Evaluation of Pedestrian and Bicycle Engineering Countermeasures: Rectangular Rapid-Flashing Beacons, HAWKs, Sharrows, Crosswalk Markings, and the Development of an Evaluation Methods Report

Pedestrian and Bicycle Safety

U.S. Department of Transportation
Federal Highway Administration

FOREWORD

The overall goal of the Federal Highway Administration (FHWA) Pedestrian and Bicycle Safety Research Program is to increase pedestrian and bicycle safety and mobility. From safer crosswalks, sidewalks, and pedestrian technologies to growing educational and safety programs, the program strives to make it safer and easier for pedestrians, bicyclists, and drivers to share roadways in the future.

This report documents an FHWA project to quantify the effectiveness of selected engineering countermeasures in improving safety and operations for pedestrians and bicyclists. The project focused on existing and new engineering countermeasures for pedestrians and bicyclists that have not yet been comprehensively evaluated in terms of effectiveness.

This report is of interest to engineers, planners, and other practitioners who are concerned about implementing pedestrian and bicycle treatments as well as city, State, and local authorities who have a shared responsibility for public safety.

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Director, Office of Safety
Research and Development

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. FHWA-HRT-11-039	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Evaluation of Pedestrian and Bicycle Engineering Countermeasures: Rectangular Rapid-Flashing Beacons, HAWKs, Sharrows, Crosswalk Markings, and the Development of an Evaluation Methods Report		5. Report Date April 2011
		6. Performing Organization Code
7. Author(s) Kay Fitzpatrick, Susan T. Chrysler, Ron Van Houten, William W. Hunter, and Shawn Turner		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. DTH61-01-C-00049 Task Order #25
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: December 2005–November 2010
		14. Sponsoring Agency Code
15. Supplementary Notes The Contracting Officer's Technical Representative (COTR) was Ann Do, HRDS-30.		

16. Abstract

This report documents a Federal Highway Administration (FHWA) project to quantify the effectiveness of selected engineering countermeasures to improve safety and operations for pedestrians and bicyclists. Through a combination of literature review, review of traffic control device experimental requests, practitioner panels, and meetings with FHWA, the research team identified four countermeasures for evaluation as well as the need for a handbook for practitioners conducting evaluations of traffic control devices. This report provides a brief summary of the evaluations of these four countermeasures and references to the full technical reports for each.

The rectangular rapid-flashing beacon (RRFB) device is a pedestrian-activated beacon system located at the roadside below pedestrian crosswalk signs. The study found that RRFBs produced an increase in yielding behavior at all 22 sites located in 3 cities (average yielding increased from 4 to 80 percent). Data collected over a 2-year follow-up period at 18 of these sites also documented the long-term maintenance of the improved yielding behavior produced by RRFBs. The High intensity Activated crossWalK (HAWK) (also known as the pedestrian hybrid beacon) consists of two red lenses above a single yellow lens. From the before-after evaluation that considered data for 21 HAWK sites and 102 unsignalized intersections, the following changes in crashes were found after HAWK installation: a 29 percent reduction in total crashes (statistically significant), a 15 percent reduction in severe crashes (not statistically significant), and a 69 percent reduction in total pedestrian crashes (statistically significant). Shared lane markings help convey to motorists and bicyclists that they must share the travel way on which they operate. A variety of hypotheses were examined, and a number of variables related to the interaction and spacing of bicycles and motor vehicles showed positive effects. Finally, the crosswalk marking study investigated the relative daytime and nighttime visibility of three crosswalk marking patterns. For the sites where markings were newly installed for this study, the detection distances to bar pairs and continental markings were similar, and they were statistically significantly longer than the detection distance to the transverse markings both during the day and at night. This report also summarizes the evaluation methods report, which provides information for traffic engineering practitioners on how to conduct evaluations of traffic control devices used by pedestrians and bicyclists.

17. Key Words Pedestrian treatments, Bicycle treatments, HAWK, Rectangular rapid-flashing beacon, Sharrow, Crosswalk markings, Evaluation methods	18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service 5301 Shawnee Road, Alexandria, VA 22312 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 65	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)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		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)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		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

Abbreviations

ADT   Average daily traffic

EB   Empirical Bayes

FHWA   Federal Highway Administration

HAWK   High intensity Activated crossWalK

IR   Intersection-related

ISN   Intersecting street name

ITS   Intelligent Transportation Systems

LED   Light-emitting diode

MEV&P   Million entering vehicles and pedestrians

MEP   Million entering pedestrians

MLK   Martin Luther King, Jr. Boulevard

MUTCD   *Manual on Uniform Traffic Control Devices*

NCUTCD   National Committee on Uniform Traffic Control Devices

n.s.   Nonsignificant

RRFB   Rectangular rapid-flashing beacon

SPF   Safety performance function

CHAPTER 1. INTRODUCTION

BACKGROUND

The Federal Highway Administration (FHWA) continuously seeks to demonstrate and evaluate the effectiveness of existing and/or new engineering countermeasures that reduce pedestrian and bicyclist fatalities, injuries, conflicts, and other surrogate safety measures. In 2008, 4,378 pedestrians were killed in traffic crashes in the United States—a decrease of 16 percent from the 5,228 pedestrians killed in 1998 (see figure 1).[1] Bicyclist fatalities have averaged about 740 per year during the previous 5 years, and there were 716 in 2008 (see figure 2).

