadway warning light (IRWL) system.(88) Nine studies were identified that provided some evaluation of potential safety effects, all using behavioral MOEs. The following results were noted from the review performed by Thomas(88):

- Short-term improvements in motorist yielding to pedestrians were reported from most sites studied. No improvement or improvement only to low levels was reported for a number of locations, approaches, or study conditions. (See references, 86, 87, 89, and 90.)

- Trends (from two studies) indicated greater improvements at nighttime; however, effects under other sub-optimal visibility conditions, such as rain or fog, have not been clearly studied.(86,91)

- There were inconsistent results (between two studies) on whether IRWL improves yielding to pedestrians in the middle of their crossing.(68,89) This MOE may have a greater bearing on safety than yielding for pedestrians waiting or just beginning to cross, but not yet in the path of vehicles. The effect of IRWL on those in the middle of their crossing, particularly for multilane roads should be further studied. In the meantime, caution should be exercised, and perhaps additional treatments implemented, if IRWL is considered for uncontrolled crosswalks at multilane locations.

- Reported effects on motorist speeds were also mixed, with studies finding the following:

    - Improvements or slight improvement in speeds.(86,92,93)
    - No improvement.(85,89)
    - Mixed results for some locations and study conditions.(86,89)

- Effects on conflicts between motorists and pedestrians using the crosswalk also varied, along with the definitions of conflicts used in the studies. Authors reported the following:

    - A non-significant increase in conflicts in one study.(92)

    - Reduced conflicts at all four locations in a study from Israel.(90)

    - Reduced conflicts following installation of high-visibility crosswalks and sidewalk improvements, but no improvement related to the IRWL in one study.(94)

    - Fewer conflicts were observed among those using the IRWL crosswalk compared with those crossing at other locations (after period only).(89)

- Longer-term data are generally lacking. When data were available, improvements in yielding and other measures were typically greatest at the shortest after-interval measured, with worsening trends seen at later time intervals.(86,89,94) Thus, the potential for a degradation of initial improvements is suggested, and the treatment should be monitored at repeated intervals over a year or more. Certainly any available crash data and characteristics should be considered.

- Most of the studies included one treatment site, and none included comparison sites to control for time-related trends or other unknown factors. Confounding treatments and other conditions were also noted in several of the studies. Most of the studies determined only short-term effects of the treatment, having examined the effects for intervals from a few weeks to several months post-implementation.

The following paragraphs provide additional details for a sample of the evaluations available for in-roadway warning lights.

Whitlock and Weinberger Transportation, Inc., in 1998, summarized the evaluation results of in-roadway warning lights at numerous locations in California.(82) In these installations, the in-roadway warning lights were supplemented with a pedestrian crosswalk sign with warning amber LED lights, as well as a pedestrian-activated pushbutton with flashing LEDs and a CROSS WITH CAUTION sign. Two different MOEs were used to report evaluation results: 1) percentage of motorists yielding to pedestrians and 2) advance vehicle braking distance. For all six study sites, the percentage of motorists yielding to pedestrians increased after treatments were installed; daytime yielding improved from 28 to 53 percent, and nighttime yielding increased from 13 to 65 percent. The improvements in motorist yielding behavior and the actual percentage of yielding motorists were typically much greater for nighttime conditions. The changes in advance vehicle braking distance showed similar results, with increases in braking distance being greater during nighttime conditions.

The city of Kirkland, WA, installed in-roadway warning lights at two midblock locations in the fall of 1997.(84) Whitlock and Weinberger Transportation, Inc. evaluated the crossing treatments at these locations and reported the results using the same two MOEs as the California study. The evaluation team found improvements to both MOEs after installation, with more dramatic improvements evident during nighttime tests. Before installation, nighttime driver yielding ranged from 16 to 65 percent. After installation of the in-roadway warning lights, yielding increased to a range of 93 to 100 percent. Daytime yielding improved from 46 to 64 percent before treatment to 85 to 94 percent after. The study found the following:

> "The concept of amber flashing lights embedded in the pavement at uncontrolled crosswalks clearly has a positive effect in enhancing a driver's awareness of crosswalks and modifying driving habits to be more favorable to pedestrians."(82) (p. 1)

Boyce and Van Derlofske compared the effectiveness of in-roadway warning lights to basic crosswalk markings at a single location with two crosswalks in Denville, NJ.(94) The authors found that the in-roadway warning lights decreased the speed at which vehicles approached the crosswalk, but that this speed reduction diminished over time. In addition, vehicle–pedestrian conflicts with the in-roadway warning lights also increased over time. The authors also reported several problems with this specific implementation of in-roadway warning lights.

Katz, Okitsu, and Associates in 2000 prepared a study of in-roadway warning lights for Fountain Valley, CA.(85) Their study analyzed the reported safety record of approximately 30 treatment locations that were in place for more than 1 year and compared it with the expected safety record for traditional crosswalk treatments. The system appears to have reduced the crash expectancy by 80 percent; however, it is not known whether this is a novelty effect or will continue over time. The study also found that marked crosswalks with in-roadway flashers had a lower crash rate than comparable marked crosswalks.

Huang et al. documented in 2000 the evaluation of in-roadway warning lights at a single location in Orlando, FL.(87) The evaluation, which was conducted to determine the effects of the in-roadway warning lights on pedestrian and motorist behavior, collected both before-and-after and treatment-and-control data. The authors reported the following results:

- Average vehicle speeds decreased by 1.9 mi/h when a pedestrian was present and 0.8 mi/h when no pedestrians were present, but the decreases were not significant.

- Vehicle yielding improved from 13 percent before to 34 percent (when flashers were activated) and 47 percent (when flashers were not activated) after installation. The authors could not explain why more drivers yielded when the flashers were not activated.

- About 28 percent of the pedestrians crossed in the flashing crosswalk when police officers were not present. The remaining 72 percent of pedestrians crossed elsewhere, depending on what was the most convenient path between their origins and destinations.

- Of the pedestrians who crossed in the flashing crosswalk, 40 percent did not experience any conflicts, compared with 22 percent of those who crossed within 30 ft and only 13 percent of those who crossed elsewhere. The researchers concluded that motorists were more likely to stop or slow for pedestrians who crossed in or near the flashing crosswalk than for those who crossed elsewhere.

In a subsequent study, Huang evaluated in-roadway warning lights at two uncontrolled pedestrian crossings—one in Gainesville, FL, and one in Lakeland, FL.(68) The evaluation used traditional before-and-after data collection and used the following MOEs: 1) motorists yielding to pedestrians, 2) pedestrians who had the benefit of motorists yielding to them, 3) pedestrians who crossed at a normal walking speed, and 4) pedestrians who crossed in the crosswalk. The results for these MOEs were quite different between the two study sites. At the study site in Gainesville, driver yielding actually decreased from 81 to 75 percent. Although the decrease was significant, it was considered practically negligible because of site characteristics. At the Lakeland site, driver yielding improved from 18 to 30 percent; this result was not statistically significant because of low sample sizes. The results from the other MOEs were not that informative because major changes were not observed.