Many pedestrians and bicyclists are injured as well. In 2008, around 69,000 pedestrians were injured. Although fatality and injury numbers have remained roughly the same (if not slightly lower), pedestrians still face risks. The goal of this project was to identify medium- to low-cost pedestrian and bicyclist engineering countermeasures that will improve safety and operations for pedestrians and bicyclists. An additional goal was to provide guidance for practitioners on how to properly conduct evaluations of traffic control devices.
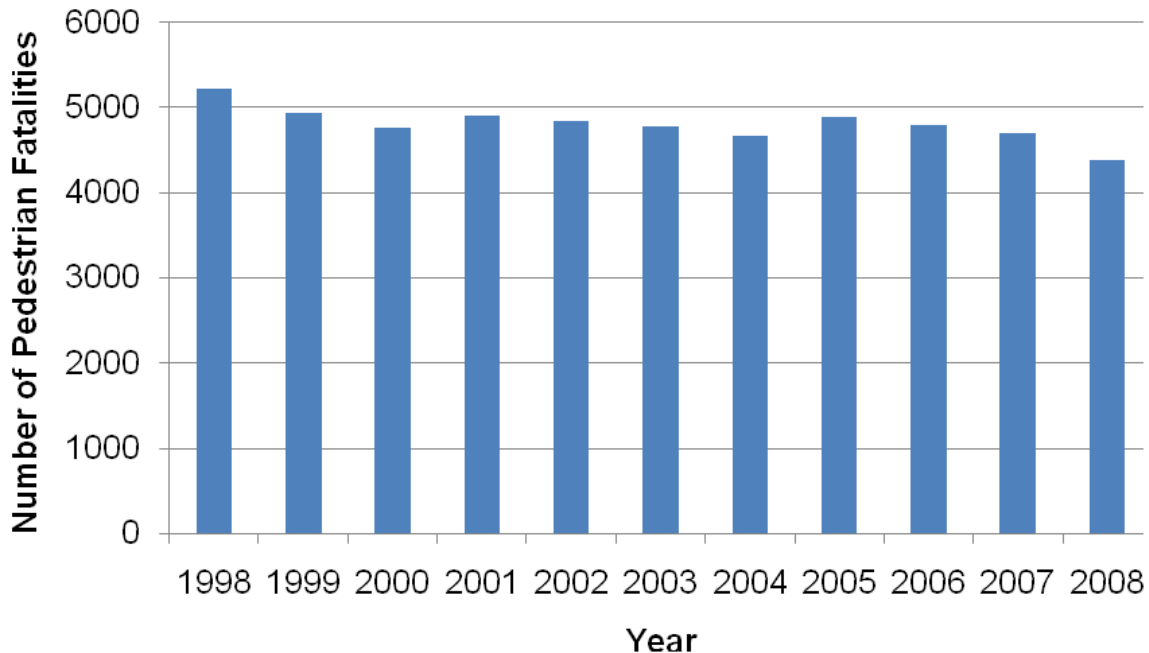
Figure 1. Graph. Total pedestrian fatalities.[1]
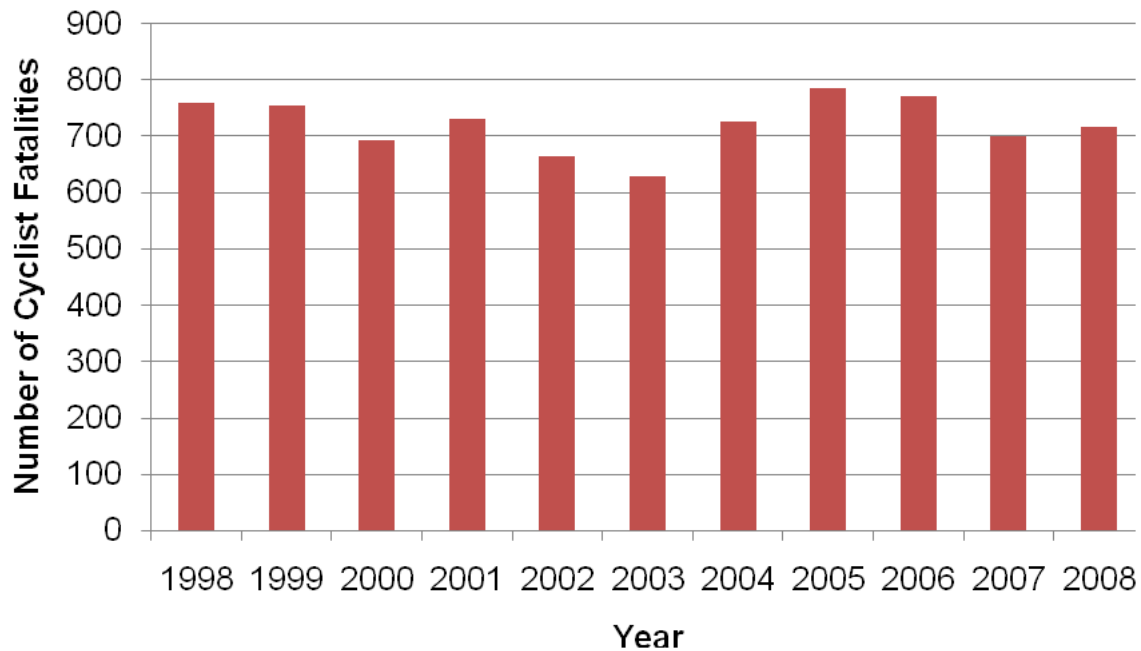
Figure 2. Graph. Total bicyclist fatalities.[1]

STUDY OBJECTIVE

The objective of this study was to quantify the effectiveness of medium- to low-cost engineering countermeasures. The project focused on existing and innovative engineering countermeasures for pedestrians and bicyclists that have not yet been comprehensively evaluated.

SCOPE OF WORK

The scope of this project included selecting appropriate pedestrian engineering countermeasures for study, developing evaluation plans and data, and performing statistical analysis to assess effectiveness. This scope was accomplished through the following tasks:

- Identifying pedestrian countermeasures to be evaluated using peer input and review.

- Developing an evaluation plan for each selected countermeasure.

- Collecting and analyzing data for each selected countermeasure.

- Developing a marketing plan for the evaluation results.

- Preparing technical brief(s) for each countermeasure.

- Preparing a handbook on how to evaluate traffic control devices.

- Developing a final technical report.

- Providing periodic briefings, reports, and presentations.

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PROJECT REPORTS

This report summarizes the entire project. Additional details are provided in the following publications generated during the project:

- Shurbutt, J. and Van Houten, R. (2010). *Effects of Yellow Rectangular Rapid-Flashing Beacons on Yielding at Multilane Uncontrolled Crosswalks*, Report No. FHWA-HRT-10-043, Federal Highway Administration, Washington, DC.

- Shurbutt, J. and Van Houten, R. (2010). TechBrief: *Effects of Yellow Rectangular Rapid-Flashing Beacons on Yielding at Multilane Uncontrolled Crosswalks*, Report No. FHWA-HRT-10-046, Federal Highway Administration, Washington, DC.

- Fitzpatrick, K. and Park, E.S. (2010). *Safety Effectiveness of the HAWK Pedestrian Crossing Treatment*, Report No. FHWA-HRT-10-042, Federal Highway Administration, Washington, DC.

- Fitzpatrick, K. and Park, E.S. (2010). TechBrief: *Safety Effectiveness of the HAWK Pedestrian Crossing Treatment*, Report No. FHWA-HRT-10-045, Federal Highway Administration, Washington, DC.

- Hunter, W.W., Thomas, L., Srinivasan, R., and Martell, C.A. (2010). *Evaluation of Shared Lane Markings*, Report No. FHWA-HRT-10-041, Federal Highway Administration, Washington, DC.

- Hunter, W.W., Thomas, L., Srinivasan, R., and Martell, C.A. (2010). TechBrief: *Evaluation of Shared Lane Markings*, Report No. FHWA-HRT-10-044, Federal Highway Administration, Washington, DC.

- Fitzpatrick, K., Chrysler, S.T., Iragavarapu, V., and Park, E.S. (2010). *Crosswalk Marking Field Visibility Study*, Report No. FHWA-HRT-10-068, Federal Highway Administration, Washington, DC.

- Fitzpatrick, K., Chrysler, S.T., Iragavarapu, V., and Park, E.S. (2010). TechBrief: *Crosswalk Marking Field Visibility Study*, Report No. FHWA-HRT-10-067, Federal Highway Administration, Washington, DC.

- Chrysler, S.T., Fitzpatrick, K., Brewer, M.A., and Cynecki, M. (2010). *Pedestrian and Bicyclist Traffic Control Device Evaluation Methods*, FHWA-HRT-11-035, Federal Highway Administration, Washington, DC.

CHAPTER 2. IDENTIFICATION OF COUNTERMEASURES

This chapter documents the process used to identify and select the countermeasures that were evaluated in this project.