Prevedouros in 2001 reported on the evaluation of in-roadway warning lights installed on a six-lane arterial street in Honolulu, HI.(86) The evaluation consisted of a traditional before-and-after study of traffic volumes, vehicle spot speeds, pedestrian crossing observations, and pedestrians' and motorists' perceptions of change in the situation. The author reported the following results:

- A 16- to 27-percent reduction in vehicle speeds was measured when the flashing lights were activated.
- The average pedestrian wait time at the curb decreased from 26 to 13 seconds, and the average crossing time decreased from 34 to 27 seconds. The crossing time decreased because pedestrians did not have to wait as long in the refuge island before crossing the second direction.
- The proportion of pedestrians who were observed to run during the crossing decreased from 22 to 12 percent after the flashing lights were installed. The proportion of pedestrians crossing outside the marked crosswalk also decreased from 16 to 8 percent after installation.

IN-STREET PEDESTRIAN CROSSING SIGNS

In-street pedestrian crossing signs (2003 MUTCD R1-6 and R1-6a signs) are intended for use at uncontrolled (unsignalized) crosswalks. The signs can be installed on the centerline or in the median with either a portable or fixed base. Because the signs are located between the lanes, they can have a traffic-calming effect from the narrowing of the lanes.

A 2009 report documented the findings from three area-wide countermeasure programs implemented in Las Vegas, NV; Miami-Dade, FL; and San Francisco, CA.(4) The three field teams used different applications of the in-street pedestrian signs in terms of location and number of signs used. The signs proved to be very effective in increasing driver yielding (see table 191). Driver yielding increased between 13 and 46 percent depending on the location. There were no significant changes in the percentage of pedestrian–vehicle conflicts at the Miami sites or at two of the three sites in San Francisco. Only one location (Mission & Admiral) in San Francisco experienced a significant decrease in pedestrian–vehicle conflicts. Conflicts were reduced from 17.1 percent in the baseline to 2.1 percent after installation of the signs.

Table 191. Driver yielding at in-street installations.(4)

Site	Before number	After number	Before—percent of drivers yielding to pedestrians	After—percent of drivers yielding to pedestrians	Percent change	*p*-value
Miami: Collins & 6th	400	440	32	78	46	0.01
Miami: Collins & 9th	400	240	21	65	44	0.01
Miami: Collins & 13th	1,200	200	34	69	35	0.01
San Francisco: 16th & Capp (marked crosswalk)	519	447	61	74	13	< 0.01
San Francisco: 16th & Capp (unmarked crosswalk)	96	109	40	60	20	< 0.01
San Francisco: Mission & France	164	91	43	78	35	< 0.01
San Francisco: Mission & Admiral	41	47	22	57	35	< 0.01
Las Vegas: Bonanza between D and F	89	106	74	47	-27[a]	> 0.05
Las Vegas: Twain between Cambridge and Swenson	141	79	7	35	18	< 0.01

[a] Counterintuitive result—results are not significant because this is a one-tailed test.

A 2007 study compared the effect on driver yielding behavior resulting from the installation of in-street pedestrian crossing signs. The signs were placed at three positions relative to the crosswalk—at 0 ft, 20 ft, and 40 ft in advance of the crosswalk—and three study sites were evaluated in the study.(4) The data showed that the sign produced a marked increase in yielding behavior at all three study sites and that installation of the sign at the crosswalk line was as effective as or more effective than installation of the sign 20 or 40 ft in advance of the crosswalk. The data also indicated that placement of the sign at all three locations at once was no more effective than placement of the sign at the crosswalk line. These data suggest that the in-roadway sign is likely effective because the in-roadway placement is particularly salient to drivers. Because drivers frequently struck the signs at one of the sites, the authors recommended that these signs be placed on median islands whenever possible to extend their useful lives.

In-street pedestrian crossing signs were examined in the TCRP/NCHRP project.(44) The field studies indicated that in-street signs had relatively high motorist yielding (ranged from 82 to 91 percent, for an average of 87 percent); all three study sites were on two-lane streets with posted speed limits of 25 or 30 mi/h.

A 2011 paper reported on installations of in-street pedestrian crossing signs at three midblock locations in Las Vegas.(53) The results either 1) showed a decrease in motorist yielding or 2) were not statistically significant. The signs were installed on roads with 35-mi/h speed limits, five- or seven-lane cross-sections, and ADTs between 17,100 and 21,400 vehicles/day. The wide crossing may have contributed to the decrease in motorist yielding.

To improve pedestrian safety at a relatively low cost, the Pennsylvania Department of Transportation has a program to provide Yield-to-Pedestrian Channelizing Devices (YTPCD) to municipalities. YTPCDs are placed on the centerline of a roadway in advance of marked crosswalks to remind motorists of the need to yield to pedestrians. A research report by Strong and Kumar and a paper by Strong and Bachman summarized an evaluation of these devices.(95,96)

Behavioral data were collected in 2006 in four different community types (urban, suburban, small city, and college town) before and after installation. Sites included crosswalks at unsignalized intersections (eight sites) and midblock locations (four sites). Speed limits at all sites were either 25 or 35 mi/h. Data were analyzed with respect to whether motorists were more likely to yield to pedestrians. The analysis showed a statistically significant increase in motorist yielding. Table 192 provides the results from the study along with findings reported from other studies.

A series of treatments were installed at a bike trail crossing site in Michigan in a study that examined the effectiveness of a “gateway” in-street sign configuration with the RRFB used alone and in combination.(10) Because of a sharp curve, the posted speed was 25 mi/h, and there were two through lanes (one in each direction) and a center turn lane. When the signs were absent and the RRFB not activated, yielding averaged 20 percent. The RRFB alone produced an average yielding level of 69 percent. The gateway in-street sign treatment, which consisted of in-street signs on the lane line on both sides of the turn lane and on each side of the road, produced 80 percent yielding. The combination of the gateway in-street sign configuration and RRFB produced 85 percent yielding. The authors concluded that the data showed that the gateway in-street signs produced effects that were similar to the RRFBs and that the combination of gateway in-street signs and RRFB may produce effects similar to the gateway in-street signs alone, which suggests that the gateway in-street signs can be more cost effective than the more expensive RRFBs.

Table 192. Evaluation results on in-street pedestrian crossing signs.

Location	Measure of effectiveness	Result	Reference
Miami, San Francisco, Las Vegas	Motorist Yielding	Before range of 7 to 74 percent After range of 35 to 78 percent Between 13 and 46 percent increase	Pécheux, K., Bauer, J., and McLeod, P. *Pedestrian Safety and ITS-Based Countermeasures Program for Reducing Pedestrian Fatalities, Injury Conflicts, and Other Surrogate Measures Draft Zone/Area-Wide Evaluation Technical Memorandum.* Contract #DTFH61-96-C-00098; Task 9842. 2009.
TCRP/ NCHRP	Motorist Yielding	With signs = 82 to 91 percent	Fitzpatrick, K., Turner, S., Brewer, M., Carlson, P., Ullman, B., Trout, N., Park, E.S., Whitacre, J., Lalani, N., and Lord, D. *Improving Pedestrian Safety at Unsignalized Crossings*. TCRP Report 112/NCHRP Report 562. 2006.
Pennsylvania (Philadelphia Haverford Township, Pottstown, and West Chester)	Motorists Yielding—Intersection Locations	Before = 27 percent After = 59 percent Increase = 30 to 34 percent	Strong, C., and Kumar, M. *Safety Evaluation of Yield-to-Pedestrian Channelizing Devices*. Western Transportation Institute. Montana State University. 2006. Strong, C., and Bachman, D. *Safety Evaluation of Yield-to-Pedestrian Channelizing Devices* in TRB 87th Annual Meeting Compendium of papers DVD. 2008.
	Motorists Yielding—Midblock Locations	Before = 10 percent After = 30 percent Increase = 17 to 24 percent	
Previous studies as reported by Strong and Kumar or Strong and Bachmann[95,96]			
New York State and Portland, OR	Pedestrians for Whom Motorists Yielded	+12 percent	Huang, H., Zegeer, C., Nassi, R., and Fairfax, B. *The Effects of Innovative Pedestrian Signs at Unsignalized Locations: A Tale of Three Treatments*, Report No. FHWA-RD-00-098, Federal Highway Administration, Washington, DC. 2000.
	Pedestrians Who Ran, Aborted, or Hesitated	-2 percent	
	Pedestrians Crossing in Crosswalk	No change	
Cedar Rapids, IA	Motorists Yielding	+3 to 15 percent	Kannel, E.J., Souleyrette, R.R., and Tenges, R. *In-Street Yield to Pedestrian Sign Application in Cedar Rapids, Iowa*, Center for Transportation Research and Education, Iowa State University, Ames, IA. 2003.
Minnesota	Speed Compliance	+20 percent	Kamyab, A., Andrle, S., and Kroeger, D., *Methods to Reduce Traffic Speed in High Pedestrian Areas*, Report 2002-18, Prepared for the Minnesota Department of Transportation, St. Paul, MN. 2002.
Madison, WI	Motorists Yielding	+5 to 15 percent	City of Madison Traffic Engineering Division, *Year 2 Field Evaluation of Experimental "In-Street" Yield to Pedestrian Signs*. City of Madison Department of Transportation, Madison, WI. 1999.

ITS = Intelligent transportation system.
TCRP = Transit Cooperative Research Program.
NCHRP = National Cooperative Highway Research Program.

MARKED CROSSWALKS

Zegeer et al. have performed the most authoritative study to date on the effectiveness of crosswalk pavement markings alone as a pedestrian crossing treatment at uncontrolled locations.(45,97) Five years of pedestrian collisions at 1,000 marked crosswalks and 1,000 matched unmarked comparison sites in 30 U.S. cities were analyzed. The study concluded that no meaningful differences in crash risk exist between marked and unmarked crosswalks on two-lane roads or on low-volume multilane roads. The study indicated that as traffic volumes, speeds, and street widths increase, crosswalk markings alone are associated with a greater crash frequency than no crosswalk markings. The study recommendations indicate that the issue should not be whether to provide crosswalk markings on these high-volume, high-speed streets. Instead, the recommendations point to the necessity of using other treatments in addition to crosswalk markings that will provide a safer street crossing for pedestrians.

Koepsell et al. in 2002 published a study of the effects of crosswalk markings on the risk of vehicle–pedestrian crashes involving older pedestrians.(98) The study gathered crash data and other site characteristics (e.g., traffic and pedestrian volumes, traffic speed, signalization characteristics) from six cities in Washington State and California from 1995 to 1999. The study used a case-control design and compared 282 case sites with 564 control sites. After adjusting for the various traffic and pedestrian characteristics, the researchers found that the risk of a pedestrian–vehicle crash was 3.6 times greater at uncontrolled intersections with a marked crosswalk. At intersections with a stop sign or traffic signal, there was "virtually no association between presence of markings and pedestrian-motor vehicle collision risk."

Knoblauch, Nitzburg, and Siefert reported on a study of the effects of pedestrian crosswalk markings on pedestrian and driver behavior.(99) The study included 11 unsignalized intersections in four cities: Sacramento, CA; Richmond, VA; Buffalo, NY; and Stillwater, MN. The researchers considered the following behavior in the crosswalk markings evaluation:

- Pedestrian compliance with crossing location.
- Vehicle speeds.
- Vehicle yielding compliance.
- Pedestrian behavior as related to level of caution.

The authors presented the following conclusions:

- Drivers appeared to drive slower when approaching a marked crosswalk. The speed reductions are modest but evident nonetheless. This finding implies that most motorists are aware of the pedestrian crossing.

- No changes in driver yielding behavior were observed after the installation of marked crosswalks. This result implies that motorists may be slowing down just in case they are forced to stop by a pedestrian stepping into the roadway.

- There were no changes in blatantly aggressive pedestrian behavior after installations of marked crosswalks, indicating that pedestrians do not feel overly protected by marked crosswalks.

- Overall, crosswalk usage increased after marked crosswalks were installed. The authors found that single pedestrians are more likely to use marked crosswalks than a group of pedestrians traveling together.

Gibby et al. analyzed pedestrian-vehicle crash data at 380 intersections on California State highways.(100) The study found that crash rates at marked crosswalks were 3.2 to 3.7 percent higher than crash rates at unmarked crosswalks (after accounting for pedestrian exposure). This result corresponded to earlier work by Herms in San Diego, and also correlates to Zegeer's study in the late 1990s. The implication is that marked crosswalks alone are not sufficient on multilane streets with high traffic volumes and speeds.

In the late 1960s, Herms examined 5 years of crash experience at 400 unsignalized intersections in San Diego, CA.(101,102) The study found that nearly six times as many crashes occurred in marked crosswalks as in unmarked crosswalks. After accounting for crosswalk usage, the crash ratio was reduced to about three times as many crashes in marked crosswalks. Many have criticized this study as leading to the removal of pedestrian accommodation on city streets. Many now think that crosswalk markings should not be removed in these cases, but rather supplemented with various other types of safety treatments that enable pedestrians to cross busy roadways.

MOTORIST WARNING SIGNS

Pedestrian crossing signs were installed at several locations in the Miami metropolitan area.(4) The signs were tested at a midblock section of Collins Avenue in Miami. Collins Avenue has a two-lane cross section with on-street parking, an ADT of 29,500 vehicles/day, and a speed limit of 30 mi/h. Following installation of pedestrian crossing signs, there were no significant changes in average vehicle speed or the percentage of drivers braking when a pedestrian was present. No conflicts were observed in the before or after conditions. The operating speed at the site in the before condition was 10 mi/h below the posted speed limit of 30 mi/h, which was suggested as a reason that a speed change was not observed.

Huang et al. evaluated three innovative pedestrian signing treatments at locations in Seattle, WA; six sites in New York State; Portland, OR; and three sites in Tucson, AZ.(103) The three treatments evaluated were an overhead crosswalk sign, a pedestrian safety cone typically placed in the roadway, and an overhead flashing regulatory sign prompting motorists to stop for pedestrians in the crosswalk. The evaluation used traditional before-and-after data collection for three MOEs: 1) percentage of pedestrians for whom motorists yielded; 2) percentage of pedestrians who ran, aborted, or hesitated; and 3) percentage of pedestrians crossing in the crosswalk. The results of the study are shown in table 193. All treatments except the overhead flashing sign in Tucson resulted in improvements in motorist yielding. The authors indicated that the effectiveness of the flashing regulatory sign may have been limited because it was installed on four- and six-lane arterial streets with speed limits of 40 mi/h. (The other study locations were primarily two-lane streets with speed limits of 25 or 30 mi/h.)