LITERATURE REVIEW

An extensive literature review of bicycle and pedestrian countermeasure evaluations was conducted. The research team identified published and unpublished reports, papers, and articles that evaluated bicycle and pedestrian countermeasures. From this preliminary list, the team reviewed each source for relevance to the project. References that provided pertinent evaluation information were summarized, and the countermeasure type, number of study sites, experimental design, and study results were noted. The evaluations were also summarized by countermeasure type, indicating the cumulative total number of study sites for each countermeasure. Requests to conduct experimental evaluations of bicycle and pedestrian-related traffic control devices that were not specifically addressed by the 2009 *Manual on Uniform Traffic Control Devices* (MUTCD) were also summarized.[2]

The following findings were developed based on the information the team gathered:

1. There have been numerous evaluations of bicycle and pedestrian countermeasures, and most of these evaluations focused on surrogate safety measures. The literature review identified several reports, papers, and articles documenting the evaluation of engineering countermeasures. Many of these evaluations used behavioral or operational measures of effectiveness (i.e., measures involving pedestrians, bicyclists, and/or motorists) as opposed to actual safety outcomes (i.e., a reduction in pedestrian-vehicle crashes). For example, many studies of pedestrian crossing countermeasures use pedestrian-vehicle conflicts or motorist yielding as a surrogate for a safety outcome. Other examples of surrogate safety measures for bicyclist and pedestrian countermeasures include pedestrian looking behavior, pedestrian compliance with crosswalks and pedestrian signals, motorist braking and other behavior, motorist speed, bicyclist positioning, and bicyclist compliance with traffic control devices.

   There may be a direct relationship between the surrogate measure and the safety outcome (i.e., a correlation between conflicts and injury crashes and fatalities) for some surrogate safety measures (e.g., bicyclist-vehicle or pedestrian-vehicle conflicts). With other surrogate safety measures, the relationship is intuitive but not explicit or clearly recognized. For example, advanced stop or yield lines may be effective if a greater percentage of motorists are stopping further away from marked crosswalks to reduce visual screening. However, it has not been demonstrated empirically that having more motorists stop further back from the crosswalk leads to fewer pedestrian-vehicle crashes.

2. The prevailing use of surrogate safety measures in bicycle and pedestrian countermeasure evaluations reflects the difficulty of using crash reduction as a safety outcome. The following factors make crash data analyses more difficult:

   - Exposure data should be collected in the before period; however, this seldom occurs.

- Bicycle and pedestrian crashes occur relatively infrequently and are typically under reported.

Therefore, a crash-based evaluation of a pedestrian- or bicycle-related treatment might require hundreds or even thousands of treatment sites (plus an equivalent number of control sites) to have a statistically adequate sample of locations for determining the effectiveness of a treatment on pedestrian or bicycle crashes. Other concerns include the following:

- Regression-to-the-mean effects and site-selection biases, especially for selecting high-crash study sites.

- Significant variations in crash data quality, particularly among local jurisdictions.

- The 1- to 2-year lag in crash reporting following countermeasure installation.

- Difficulty controlling land use or other environmental changes that may affect pedestrian and bicyclist activity levels, behavior, and safety.

Conversely, the following factors make observational studies with surrogate safety measures more appealing:

- Researchers have better control over the data collection process.

- Researchers have experimental control over when the countermeasures are introduced at each site.

- Exposure data can typically be collected in both the before and after periods.

- There is less lag time (typically 1–3 months after installation) in the analysis and reporting.

- Before and after data are collected in a shorter time period, minimizing possible changes in land use or other environmental variables.

- Researchers have the ability to measure the effects of escalating treatments or varying treatment protocols in a relatively short period of time.

Many countermeasure evaluations have weaknesses in their experimental design or data collection protocol that limit the value of their results. Even a cursory review of the evaluations in the literature review reveals that many studies have not used control sites or alternately introduced and removed the treatment at the same site to adjust for area-wide changes and other potential confounding factors. In addition, researchers have not used sufficient sample sizes in data collection or addressed regression-to-the-mean biases at study sites with high crash rates prior to treatment installation. Many evaluations were conducted by local transportation agencies with limited resources where engineering judgment was typically used when interpreting study results.

3. Some evaluations treat effectiveness and safety as a binary outcome (i.e., safe or not safe) with little consideration for how it may change for various street characteristics and user populations. For example, the in-street pedestrian crossing sign has been found to be fairly effective on low-speed streets. However, other evaluations of this sign had less than promising results but failed to consider the context in which the sign was measured (i.e., moderate-speed, high-volume streets). Therefore, it is important for the study design and the evaluation plan to address the full range of street characteristics. Based on the literature review and evaluation, five candidate bicycle countermeasures and nine candidate pedestrian countermeasures were identified for potential study.

4. The most promising low-cost bicycle engineering countermeasures that could benefit from additional safety evaluation were as follows (in no particular priority order):

- **Shared lane pavement markings**: Shared lane pavement markings (a bike symbol with two chevrons) have been tested in San Francisco, CA, and are in the California MUTCD.[3] However, at the time of this review, these markings were not included in the 2003 MUTCD, and numerous cities in other States were using different variations of this pavement marking.[4] Ft. Collins, CO, Minneapolis, MN, and Portland, OR, are evaluating shared lane pavement markings as part of the official experimentation process. The 2009 MUTCD now includes a provision for shared lane markings.[2]

- **Colored bike lanes (or other signing and marking) in high-conflict areas**: Colored bike lanes are still considered experimental and were not included in the 2003 MUTCD.[4] Several cities have experimented with colored bike lanes, most notably Portland, OR, and Cambridge, MA, while others are currently experimenting with them (i.e., New York City, NY). Some cities have used colored bike lanes only in high-conflict areas, whereas others have proposed to use continuous colored bike lanes.

- **Standard width bicycle lanes**: Several studies have looked at operational or behavioral effects of standard width bicycle lanes (i.e., approximately 5 ft), but few have quantified the crash experience. Although a sufficient number of study sites could be identified for crash analysis, gathering exposure data prior to treatment installation could be problematic. Various street characteristics (e.g., on-street parking, driveway/curb cut frequency, etc.) would have to be controlled in a crash analysis.

- **Road diet**: Road diets are often conversions of four-lane undivided roads into three lanes (two through lanes and a center turn lane/median refuge island), with the fourth lane converted into bicycle lanes, sidewalks, and/or on-street parking. A 2004 FHWA study quantified the crash reduction of road diets for vehicle traffic, but little is known about any potential safety benefits for bicyclists and pedestrians.[5]

- **"BICYCLISTS MAY USE FULL LANE" regulatory sign**: At the time of this study, the National Committee on Uniform Traffic Control Devices (NCUTCD) was discussing a regulatory sign that would replace the existing "SHARE THE ROAD" sign for bicycles because the sign is ambiguous and can be interpreted differently by bicyclists and motorists. However, it is difficult to quantify the safety effectiveness of similar simple sign treatments even when surrogate safety measures are used.

5. The most promising low-cost pedestrian engineering countermeasures that could benefit from additional safety evaluation are as follows (in no particular priority order):

- **Pedestrian countdown signals**: Pedestrian countdown signals have been studied in San Jose, CA, and most recently in San Francisco, CA. Results of the crash study in San Francisco, CA, found a significant crash reduction; however, crash reduction was also significant at control sites.[6] The authors indicated that regression-to-the-mean played a major role in the crash decline. Evaluation of pedestrian countdown signals are currently planned as part of FHWA's Intelligent Transportation Systems (ITS) countermeasures study in Miami, FL; Las Vegas, NV; and San Francisco, CA.[7] At this time, there may be a sufficient number of study sites to perform a crash analysis by pooling study sites from several States.

- **Median refuge islands**: Median refuge islands are often cited as one of the most cost-effective countermeasures; however, many practitioners have indicated a need for additional quantitative data on safety benefits. There are several evaluations of median refuge islands in the literature review, and the FHWA crosswalk marking study by Zegeer et al. indirectly quantified the effects of median refuge islands.[8]

- **In-roadway warning lights**: In-roadway warning lights have become a popular pedestrian enhancement, and they are found in the 2003 MUTCD.[4] There are several studies that document improved motorist yielding and increased braking distance, particularly in lowlight conditions. However, there has been some discussion about their actual safety benefit, and some engineers have suggested that they be removed from the 2003 MUTCD.[4]

- **Rectangular rapid-flashing beacons (RRFBs)**: The research team has identified a low-cost, solar-powered flashing beacon that includes a strobe display. Preliminary tests in Florida indicate that this beacon may be effective at increasing motorist yielding at uncontrolled crosswalks on multilane, high-volume streets. Since the number of installations is limited, more experimental data are needed.