High-visibility signs and markings were examined in the TCRP/NCHRP project (documented in TCRP Report 112/NCHRP Report 562) in 2004.(44) The results demonstrated the effect of higher posted speed limits. One site with high-visibility signs and markings and a posted speed limit of

25 mi/h had a motorist yielding value of 61 percent. However, the other two study sites with high-visibility signs and markings and a posted speed limit of 35 mi/h had motorist yielding values of 10 and 24 percent, for an average of 17 percent.

Table 193. Effectiveness of pedestrian treatments at unsignalized locations.(103)

Study Location	Percent of pedestrians for whom motorists yielded	Percent of pedestrians who ran, aborted, or hesitated	Percent of pedestrians crossing in the crosswalk
Overhead crosswalk sign, (1 site in Seattle)	Before—46 After—52	Before—58 After—43	Before—100 After—100
In-roadway pedestrian safety cone (6 sites in New York, 1 site in Portland)	Before—70 After—1	Before—35 After—33	Before—79 After—82
Overhead flashing crosswalk regulatory sign (3 sites in Tucson)	Before—63 After—52	Before—17 After—10	Before—94 After—94

OVERPASSES AND UNDERPASSES

Pedestrian overpasses (bridges) and underpasses (tunnels) allow pedestrians and bicyclists to cross streets while avoiding potential conflicts with vehicles.(104) Because they are expensive to construct, grade separated crossings should be reserved for locations where there is high demand for crossings by pedestrians, bicycles, and individuals with physical disabilities, and the risks of crossing the roadway are high. Ideally, overpasses and underpasses should take advantage of the topography of a site—grade separations are less expensive to construct and more likely to be used if they can help pedestrians avoid going up and down slopes, ramps, and steps.

Zegeer et al. discussed several grade separation treatment studies.(54) An analysis was made of reported pedestrian crashes for 6 months before and 6 months after the installation of pedestrian overpasses at 31 locations in Tokyo, Japan.(54,62) The overall results are shown in table 194. The table shows data for 656-ft sections and 328-ft sections on either side of each site. Crashes determined to be "related" to the treatment (assumed to be pedestrian crossing crashes) decreased substantially after overpass installation, but non-related crashes increased by 23 percent in the 656-ft sections. There was also a greater reduction in daylight pedestrian collisions than nighttime collisions.

The effectiveness of pedestrian overpasses and underpasses depends a great deal on their level of use by pedestrians. A 1965 study by Moore and Older found that use of overpasses and underpasses depended on walking distances and convenience of the facility.(54,105) They defined a convenience measure (R) as the ratio of the time to cross the street on an overpass divided by the time to cross at street level. The researchers found that approximately 95 percent of pedestrians will use an overpass if the walking time in using the overpass is the same as crossing at street level (i.e., R = l). However, if crossing using the overpass takes 50 percent longer than crossing at street level (R = l.5), almost no one will use the overpass. Usage of pedestrian underpasses was not as high as overpasses for similar values of R.

Table 194. Comparison of crashes before and after installation of pedestrian overpasses in Tokyo.(54)

	656-ft sections			328-ft sections		
Type of Crash	**Before**	**After**	**Reduction (percent)**	**Before**	**After**	**Reduction (percent)**
Related crashes	2.16	0.32	85.1	1.81	0.16	91.1
Non-related crashes	2.26	2.77	-22.9	1.65	1.87	-13.7
Total	4.42	3.09	29.9	3.46	2.03	41.1

Accessibility must also be considered when designing grade-separated crossings. A panel of people with disabilities was asked to comment on accessibility issues after using three pedestrian overpasses in San Francisco, CA.(54,106) They identified the following major elements as creating a barrier or hazard to the user with disabilities:

- Lack of adequate railings to protect pedestrians from drop-offs on overpass approaches.
- Greater than acceptable cross slopes.
- No level area at the terminals of the ramps on which to stop wheelchairs before entering the street.
- Lack of level resting areas on spiral bridge ramps.
- Railings difficult to grasp for wheelchair users.
- Lack of sight distance to opposing pedestrian flow on spiral ramps.
- Use of maze-like barriers to slow bicyclists on bridge approaches that create a barrier to those who use wheelchairs or who are visually impaired.
- Lack of sound screening on the bridge to permit people with visual impairments to hear oncoming pedestrian traffic and otherwise more easily detect direction and avoid potential conflicts.

A 1980 study by Templer et al. investigated the feasibility of accommodating pedestrians with physical disabilities on existing overpass and underpass structures.(54,107) A review of 124 crossing structures revealed that 86 percent presented at least one major barrier to the physically handicapped; the most common barriers were the following:

- Stairs only (i.e., no ramps for wheelchair users) leading to an overpass or underpass.
- Ramp or pathway to ramp that is too long and steep.
- Physical barriers along the access paths on structure.
- Sidewalk on the structure that is too narrow.
- Cross slope on the ramp that is too steep.

Various solutions to these access problems were developed and assessed based on cost effectiveness. The Americans with Disabilities Act has since required the barriers to wheelchair users to be removed, requiring more gentle slopes and periodic level areas for wheelchair users to rest. While use of these gentle slopes also makes it easier for bicyclists and other users, it has also greatly increased the length of ramps, which may discourage usage. Methods such as carefully planned fencing have been used to channel pedestrians to the overpasses and underpasses to increase usage and discourage potentially risky at-grade crossings.

PEDESTRIAN HYBRID BEACON (ALSO KNOWN AS HAWK)

The pedestrian hybrid beacon (PHB) is located both on the roadside and on mast arms over the major approaches to an intersection. The head of the PHB consists of two red lenses above a single yellow lens. It is normally "dark," but when activated by a pedestrian, it first displays a few seconds of flashing yellow followed by a steady yellow change interval, and then displays a steady red indication to drivers, which creates a gap for pedestrians to use to cross the major roadway. During the flashing pedestrian clearance interval, the PHB changes to a wig-wag flashing red to allow drivers to proceed after stopping if the pedestrian has cleared the roadway, thereby reducing vehicle delays.

A recent study conducted a before-and-after evaluation of the safety performance of the PHB.(108) Using an empirical Bayes method, the study evaluations compared the crash prediction for the before period without the treatment to the observed crash frequency after installation of the treatment. To develop the datasets used in the evaluation, the researchers counted the crashes that occurred during the study period, typically 3 years before and 3 years after the installation of the PHB.

The researchers created two crash datasets. The first dataset included crashes coded as occurring at the intersecting streets (identified by using street names). The second dataset was a subset of the first dataset and only included those crashes that had "yes" for the intersection-related code in the police report.

The crash categories examined in the study included total, severe, and pedestrian crashes. From the evaluation that considered data for 21 pedestrian hybrid beacon treatment sites and 102 unsignalized intersections (reference group), the researchers found the following changes in crashes after installation of the PHBs:

- A 29-percent reduction in total crashes (statistically significant).
- A 15-percent reduction in severe crashes (not statistically significant).
- A 69-percent reduction in pedestrian crashes (statistically significant).