- **Leading pedestrian intervals**: Leading pedestrian intervals provide a "head start" for pedestrians before turning traffic is released. There are a few studies that have evaluated leading pedestrian intervals, and it is planned for evaluation in the FHWA ITS countermeasures study in Miami, FL, and San Francisco, CA.[7]

- **Raised crosswalks**: The literature review contains few studies on raised crosswalks. All studies focused on surrogate safety measures, such as driver yielding. The city of Boulder, CO, has installed numerous raised crosswalks, particularly at right-turn bypass lanes. Raised crosswalks also serve a traffic calming role, but they have limited application on arterial streets.

- **Advanced stop or yield line with regulatory sign at marked crosswalks**: This countermeasure has been evaluated in several studies and is offered as an option in the 2003 MUTCD, but it is not widely used in practice.[4] Advanced stop or yield lines are

thought to be effective at reducing multiple-threat crashes on some roadway types; however, their effectiveness may not be as great for high-speed, high-volume streets.

- **Improved crosswalk or intersection lighting**: The literature review contains limited evaluations of lighting, with a few studies conducted in the 1970s. The concept of smart lighting, or lighting that becomes brighter in the presence of a pedestrian, is planned for evaluation in the FHWA ITS countermeasures study in Miami, FL, and Las Vegas, NV.[7]

- **High intensity Activated crossWalK (HAWK) or pedestrian hybrid signal**: The HAWK has been extensively installed in Tucson, AZ; however, a comprehensive safety study has not been performed yet.

PRACTITIONER PANEL

A practitioner panel was identified and selected to provide feedback and weighting to the candidate countermeasures. The panel was sent the list of candidate bicycle and pedestrian countermeasures and the following rankings were derived:

Bicycle countermeasures:

1. Colored bicycle lanes.

2. Shared lane pavement markings.

3. Standard width bicycle lanes.

Pedestrian countermeasures:

1. Advanced stop/yield line.

2. Leading pedestrian interval.

3. HAWK.

4. RRFB.

5. Pedestrian countdown signals.

The next step of the process was to meet with FHWA staff to select the final list of countermeasures for study. Once the countermeasures were selected, the research team would develop an evaluation plan for each countermeasure.

IDENTIFY POTENTIAL EVALUATION SITES AND EXPERIMENTAL DESIGN

After the top bicycle and pedestrian countermeasures were identified, researchers began to search for potential evaluation sites. The experimental designs and measures of effectiveness that would be appropriate for the given countermeasure were also considered. This research team made the following recommendations at a meeting with FHWA staff on October 23, 2006:

Candidate bicycle countermeasure recommendations:

1. Colored bike lanes.

2. Shared lane pavement markings.

3. Standard width bike lanes.

Candidate pedestrian countermeasure recommendations:

1. Advance yield/stop lines.

2. HAWK.

3. RRFB.

4. Countdown signals.

The final consensus on the priority ranking of countermeasures to be evaluated was as follows:

1. RRFB.

2. HAWK.

3. Shared lane pavement markings for bicyclists.

Following the October 23, 2006, meeting, the research team developed the experimental designs that were used to conduct the evaluation.

ADDITIONAL STUDIES

Approximately 18 months after evaluations of RRFBs, HAWKs, and shared lane markings for bicyclists began, additional funding was provided to examine a fourth countermeasure and to develop a user-friendly safety evaluation document. The following possibilities were discussed for the fourth countermeasure:

- Driver's view (detection distance) of crosswalk markings.

- Crash rates at midblock crossings.

- Midblock transit stops.

Those in attendance at the meeting determined that the driver's view (detection distance) of crosswalk markings should be the fourth countermeasure for this project. A key question to be explored in the study was whether parallel white lines were sufficient for midblock crosswalks. Additionally, the following components were recognized as necessary for a potential update to the 2003 MUTCD:[4]

- Additional figures or illustrations for crosswalk markings similar to the figures that already exist for school and construction zones.

- Text that indicates differences between intersection and midblock pedestrian crossings.

Participants at the meeting liked the systematic approach of the proposed crosswalk marking study, with one participant expressing the importance of having good basic data.

The development of an evaluation methods report for pedestrian and bicycle traffic control devices was also added as part of the project. The purpose of the report is to teach practicing engineers, planners, and public works employees at the local, county, and State levels how to conduct an evaluation of traffic control device effectiveness. The need for this report became apparent because many of the evaluations that were reviewed lacked solid experimental design and research methods.

CHAPTER 3. EFFECTS OF YELLOW RRFBS ON YIELDING AT MULTILANE UNCONTROLLED CROSSWALKS

This chapter summarizes the FHWA report, *Effects of Yellow Rectangular Rapid-Flashing Beacons on Yielding at Multilane Uncontrolled Crosswalks*, FHWA-HRT-10-043.[9]

OBJECTIVE

This study included a series of experiments to examine the effects of side-mounted yellow light-emitting diode (LED) RRFBs at uncontrolled marked crosswalks. Many methods to increase driver yielding behavior to pedestrians at multilane crosswalks at uncontrolled sites with relatively high average daily traffic (ADT) were examined. In previous studies, only treatments that employed a red phase consistently produced sustained high levels of driver yielding behavior.[10] A series of 5 experiments at 22 sites in 3 cities in the United States (St. Petersburg, FL; Washington, DC; and Mundelein, IL) examined the effects of RRFBs on driver yielding behavior. Data were also collected over a 2-year follow-up period at 18 of these sites to determine any long-term effects of the RRFB treatments. Another objective of the study was to compare an RRFB with a traditional overhead yellow flashing beacon and a side-mounted traditional yellow flashing beacon. A final objective of the study was to assess ways to further increase the effectiveness of the treatments. Variants subjected to evaluation included mounting additional units on a median or pedestrian refuge island and aiming the RRFB systems to maximize brightness.

INTRODUCTION

Drivers generally do not yield the right-of-way to pedestrians in marked crosswalks at uncontrolled sites. One alternative to in-roadway signs and yellow flashing beacons is to add yellow LED RRFBs to pedestrian warning signs. These LED RRFBs are similar in operation to emergency flashers on police vehicles. Figure 3 shows an example of an RRFB mounted below a W11-2 pedestrian warning sign at a crosswalk. This system is solar powered and is linked to the unit on the other side of the street by radio frequency transmitters and receivers. Each LED flasher is 6 inches wide and 2.5 inches high and is placed 9 inches apart. Each unit is dual indicated, with LEDs on the front and back. Each side of the LED flasher illuminates in a wig-wag sequence (left and then right). The left LED flashes two times in a slow volley each time it is energized (124 milliseconds (ms) on and 76 ms off per flash). This is followed by the right LED, which flashes four times in a rapid volley when energized (25 ms on and 25 ms off per flash) and then has a longer flash for 200 ms. The effect has been described as a "stutter-flash effect."[11] This pattern was selected because it is similar to one of the patterns used by emergency vehicles. Advance yield markings were installed prior to collecting baseline data to reduce the risk of multiple-threat crashes.