FHWA added the PHB to the MUTCD in the 2009 edition (see chapter 4F).(2) However, the PHBs included in the FHWA safety study differ from the material in the 2009 MUTCD in the following ways because the installations included in the FHWA study preceded the MUTCD guidance:

- Section 4F.02 of the MUTCD states the following(2):

  > When an engineering study finds that installation of a pedestrian hybrid beacon is justified, then … the pedestrian hybrid beacon should be installed at least 100 feet [31 meters] from side streets or driveways that are controlled by STOP or YIELD signs.

  All 21 pedestrian hybrid beacons included in this study are located either at a minor intersection (where the minor street is controlled by a stop sign) or at a major driveway (where the driveway is controlled by a stop sign).

- The 2009 MUTCD depicts an R10-23 sign with the symbolic red circle and a white background for the word "crosswalk" on the sign.(2) The signs typically used at the PHB locations do not have the symbolic red circle, and the crosswalk background is yellow.

The MUTCD includes guidelines for the installation of the pedestrian hybrid beacons for low-speed roadways where speeds are 35 mi/h or less, and high-speed roadways where speeds are more than 35 mi/h.(2) Changes proposed for the next edition of the MUTCD (i.e., the version that will follow the 2009 edition) is to remove the 100-ft guidance statement and to add text stating that if the PHB is installed at or immediately adjacent to an intersection with a minor street, a stop sign shall be installed for each minor-street approach.

A study in Oregon investigated the public's understanding of the PHB display.(109) A survey was conducted in Corvallis, which was selected because there were no PHBs installed there, and users would likely be seeing images of the device for the first time. Images of the PHB display were shown to respondents, who were asked questions about what the various indications meant. Survey questions showed only a replication of the PHB display and consistently labeled the device a "signal." Results of the survey indicated that the PHB was not widely recognized, especially when it was presented out of context, and there was confusion about the sequence of the six indications. The vast majority of respondents answered that they had not seen a PHB before or were not sure whether they had. Of the respondents that said they had seen a PHB before, a large majority (85 percent) responded that it was installed at a rail crossing. Many respondents did not understand the meaning of the various indications of the PHB. Both younger (67 percent) and older (49 percent) drivers responded correctly to the dark indication, stating that they knew to continue through the signal. Most (71 percent) responded that it was necessary to stop for the solid red indication, but there appeared to be confusion with the alternating flashing red indication. A low percentage of drivers correctly responded that they must stop but could proceed through if the crossing was clear. Researchers concluded that a public education campaign on the different indications of the device should precede the deployment of a new installation.

PUFFIN

A recent British report documented safety at pedestrian user-friendly intelligent (Puffin) crossings.(110) Puffins have the following characteristics(56,110):

- Nearside pedestrian signals that encourage pedestrians to view oncoming traffic.
- No flashing pedestrian green period as at Pelican crossings (i.e., an acronym for pedestrian light control; a British pedestrian crossing with traffic signals that are controlled by pedestrians) or pedestrian signal blackout period at junctions (simplifies pedestrian signal phasing to "green man" for walk and "red man" for don't walk and eliminates a flashing "don't walk" for don't start phase).
- On-crossing pedestrian detectors that provide an extension to the pedestrian clearance period while pedestrians are still within the crossing.
- No flashing amber traffic period as at Pelican crossings.
- An indicator light that confirms when the pedestrian signal has been activated.
- Pedestrian curbside detectors to cancel the pedestrian demand if there are no pedestrians in the wait areas.

Puffins were developed to replace Pelican crossings at midblock sites and far-side pedestrian signals at junctions. As reported by Maxwell et al., previous research has shown that, compared with existing pedestrian signal facilities, Puffin facilities can reduce both driver and pedestrian delay at junctions and improve pedestrian comfort (particularly for older pedestrians and those with impaired mobility).(110) The aim of the Maxwell et al. study was to quantify the safety benefit. Accident data was analyzed from 50 sites (40 midblock crossings and 10 junctions) that had been converted to Puffin facilities from Pelican crossings and far-side pedestrian signals at junctions. The sites had no other significant changes in layout or operation, and were in general conformance with current Puffin guidance. Statistical analysis was undertaken by using a generalized linear model, which included time trends and seasonal factors. Midblock Puffin crossings were shown to be safer than Pelican crossings as follows:

- 17 percent lower at the midblock sites (statistically significant at the 5-percent level).
- 19 percent lower over all the sites (statistically significant at the 5-percent level).
- 24 percent lower for all pedestrian accidents (statistically significant at the 10-percent level).
- 16 percent lower for all vehicle accidents (statistically significant at the 10-percent level).

RAISED CROSSWALKS

Huang and Cynecki evaluated three raised crosswalks in Durham, NC, and Montgomery County, MD, using a treatment-and-control study approach.(76) All three sites were on two-lane, two-way roadways. One site in Durham also had a continuously operating overhead flashing beacon in addition to the raised crosswalk treatment, and staged pedestrians were used at the Maryland site. The researchers found that speeds at the treatment sites were lower than at nearby control sites (table 195), but motorist yielding behavior was mixed (table 196).

Table 195. Comparison of vehicle speeds at raised crosswalks.(76)

Location	50th percentile speed (mi/h)			Significance at 0.05 level or better[a]
	Treatment site	Control site	Difference in speeds	
Durham, NC—Research Drive	20.7	24.7	4.0	Yes
Durham, NC—Towerview Dr[b]	11.5	23.9	12.4	Yes
Montgomery County, MD[c]	21.5	24.0	2.5	No

[a]Significance based on two-tailed test.
[b]Towerview site had an overhead flashing beacon in addition to the raised crosswalk.
[c]Speeds at Montgomery County site were measured only when the staged pedestrian was present.

Table 196. Pedestrians at raised crosswalks for whom motorists stopped.(76)

Location	Treatment site[a] (percent (sample size))	Control site[a] (percent (sample size))	Significance[b]
Durham, NC—Towerview Drive	79.2 (159)	31.4 (35)	Y (0.000)
Montgomery County, MD	1.2 (169)	1.0 (198)	N

[a]Sample size in parentheses.
[b]Y = Significant at the 0.10 level or better (*p*-value in parentheses); N = Not significant at the 0.10 level or better.

RECTANGULAR RAPID-FLASHING BEACON

See discussion in chapter 2 of this report.

REFUGE ISLANDS

Crossing the street can be a complex task for pedestrians. Pedestrians must estimate vehicle speeds, adjust their walking speeds, determine adequacy of gaps, predict vehicle paths, and time their crossings appropriately. Drivers must see pedestrians, estimate vehicle and pedestrian speeds, determine the need for action, and react accordingly. At night, darkness and headlamp glare make the crossing task even more complex for both pedestrians and drivers.(111) Some midblock crossings may be too wide to be crossed during available gaps without the protection of a signal. Median refuge islands simplify the street crossing task by permitting pedestrians to make vehicle gap judgments for one direction of traffic at a time. Recent refuge island designs can incorporate an angled or staggered pedestrian opening, which better aligns pedestrians to face the second direction of oncoming traffic. Refuge areas may be delineated by markings on the roadway or raised above the surface of the street.