Figure 3. Photo. RRFB with two forward-facing LED flashers and a side-mounted LED flasher.

METHODOLOGY

The general methodology for all of the experiments was measuring driver yielding behavior and vehicle/pedestrian conflicts. Details on methodology are contained in the final report.[9] For driver yielding, observers scored the percentage of drivers who did and did not yield to pedestrians. Drivers were scored as yielding if they stopped or slowed and allowed the pedestrian to cross. Conversely, drivers were scored 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.

The Institute of Transportation Engineers signal formula applied to calculate the duration of the yellow signal phase was used to determine whether a driver could stop safely.[12] A landmark associated with this distance was identified for each approach to the crosswalk. Drivers who passed this landmark before the pedestrian started to cross could be scored as yielding to pedestrians but not as failing to yield because they may not have had sufficient distance to stop safely. Drivers beyond the landmark when the pedestrian entered the crosswalk could be scored as yielding or not yielding because they had sufficient distance to stop safely. When the pedestrian first started to cross, only drivers in the first half of the roadway were scored for yielding. Once the pedestrian approached the painted median, the yielding behaviors of drivers in the remaining two lanes were scored. This procedure was used because it conformed to the obligation of drivers specified in the statutes of each of the three cities that were studied.

RESULTS

Geographic Sustainability

Yielding during the baseline period before the introduction of the RRFB ranged between zero and 26 percent. The introduction of the RRFB was associated with yielding that ranged between 72 and 96 percent at the 2-year follow-up. Table 1 shows the percentage yielding at each of the 22 sites.

Table 1. Baseline and follow-up yielding data at sites in Florida, Illinois, and Washington, DC.

Site	Baseline (Percent)	Day (Percent)							
		7	30	60	90	180	270	365	730
Florida									
31st Street south of 54th Avenue S	0	54	76	N/A	59	N/A	91	75	83
4th Street at 18th Avenue S	0	63	72	N/A	69	N/A	69	80	80
22d Avenue N and 7th Street	0	97	96	91	93	92	91	98	96
9th Avenue N and 26th Street	0	80	82	85	95	81	88	77	78
22d Avenue N and 5th Street	8	87	89	92	92	87	96	92	95
Martin Luther King Street and 15th Avenue S	1	86	84	85	82	N/A	89	88	88
Martin Luther King Street and 17th Avenue N	0	96	94	80	82	83	88	82	83
1st Avenue N and 13th Street	2	85	87	75	78	N/A	91	88	N/A
9th Avenue N and 25th Street	0	86	90	83	90	N/A	88	81	79
1st Street and 37th Avenue N	0	79	87	85	87	N/A	90	97	95
58th Street and 3d Avenue N	0	85	84	85	85	79	92	82	88
Central Avenue and 61st Street	0	94	95	77	73	72	79	67	72
1st Avenue S and 61st Street	5	68	72	73	75	72	90	72	78
1st Avenue N and 61st Street	0	75	75	68	82	42	76	79	83
83d Avenue N and Macoma Drive	0	86	93	91	73	88	84	80	90
9th Avenue N and 45th Street	0	54	91	89	90	80	83	77	78
22d Avenue S west of 23d Street	0	89	86	78	77	60	75	81	82
62d Avenue S and 21st Street	0	77	76	77	53	78	81	84	80
9th Avenue N and 31st Street	16	93	95	89	88	82	82	89	N/A
Florida Average	2	81	86	82	80	76	86	83	84
Illinois									
Midlothian Road and Kilarny Pass Road	7	62	62	N/A	N/A	N/A	N/A	N/A	N/A
Hawley Street and Atwater Drive	19	71	68	N/A	N/A	N/A	N/A	N/A	N/A
Illinois Average	13	67	65	N/A	N/A	N/A	N/A	N/A	N/A
Washington, DC									
Brentwood Road and 13th Street	26	62	74	N/A	N/A	80	N/A	N/A	N/A
Average Yield (All Sites)	4	78	82	83	80	77	85	83	84

N/A indicates that the measure was missed or has not yet been scheduled.

The general statistical methodology used in this study was based on the general time-series intervention regression modeling approach described in Huitema and McKean and McKnight et al. (See references 13–16.)

The five main parameter estimates are shown in table 2. There is an immediate and large increase in yielding from the baseline to day 7, a small but statistically significant additional increase from day 7 to day 30, a minor and not statistically significant decrease at day 60, and a general trend after day 60 that has little slope across the remaining observation days. Therefore, the evidence for change is overwhelming, and the change is maintained for the 2-year duration of the study.

Table 2. Florida data estimates of treatment effect parameters and associated *t*-ratios and *p*-values.

Treatment Effect Parameter	Parameter Estimate	*t*-Ratio	*p*-Value
Baseline level	1.79		
Level change day 7	77.25	29.22	0.001
Level change day 30	6.03	2.38	0.02
Level change day 60	-4.26	-1.75	0.08
Follow-up slope	0.0059	1.62	0.11

Note: Certain cells were left blank because only *t*-ratios and *p*-values that show change from the baseline were included. In the table, there are 166 degrees of freedom for all tests.

Two-Beacon Versus Four-Beacon Systems

This experiment evaluated the effectiveness of the installation of only two RRFBs (one for each direction of an approach mounted at the right-hand side of the approach) as opposed to the installation of four RRFBs (two per approach with one on the roadway median and one on the right-hand side). The average yielding during baseline conditions across four sites was 18.2 percent. Installation and activation of the two RRFB systems increased the average yielding to 81.2 percent. The addition of the median beacons produced a further increase in yielding to 87.8 percent. Yielding for the four-beacon system continued to improve over time during follow-up data collection.

Aimed Versus Unaimed Beacons

This experiment evaluated the effectiveness of RRFBs with LEDs aimed parallel to the approach roadway compared to RRFBs with LEDs specifically aimed toward the eyes of approaching drivers at a given distance in advance of the crossing. The percentage of drivers yielding to pedestrians during the baseline condition was zero percent. The average yielding compliance 7 days after RRFB installation increased to 33.4 percent. There was an additional increase to 72 percent 30 days after installation. The change from parallel LEDs to LEDs that could be aimed produced an increased average of 89 percent.

Night Versus Day Operations

Night data were collected at one site where data had also been collected during the daytime. During daytime collection, the site had a baseline average yielding rate of 18.3 percent. The initiation of the two-beacon and four-beacon RRFB systems increased yielding to 86.7 and 89.6 percent, respectively. When the site was evaluated during nighttime hours, baseline yielding was only 4.8 percent. Introduction of the two-beacon and four-beacon RRFB systems showed increases in yielding to 84.6 and 99.5 percent, respectively.

Standard Beacons Versus RRFBs

Two sites were selected for this experiment. The first site had an above roadway standard yellow flashing beacon, while the second site was equipped with a side-mounted standard yellow flashing beacon attached to a pedestrian warning sign. The average baseline yielding when the standard beacons were present but not activated was 12 percent for the above roadway beacon and zero percent for the side-mounted beacon. Activating the overhead standard beacon produced an average yielding compliance of 15.5 percent. The introduction of a two-beacon RRFB system at this site produced an increase in yielding to 78.3 percent. The introduction of the four-beacon RRFB system was associated with 88 percent yielding compliance. At the second site, activation of the side-mounted standard beacon produced 12 percent yielding compliance. The two-beacon RRFB produced 72 percent yielding compliance. A four-beacon RRFB system was not available for this second site.

CONCLUSION

The results show that the rectangular LED yellow RRFBs appear to be an effective tool for producing large numbers of drivers who yield right-of-way to pedestrians in crosswalks at sites where drivers rarely yielded to pedestrians in the past. The results seem to be maintained over time. Because 19 systems were introduced in St. Petersburg, FL, it is evident that the effects do not diminish when a modest number of systems are installed. However, it is not clear whether the effects will diminish if the device is installed at hundreds or thousands of sites. The findings of this study suggest that the RRFB used in conjunction with advance yield markings can increase yielding and may increase safety at uncontrolled crosswalks at high ADT multilane sites. The data also indicate that mounting additional beacons on a pedestrian refuge island or median increases yielding behavior over using just side-mounted beacons alone. Additionally, aiming the beacon to vehicles at the dilemma zone may also increase yielding behavior. Future research should examine crash data using time-series or empirical Bayes (EB) methodology to determine the safety benefits of the RRFB.

CHAPTER 4. SAFETY EFFECTIVENESS OF THE HAWK PEDESTRIAN CROSSING TREATMENT

This chapter summarizes the FHWA report, *Safety Effectiveness of the HAWK Pedestrian Crossing Treatment,* FHWA-HRT-10-042.[17]

OBJECTIVE

The city of Tucson, AZ, developed the HAWK pedestrian crossing beacon in the late 1990s to assist pedestrians in crossing major arterials.[18] Previous research found driver yielding percentages above 95 percent for the HAWK treatment even on major streets with multiple lanes or higher speeds.[10] Because of the limited number of promising treatments with high yielding rates on major arterials, FHWA sponsored this study to evaluate the safety effectiveness of the HAWK device.

BACKGROUND

Although several roadway treatments are available to address pedestrian concerns, only a few are appropriate for high-speed or wide roadway crossing conditions. The HAWK beacon was developed to address these conditions. At a HAWK crossing, drivers receive multiple cues emphasizing the potential presence of a pedestrian. These cues include the HAWK beacon (two red lenses over a single yellow lens), high-visibility crosswalk markings (ladder-style markings as opposed to only two transverse white lines), a stop bar approximately 50 ft from the crosswalk, 8-inch solid lane lines between through travel lanes, signs which are in some cases illuminated that read "CROSSWALK," and school warning signs. When activated, the HAWK provides drivers with a red indication informing them to stop, allowing pedestrians to cross the major roadway. Figure 4 shows an example of the current head configuration for a HAWK. At the time of this study, HAWKs were being used at more than 60 locations in Tucson, AZ.

Figure 4. Photo. Example of a HAWK treatment in Tucson, AZ.

The HAWK beacon is dark until it is activated by a pedestrian. Activation triggers the warning flashing yellow lens on the major street. After a set time, the indication changes to a solid yellow light to inform drivers to prepare to stop. The beacon then displays a dual solid red light to drivers on the major street and a walking person symbol to pedestrians. At the conclusion of the walk phase, the beacon displays an alternating flashing red light, and pedestrians are shown an upraised hand symbol with a countdown display informing them of the time left to cross. During the alternating flashing red lights, drivers can proceed after coming to a full stop and checking that pedestrians have already crossed their lane of travel. Each successive driver is legally required to come to a full stop before proceeding during the alternating flashing red phase.

The alternating flashing red phase allows the delay to traffic to match the actual crossing needs of the pedestrians. Drivers can proceed with a stop-and-go operation during the flashing red phase. If pedestrians need more time, then the drivers remain stopped until they finish crossing. The ability to balance the pedestrian needs with driver delay is a valuable component of the HAWK treatment. Concerns have been expressed regarding driver behavior and understanding of the dark phase and the flashing red phase. Experiences in Tucson, AZ, have demonstrated that with proper education and experience, drivers understand when they should stop and when they should resume travel. The city of Tucson, AZ, has conducted public campaigns and increased enforcement to teach and encourage appropriate driver and pedestrian behavior at HAWK crossings as well as at all pedestrian crossings.

The city of Tucson, AZ, uses the following criteria when considering the installation of a HAWK:

- Presence of a school crossing.

- Pedestrian crossing activity.

- Traffic speed.

- Gaps.

- Crash experience.

- Number of travel lanes and traffic volumes.

- Spacing of traffic control along the route.

Following the completion of this study but prior to its publication, the 2009 MUTCD was released.[2] It includes information about the pedestrian hybrid beacon, which is similar to the HAWK. The material on pedestrian hybrid beacons in the 2009 MUTCD differs from the HAWKs included in this safety study in the following ways:

- Section 4F.02 of the 2009 MUTCD states, "When an engineering study finds that installation of a pedestrian hybrid beacon is justified, then: A. the pedestrian hybrid beacon should be installed at least 100 feet from side streets or driveways that are controlled by STOP or YIELD signs."[2] All 21 HAWKs in this study were located either at a minor intersection (where the minor street was controlled by a STOP sign) or at a major driveway (where the driveway was controlled by a STOP sign).

- The 2009 MUTCD includes an R10-23 sign with the symbolic red circle and a white background for the crosswalk section of the sign (see figure 5).[2] The signs typically used at the HAWK locations in Tucson, AZ, do not have the symbolic red circle, and the crosswalk background is yellow.

Figure 5. Photo. R10-23 sign from the 2009 MUTCD.[2]

METHODOLOGY

This section presents the safety benefits of the HAWK device. The before-after evaluation used an EB method to compare the observed crash frequency during the after period (with the treatment installed) to an estimate what the crash frequency would have been during the after period if the treatment had not been applied.[19]

Development of Safety Performance Functions

The first step in the before-after EB method was to develop and calibrate safety performance functions (SPFs) using data from a reference group. Development of the SPFs involved determining which predictor variables should be used in the model, how the variables should be grouped, and what model should be used. The major street and minor road ADT values are often the key variables in developing SPFs for intersections. In addition, pedestrian volumes are likely to play an important role in pedestrian crashes. To account for additional intersection-to-intersection variability (other than that caused by the differences in traffic volumes and pedestrian volumes), intersection type, median refuge presence, number of lanes, and major street speed limit were also considered in the SPF predictions.

Site Selection and Geometric Data

The city of Tucson, AZ, provided the research team with a list of all HAWKs that were installed or planned. Sites planned or installed less than 18 months prior to this study were not evaluated. Only sites with the current head configuration (see figure 4) that were newly installed (21 locations) were included in the before-after study. The previous head configuration had a similar appearance as a vertical traffic signal.

Crash evaluations are beneficial when a reference group of similar sites without treatment is identified. Two potential reference groups were identified, and the safety effectiveness estimate for HAWKs were derived using each group. Reference group 1 included 36 signalized and 35 unsignalized intersections. Because of concerns with including signalized intersections, reference group 2 was developed and consisted of 102 unsignalized intersections.

Traffic Counts

Several sources were used to obtain vehicle counts including traffic counts (or historical maps) available on the Web and historical counts from the Pima Association of Governments.[20,21] Vehicle counts from existing sources were identified for most of the major streets in the intersections. None of the existing sources had pedestrian counts available. Therefore, 2-h pedestrian counts were collected during spring 2008 and spring 2009. The city of Tucson, AZ, provided the research team with 24-h video surveillance of five HAWK sites. The number of pedestrian crossings for each hour was counted from the videos, and pedestrian crossing distributions were determined and used to adjust the 2-h count into 24-h counts. Appropriate seasonal variations were determined from *Traffic Volumes Map*, which noted that winter visitors and college students contributed to higher volumes during spring.[21]

Study Periods

For the before-after study, the goal was to have 36 months of before data and 36 months of after data. The before period reflected month 38 to month 2 prior to the installation date of the HAWK. The calculations assumed 2 months prior to the installation date as construction. The 2 months following installation of the HAWK were assumed to be a learning period for drivers to become familiar with the treatment. The after period occurred 2 to 38 months following the installation of the HAWK or until December 31, 2007, which was the limit of crash data available.