Bowman and Vecellio in 1994 reported comparisons of several kinds of medians, including undivided multilane roadways, TWLTL, and raised curb medians.(54,112,113) Raised curb facilities were associated with lower pedestrian crash rates, but the authors reported that both raised and TWLTL medians significantly reduced the number and severity of vehicular crashes at the study sites. In general, raised curb medians may be better than TWLTL medians which are, in turn, better than undivided highways, but the literature search did not conclusively find that medians improved pedestrian safety.(113)

A study by Bacquie et al. compared median refuge islands and split pedestrian crossovers in an analysis of crash reports at 10 crossing locations in Toronto, ON.(114) The split pedestrian crossover treatment includes a median refuge island with pedestrian-activated signal control. The crash data were not normalized by exposure data, but some indication was given about pedestrian and vehicle exposure for the two treatments. The study found that pedestrians were seldom struck while standing on the refuge island and were more often struck while crossing, due to poor gap judgment or improper driver yielding. Vehicle rear-end collisions were higher at the split pedestrian crossovers, and researchers surmised it was because it was a less common treatment than traditional intersection signals. The authors indicated some drivers did not act uniformly when approaching the split pedestrian crossovers because the drivers might not know when to stop or whether other drivers would stop in front or behind them.

Huang and Cynecki evaluated five refuge islands in Corvallis, OR, and Sacramento, CA, using a before-and-after study approach.(76) The Corvallis site was on a four-lane urban arterial with a center left-turn lane, while the Sacramento sites were on intersections of two-way, two-lane residential streets. The authors reasoned that, because refuge islands constrict the roadway and slow vehicle speeds, the islands would increase the number of motorists yielding to pedestrians. In other words, more pedestrians would have the benefit of motorists yielding to them. However, none of the treatments had a statistically significant effect on motorist yielding, as shown in table 197.

Table 197. Pedestrians at refuge islands for whom motorists yielded.(76)

Location	Locations	Lanes	Before[a] (percent (sample size))	After[a] (percent (sample size))	Significance[b]
Corvallis, OR	1	4 + TWLTL	5.7 (35)	7.5 (53)	Small
Sacramento, CA	4	2	32.6 (46)	42.1 (38)	No

[a] Sample size in parentheses.

[b] No = Not significant at 0.10 level; Small = Small sample size.

Median refuge islands were installed at two signalized intersections in San Francisco and a midblock location in Las Vegas. Pécheux et al. reported that there were no measurable changes in the percentage of pedestrians trapped in the roadway, the percentage of pedestrians that were diverted to the crosswalk, or the percentage of pedestrian-vehicle conflicts at any of the sites where data for these MOEs were collected.(4) They also found no significant impacts on drivers' yielding behavior at the intersection locations, but yielding increased significantly at the midblock location, as shown in table 198. The researchers surmised that the installation of a median refuge island at a midblock location was effective in increasing driver yielding to pedestrians and reducing pedestrian delay, while the median refuge islands at the signalized intersections in San Francisco appeared to be less effective in altering driver and pedestrian behaviors.

Pécheux et al. also reported on an offset pedestrian opening in two other median islands.(4) The offset is a type of channelization that encourages pedestrians to turn and walk parallel to the traffic they are crossing; it provides refuge for pedestrians in terms of physical separation from traffic and ensures they are facing the traffic before crossing the second half of the roadway. The crosswalk was created using waist-high bollards and raised medians; the offset at the other study site was developed through median cutouts in an existing raised median, and a new marked crosswalk was added. At both locations the percentage of pedestrians trapped in the roadway fell significantly, particularly at the Lake Mead site with a 57 percent decrease (see table 199). Researchers suggested that the large percentage of pedestrians trapped at the Lake Mead site in the before condition was likely caused by the absence of a marked crosswalk. The research team also measured large, significant increases in driver yielding at both sites as shown in table 200.

Table 198. Drivers yielding to pedestrians at median refuge islands.(4)

Location	Site (location)	Percent of drivers yielding to pedestrians		Percent change	*p*-value
		Before	After		
San Francisco	Geary & Stanyan (Intersection)	80.4 (n = 158)	86.6 (n = 164)	+6.2	0.18
	Geary & 6th (Intersection)	96.1 (n = 186)	89.7 (n = 262)	-6.4	0.15
Las Vegas	Harmon: Paradise Rd. to Tropicana Blvd. (Midblock)	22 (n = 77)	46 (n = 284)	+24	< 0.001

Table 199. Trapped pedestrians at offset median openings.(4)

Location	Site	Percent of drivers yielding to pedestrians		Percent change	*p*-value
		Before	After		
Las Vegas	Maryland Pkwy & Dumont	12 (n = 631)	4 (n = 198)	-8	< 0.001
Las Vegas	Lake Mead: Belmont to McCarran	62 (n = 61)	5 (n = 123)	-57	< 0.001

Table 200. Drivers yielding to pedestrians at offset median openings.(4)

Location	Site	Percent of drivers yielding to pedestrians		Percent change	p-value
		Before	After		
Las Vegas	Maryland Pkwy & Dumont	32 (n = 432)	76 (n = 246)	+44	< 0.001
Las Vegas	Lake Mead: Belmont to McCarran	3 (n = 296)	40 (n = 117)	+37	< 0.001

ROAD DIETS

A road diet involves narrowing or eliminating travel lanes on a roadway to accommodate pedestrians and bicyclists. While there can be more than four travel lanes before treatment, road diets are often conversions of four-lane, undivided roads into three lanes—two through lanes plus a center turn lane (see figure 104 and figure 105). The fourth lane may be converted to a bicycle lane, sidewalk, and/or on-street parking. Thus, the existing cross-section is reallocated. A recent HSIS report documented an empirical Bayes analysis of road diet installations in Iowa, California, and Washington.(115) Researchers estimated the change in total crashes resulting from the conversions in each of the two databases and combined these estimates into a crash modification factor (CMF). The empirical Bayes evaluation of total crash frequency indicated a statistically significant effect of the road diet treatment in both datasets and when the results were combined. Table 201 shows the results from each of the two studies and the combined results—the CMFs and their standard deviations.

Source: Pedestrian & Bicycle Information Center and FHWA.

Figure 104. Photo. Four-lane configuration before road diet.(115,116)

Source: Pedestrian & Bicycle Information Center and FHWA.

Figure 105. Photo. Three-lane configuration after road diet.(115,116)

Table 201. Results of EB analysis on four-lane to three-lane road diets.(115)

State/site characteristics	Accident type	Number of treated sites (roadway length)	CMF (standard deviation)
Iowa: Predominantly U.S. and State routes in small urban areas (average population of 17,000)	Total crashes	15 (15 mi)	0.53 (0.02)
California/Washington: Predominantly corridors in suburban areas surrounding larger cities (average population of 269,000)	Total crashes	30 (25 mi)	0.81 (0.03)
All sites	Total crashes	45 (40 mi)	0.71 (0.02)

SIDEWALKS

Tobey et al. investigated the safety effects of sidewalks.(117) The researchers found that sites with no sidewalks or pathways were the most hazardous for pedestrians, with pedestrian hazard scores of +2.6. These scores indicate that crashes at sites without sidewalks are more than twice as likely to occur as expected. Sites with sidewalks on one side of the road had pedestrian hazard scores of +1.2, compared with scores of -1.2 for sites with sidewalks on both sides of the road. Thus, according to Tobey et al., sites with no sidewalks were the most hazardous to pedestrians, and sites where sidewalks were present on both sides of the road were least hazardous.