The number of months in the after period for the 21 HAWK sites varied depending on when the HAWK was installed. The majority of the sites had a 32-month or greater after period, with more than 80 percent of the sites having at least a 28-month after period. Reference group sites had the same time period in their before and after periods as their corresponding HAWK site.

Crash Data

Crash data were supplied by Tucson, AZ, and street names were used to match crashes with the geometric database. Identifying all crashes with matching street names should capture the crashes that could be influenced by the intersection's traffic control; however, it can also capture crashes that would not have been influenced. The intersection-related (IR) variable may provide insight into whether or not the crash is related to the intersection's traffic control. The permitted responses for IR crashes were "yes," "no," or blank, and about a third of the crashes left this field blank. A comparison of the number of IR crashes for a sample of intersections to information from a previous study indicated that the IR variable may be too restrictive. Therefore, the following two crash datasets were used in the evaluations:

- **Intersecting street name (ISN) crashes:** Identified by matching the street names for the intersection.

- **IR crashes:** Identified as crashes in the ISN crash dataset with "yes" for the IR code.

The following types of crashes from each of the crash datasets were considered:

- **Total crashes:** Included all crashes identified.

- **Severe crashes:** Included all crashes with an injury severity code of possible injury, nonincapacitating injury, incapacitating injury, or fatal injury.

- **Pedestrian crashes:** Included all crashes with the type of collision coded as pedestrian.

Aggregating Crash Data

In developing the SPFs, the crash counts at the reference sites could be treated as aggregated data over the entire study period (including both the before and after periods) or as disaggregated data with two crash counts from each intersection—one for the before period and one for the after period. Aggregating the data is one way to account for the correlations that might be present in the crash counts when the intersections are included twice (once for the before period and once

for the after period) in estimating the SPFs. Disaggregating the data allows researchers to account for general time trends (if any exist) within the two periods. For the disaggregated data, it is desirable to use the generalized estimating equation approach for estimating the SPF coefficients. This incorporates the potential correlation in the before and after crash counts from the same intersection. Both approaches were explored in this study.

OBSERVATIONS

Table 3 summarizes the number of crashes by traffic control type. HAWKs were installed to assist pedestrians in crossing the roadway; therefore, installing the device should have had an impact on pedestrian crashes. The impact on total or severe crashes was not as intuitive. Using IR crashes, the HAWK sites experienced a decrease of about 34 percent in the total crash rate after installation. The 102 unsignalized intersections in reference group 2 experienced a decrease of 9 percent, and the 36 signalized intersections in reference group 1 had a 17 percent decrease. These observations indicate that citywide conditions may be contributing to the reduction in crashes since all types of intersection controls showed reductions in total IR crashes.

The HAWK sites experienced a significantly large decrease of 86 percent in the pedestrian IR crash rate after installation. The 102 unsignalized intersections in reference group 2 experienced an increase of 143 percent in pedestrian crashes. Therefore, if citywide conditions are contributing to reductions in total crashes, these conditions do not have the same impact on pedestrian crashes. Other factors may be contributing to a rise in pedestrian crashes at unsignalized intersections but not signalized and HAWK intersections.

In table 3, it is observed that HAWK locations have crash rates higher than unsignalized intersections. For this dataset, the HAWK locations were associated with a slightly greater number of crashes per million entering vehicles and pedestrians as compared to the nearby unsignalized intersections. This observation does not imply that if the HAWK was removed, the crash rate for a given intersection would be similar to the crash rate identified for the neighboring unsignalized intersections. The crash rate at the HAWK sites when they were unsignalized intersections (i.e., before the HAWK was installed) exceeded the crash rate for nearby unsignalized intersections. Therefore, conditions at the HAWK locations before the treatment was installed were generating crashes in greater numbers than the unsignalized intersections. This indicates that those intersections were associated with conditions that resulted in a higher number of crashes. Addressing those conditions with a HAWK resulted in a decrease in total crashes and a large decrease in pedestrian crashes. The following section provides the findings from the statistical evaluation.

Table 3. Crash data for before-after study by groups.

Treatment Group	Measure	ISN Crashes			IR Crashes		
		Before	After	Percent Change	Before	After	Percent Change
HAWK sites (21)	Frequency	11.0	9.2	-17	5.0	3.3	-34
	Total crashes/MEV&P[1]	0.748	0.618	-17	0.341	0.223	-35
	Severe crashes/MEV&P	0.265	0.210	-21	0.138	0.094	-32
	Pedestrian crashes/MEV&P	0.029	0.005	-83	0.017	0.002	-86
	Pedestrian crashes/MEP[2]	3.081	0.511	-83	1.826	0.255	-86
Reference group 1: signalized intersections (36)	Frequency	44.9	41.9	-7	19.6	16.8	-14
	Total crashes/MEV&P	1.953	1.788	-8	0.854	0.716	-16
	Severe crashes/MEV&P	0.549	0.503	-8	0.294	0.241	-18
	Pedestrian crashes/MEV&P	0.020	0.016	-23	0.010	0.008	-16
	Pedestrian crashes/MEP	2.051	1.546	-25	1.025	0.839	-18
Reference group 1: unsignalized intersections (35)	Frequency	4.2	4.3	3	1.6	1.3	-17
	Total crashes/MEV&P	0.285	0.292	2	0.108	0.090	-17
	Severe crashes/MEV&P	0.098	0.088	-10	0.043	0.038	-10
	Pedestrian crashes/MEV&P	0.006	0.009	52	0.003	0.004	42
	Pedestrian crashes/MEP	1.383	2.078	50	0.615	0.866	41
Reference group 2: unsignalized intersections (102)	Frequency	5.9	6.1	3	2.4	2.1	-9
	Total crashes/MEV&P	0.418	0.430	3	0.166	0.150	-9
	Severe crashes/MEV&P	0.140	0.141	0	0.060	0.056	-6
	Pedestrian crashes/MEV&P	0.006	0.011	93	0.001	0.003	143
	Pedestrian crashes/MEP	1.233	2.297	86	0.257	0.602	134

[1]Crashes/MEV&P = Type of given crash (total, severe, or pedestrian crashes) per million entering vehicles and pedestrians (MEV&P).
[2]Pedestrian crashes/MEP = Pedestrian crashes per million entering pedestrians (MEP).
Note: Frequency is expressed as the average annual number of total crashes for a site with the given intersection control and study period.

RESULTS

To account for the effects of variables in crash reduction as well as the potential regression-to-the-mean bias, an EB approach was employed to identify the safety effectiveness of the HAWK treatment. The main corresponding report includes the reasonable SPFs identified in this study.[17] Although the magnitude of the safety effectiveness estimate varies to some extent as different predictors are included in the SPFs, the results did not seem to change materially.

Table 4 summarizes the percent reduction and whether the findings were significant at the 95 percent level from the different approaches used in evaluating the HAWK beacon.

Table 4. Summary of results.