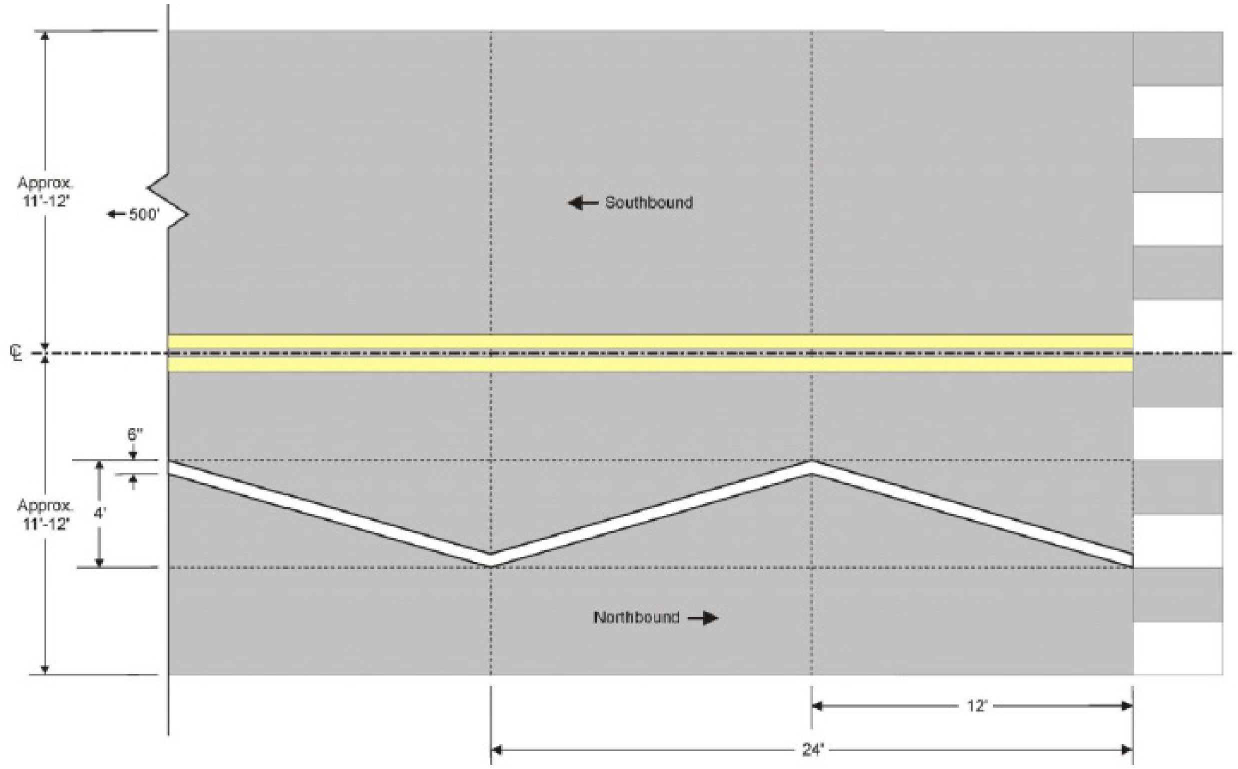
Sidewalks separated from the roadway are the preferred accommodation for pedestrians.(118) Providing walkways for pedestrians dramatically increases how well pedestrians perceive their needs are being met along roadways. The wider the separation is between the pedestrian and the roadway, the more comfortable the pedestrian facility. One recent study indicated that roadways without sidewalks are more than twice as likely to have pedestrian crashes as sites with sidewalks on both sides of the street.(118,119) By providing sidewalks on both sides of the street, numerous midblock crossing crashes can be eliminated.

ZIGZAG LINES

Zigzag lines are applied at midblock pedestrian crossings to restrict parking, stopping, and overtaking to improve pedestrian conspicuity. They are used in New Zealand, Canada, Europe, Trinidad, Great Britain, South Africa, Hong Kong, and Australia. A 2010 paper reviewed the literature to discuss how different countries use and interpret the meaning of zigzag pavement markings (lines) used at midblock crossings.(120) The review indicated that zigzag lines at pedestrian zebra crossings are misunderstood by most Trinidadian and Australian drivers as well as some researchers in North America. Such misunderstanding is associated with frequent vehicles parking, stopping, and overtaking in the vicinity of the pedestrian crossing. More education and public information on the crossing features and its use is needed.

The Virginia Department of Transportation studied the effectiveness of zig-zag pavement markings (shown in figure 106) in Loudoun County where the Washington and Old Dominion Trail crosses Belmont Ridge Road and Sterling Boulevard.(121) Effectiveness was defined in three ways: 1) an increase in motorist awareness in advance of the crossing locations, 2) a positive change in motorist attitudes, and 3) motorist understanding of the markings. Motorist awareness was measured by computing the difference in vehicle speeds before and after the installation of the markings. Attitudinal changes were measured through a survey targeting motorists, pedestrians, and bicyclists familiar with the markings. Motorist understanding was measured through another survey administered elsewhere in the State that targeted motorists unfamiliar with the zig-zag markings in Loudoun County.

The study found that the zig-zag markings installed in advance of the two crossings heightened the awareness of approaching motorists. This was evidenced by reduced mean vehicle speeds within the marking zones; speed reductions were largely sustained at observations 6 and 12 months after installation, compared with 1 week after installation. Further, the majority of survey respondents indicated an increase in awareness, a change in their driving behavior, and a higher tendency to yield than before. The study also found that motorists had limited understanding of the purpose of the markings. When seen with context, motorists' correct interpretations of their meaning increased, but not to levels compatible with guidance set forth in the MUTCD.(2) Researchers concluded that public information and education campaigns would help to increase understanding of the zig-zag pavement markings further.



Source: Dougald, Dittberner, and Sripathi/*Transportation Research Record 2299*.

Figure 106. Diagram. Schematic of zig-zag pavement marking design.(121)

MULTIPLE TREATMENTS

A 2009 paper reported on the effectiveness of engineering countermeasures toward crash reductions at eight corridors in Miami-Dade, FL.(121) A before-and-after study was used to compare the sequential implementation of a 3-year large-scale NHTSA project. The project focused primarily on education and enforcement components followed by a large-scale FHWA engineering countermeasure project that was added to the NHTSA project along specific corridors. Results showed that the NHTSA pedestrian safety project reduced countywide pedestrian crash rates by 13 percent along the targeted corridors, and the FHWA engineering safety project produced a further reduction to 50 percent of the baseline level. These results translate to 50 fewer pedestrian crashes annually along the treated corridors. Countermeasures implemented included the following:

- Reduced minimum green time at midblock crosswalks controlled by a traffic signal.
- Advance yield markings at crosswalks with an uncontrolled approach.
- Recessed or offset stop lines for intersections with traffic signals.
- Leading pedestrian intervals.

- Pedestrian pushbuttons that confirm having been pressed.
- "Turning Vehicles Yield to Pedestrians" symbol signs for drivers.
- Elimination of permissive left turns at a signalized intersection.
- In-street pedestrian signs.
- Pedestrian zone signs.
- Midblock traffic signal.
- Intelligent transportation system (ITS) video pedestrian detection.
- RRFB for uncontrolled multilane crosswalks.
- ITS smart lighting at crosswalks with nighttime crashes.
- ITS "No Right Turn on Red" signs.
- Pedestrian countdown timers.
- Speed trailer.

In 2005, the Chicago Department of Transportation reported on the effects of a combination of traffic control devices and calming measures used to slow traffic and improve safety around schools.(123) These measures included the following:

- Installation of speed humps along local street frontages of schools.

- Variable speed indicator signs giving interactive speed indication to motorists passing by schools on arterial streets.

- Installation of traditional school crossing warning signs and school zone 20 mi/h speed limit signs.

- Experimental use of strong yellow/green pavement marking materials to mark crosswalks, "school" legends, speed humps, center lines, and stop bars in the blocks adjacent to schools.

The following summary was provided(123):

> The analysis conducted was limited by the absence of control locations where similar marking treatments might have been installed using standard white pavement marking colors for crosswalks, "SCHOOL" legends, stop bars, and speed hump markings. The program analysis also generally was limited to assessing the combined effect of yellow/green markings, improved signing, and speed humps (on local streets), rather than analyzing the effect of individual traffic control measures. Understandably, it was the City's intent to maximize the impact on motorists to increase their awareness, slow traffic, and improve overall safety in the school zones, rather than simply conduct a limited experiment on alternating color pattern crosswalks using a combination of white and strong yellow/green pavement marking materials.
>
> The usefulness of the crash analysis was somewhat limited by only having one year of After-condition data available for the 2002 Program installation locations. No After-condition analysis was possible for the 2003 Program locations, nor, obviously, for the 2004 Program schools.

> The results of the analysis suggest that the use of strong yellow/green pavement markings did not seem to have a significant effect on traffic speeds or crash experience. On arterial streets, the change in aggregate mean speeds, the aggregate percentage of traffic exceeding the speed limit, and the mode and median values of peak hour 85th percentile speeds was minimal. The use of speed indicators, which have proven effective in reducing speeds in other locations throughout the country, did not have a large effect on either speeds or crashes during school peak hours. The combined use of speed indicators and strong yellow/green markings also did not have a major impact on reducing speeds or crashes.
>
> On local streets, the locations studied all had a combination of speed humps and strong yellow/green pavement markings. Most of these locations already had all-way stop control at adjoining intersections, thus already limiting the speeds on those streets. While the change in aggregate mean speeds and the aggregate percentage of traffic exceeding the speed limit was minimal, there did appear to be a reduction in the mode and median values of peak hour 85th percentile speeds. However, it seems reasonable to conclude that this reduction may have been largely attributable to the installation of speed humps rather than the yellow/green markings or upgraded school zone signing. This conclusion was reflected by the perception of survey respondents on the relative effectiveness of speed humps versus yellow/green markings. (pp. 9–10)

The city of Los Angeles, CA, has developed what it refers to as a “Smart Pedestrian Warning” system that includes the following multiple pedestrian crossing treatments(67):

- Advance pavement messages (“PED XING”).
- Advance warning pedestrian signs.
- Extended red curb.
- Double posting of intersection pedestrian signs.
- Ladder-style crosswalk markings.
- Automated pedestrian detection (video imaging).
- Actuated alternating flashing overhead amber beacons.

This pedestrian crossing design and its various elements have evolved over the past several years based on experimentation and testing. To date, about 25 pedestrian crossing warning systems have been installed in Los Angeles. Fisher, in an undated paper, reports on informal evaluations by city engineering staff that indicate that this pedestrian warning system has improved motorist yielding to pedestrians from 20 to 30 percent to the 72- to 76-percent range.(67) Their evaluation also indicates that, of the 24 to 28 percent of motorists who did not yield, at least they traveled more slowly when approaching the enhanced crossings. For example, limited data indicate that 85th percentile vehicle speeds were reduced from 2 to 12 mi/h.

A study by Chen, Chen, and Ewing sought to evaluate the relative effectiveness of five countermeasures in New York City—increasing the total cycle length, Barnes Dance, split-phase timing, signal installation, and high-visibility crosswalk—and examine potential trade-offs in their effectiveness in reducing pedestrian crashes and multiple-vehicle crashes.(124) They adopted a rigorous two-stage design that first identified a comparison group of intersections, corresponding to each treatment group, and then estimated a negative binomial model with the Generalized Estimating Equation method to further control confounding factors and within-subject correlation; the model also accounted for built environment characteristics. Researchers concluded that the four signal-related countermeasures were more effective in reducing crashes than high-visibility crosswalks, but they added that there are trade-offs between improving pedestrian safety and motorist safety. Treatments that indirectly resolve conflicts (e.g., increasing total cycle length and Barnes Dance) were more effective in reducing pedestrian crashes and yet less effective in reducing vehicle crashes than those that directly separate conflicts (i.e., split phase and signal installation). In the case of Barnes Dance, there was a potential increase in vehicle crashes. This finding suggests that selection of a specific countermeasure at a location highly depends on the characteristics of the location and the problem at hand. Researchers suggested that the types of conflicts and balance of time for different groups of road users at the intersections should be considered so that the improvement of the safety of one group does not compromise that of other groups.

ACKNOWLEDGMENTS

This research is sponsored by FHWA as part of the “Evaluation of Pedestrians Safety Engineering Countermeasures at Urban and Suburban Midblock Crossing Locations” project. The research was performed at the TTI and MRIGlobal.

The project was under the direction of Ann Do of FHWA. The following panel members provided comments and advice and generously donating their time and effort during the project: George Branyan, Michael Cynecki, Dwight Kingsbury, Peter Koonce, David Levinger, Ransford McCourt, Meghan Mitman, Richard Nassi, Richard Retting, and Roger Wentz. Their advice and guidance was greatly appreciated during the course of the study.

Several TTI employees assisted the authors with the closed-course study, including Mehdi Azimi, Jared Buckler, Seth Cole, Martin Fuest, Blanca Garcia, Jonathan Graber, Sarah Hammond, Michael Hardy, Laura Higgins, Grant Jackson, Greg Larson, Ivan Lorenz, Jeff Miles, Hailey Minter, Sarah Motes, Madison Munson, Scott Nemec, Jesse Ortega, Jose Rocha, Elizabeth Sandefur, Nada Trout, Dan Walker, Christine Yager, and Dick Zimmer.

Several TTI employees also assisted the authors with the open-road study by collecting or reducing the data, including Adrian Contreras, Amanda Martin, Blanca Garcia, Carla Kolber, Colleen Dau, Dan Walker, Daniel Aaron, Jeff Miles, Jeremy Johnson, Michael Hardy, Mike Pratt, Nicholas Wood, Sarah Motes, and Seth Cole. John Ronchetto of MRIGlobal was also a key staff member in collecting open-road data.

The research team is also grateful to the representatives and staff of the cities that participated in and facilitated the open-road study: Austin, TX (Gary Schatz, Jim Dale, Ronnie Bell, and Willard Peavy); College Station, TX (Troy Rother and Lee Robinson); Flagstaff, AZ (Jeffrey Bauman, Randy Whitaker, and Steven Hill); and Milwaukee, WI (Robert Bryson and Scott Reinbacher).

We also value the comments provided by reviewers of draft versions of this material and members of the NCUTCD.

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