Reference Group (Aggregation)	Percent Reduction (Significant at the 95 Percent Confidence Level)		
	Total Crashes	Severe Crashes	Pedestrian Crashes
ISN Crashes			
1 (aggregated)	15 (Yes)	11 (No)	57 (Yes)
2 (aggregated)	14 (Yes)	13 (No)	59 (Yes)
2 (disaggregated)	19 (Yes)	14 (No)	69 (Yes)
IR Crashes			
1 (aggregated)	29 (Yes)	18 (No)	56 (No)
2 (aggregated)	29 (Yes)	15 (No)	51 (No)
2 (disaggregated)	23 (Yes)	8 (No)	65 (Yes)

The results for total crashes were similar regardless of the approach used to evaluate the data. The reduction was about 16 percent for ISN crashes (14 to 19 percent) and 27 percent for IR crashes (23 to 29 percent), which were all significant at the 95 percent confidence level.

There were similar results for pedestrian crashes, with the disaggregate approach resulting in higher reductions (65 or 69 percent) than the aggregate approaches (between 51 and 59 percent). As seen in several evaluations, severe crash results were not significant. The smaller sample size probably affected the results.

Although the safety effectiveness estimate did not change significantly with which reference group was used, reference group 2 was chosen as the more appropriate reference group because the HAWK was installed at a previously unsignalized intersection in most cases.

SUMMARY AND CONCLUSIONS

The objective of this study was to evaluate the safety effectiveness of the HAWK device. A before-after EB method was used, which accounts for possible regression-to-the-mean bias as well as traffic, weather, citywide public relations campaigns, and other factors that change over time. SPFs were developed using reference site data consisting of nearby intersections that did not have HAWK treatments. The study included 21 intersections where a HAWK had been installed and two reference groups. Evaluation approaches explored the following:

- Three types of crashes (total, severe, and pedestrian).

- Two methods for identifying crashes (ISN and IR).

- Two reference groups (reference group 1 with 36 signalized and 35 unsignalized intersection and reference group 2 with 102 unsignalized intersections).

- Two ways to combine the reference group before and after data (aggregated and disaggregated).

The crash prediction during the before period was calculated from SPFs and combined with the observed crash count for the before period by using a weighted average to control for regression-to-the-mean bias. This weighted average was adjusted for differences in duration and traffic volumes (and general time trends if any existed) between the before and after periods to lead to a crash prediction for the after period had the treatment not been applied. EB then compared this predicted value to the observed crash frequency for the after period.

Two crash datasets were used in the before-after evaluation. In theory, the IR crash dataset should better represent crashes that would be affected by the traffic control at the intersection. A closer review revealed that the IR code was not used in over a third of the crashes; therefore, too many crashes may have been eliminated. The ISN crash dataset, however, may include crashes that are not related to the traffic control. Therefore, both datasets were considered. The IR crashes were considered as the more appropriate dataset for total and severe crashes. the ISN crash dataset may be more representative of the change in pedestrian crashes since the HAWK device could induce pedestrians to walk an additional distance to benefit from an activated traffic control device.

The before-after evaluation results were as follows:

- There was a 29 percent reduction in total crashes, which is statistically significant at the 95 percent confidence level.

- There was a 69 percent reduction in pedestrian crashes, which is statistically significant at the 95 percent confidence level.

- There was a 15 percent reduction in severe crashes, which is not statistically significant at the 95 percent confidence level.

The prime objective of a HAWK is to provide pedestrians with safe crossing opportunities. As such, a reduction in pedestrian crashes was expected to be associated with the HAWK, and a statistically significant reduction in pedestrian crashes was found. The installation of the HAWK was also associated with a statistically significant reduction in total crashes. It should be noted that the HAWK treatment, just like any other warning traffic control device, may not work as effectively if it is overused. In addition, the high crash reductions identified in this study may not be achieved at future locations if the site has different characteristics, such as reduced pedestrian activity.

CHAPTER 5. SHARED LANE MARKINGS

This chapter summarizes the FHWA report, *Evaluation of Shared Lane Markings,* FHWA-HRT-10-041.[22]

OBJECTIVE

Shared lane markings, widely referred to as sharrows, are intended to convey to motorists and bicyclists that they must share the roads on which they operate. The markings create improved conditions by clarifying where bicyclists are expected to ride and by notifying motorists to expect bicyclists on the road. Figure 6 illustrates a generic sharrow as it appears in the 2009 MUTCD.[2] This study evaluated the impact of several uses of shared lane markings, specifically the sharrow design, on operational and safety measures for bicyclists and motorists. Experiments were conducted in Cambridge, MA, Chapel Hill, NC, and Seattle, WA.
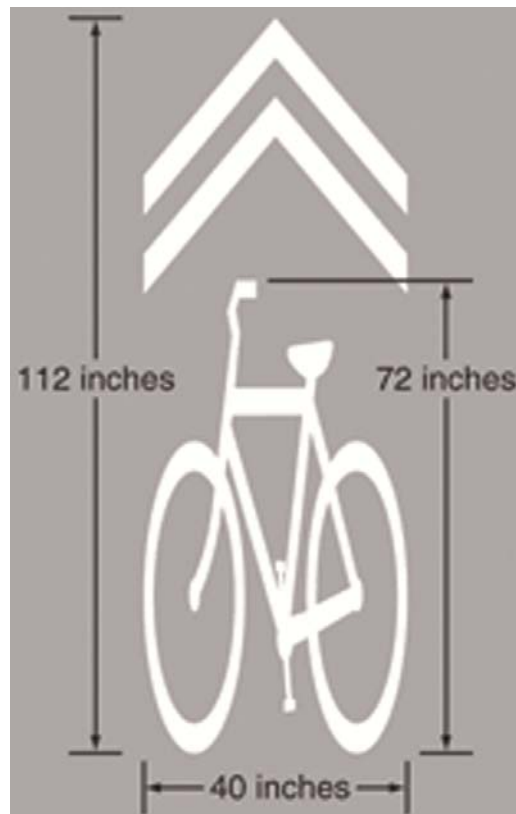

112 inches 72 inches

40 inches

Figure 6. Illustration. Generic version of a sharrow.

BACKGROUND

In 2008, NCUTCD recommended the inclusion of shared lane markings in the next version of MUTCD.[23] The recommendation was made with limited research conducted only on an 11-ft spacing from the center of the shared lane marking to the curb to prevent a bicyclist from striking an opening door of a parked motor vehicle (i.e., a dooring crash).[24] The 2009 MUTCD includes a provision for shared lane markings, specifically the sharrow design, with guidance

that the markings should be placed at least 11 ft from the curb face or the edge of the pavement on a street with parallel parking.[2] On streets with no parking and an outside lane less than 14 ft wide, the centers of the sharrows should be placed at least 4 ft from the curb or edge of the pavement.

Many cities and States have started implementing shared lane markings to encourage the safe coexistence of bicyclists and motorists. However, few localities have formally evaluated the impact of these markings on safety or operations. The following hypotheses were explored for sharrows:

- The markings may help indicate a preferred path of travel, thereby improving bicyclist positioning relative to parked motor vehicles when riding in shared lanes with on-street parking.

- The markings may help improve spacing or operations when motorists pass bicyclists on streets both with and without parking.

- The markings may help improve bicyclist positioning relative to the curb or other hazards along the roadway edge, including unsafe drain grates or uneven pavement.

- The markings could be used where bicyclists need to take control of the lane, such as on a section of steep downgrade where they need more operating space and where there is inadequate width to provide a sufficiently wide bicycle lane. They could also be used in a shared lane situation or in a narrow lane situation where bicyclists need to move away from the door zone or other hazards.

- The markings may reduce bicyclist wrong-way and sidewalk riding, which can cause collisions.

- The markings may increase the distance from motor vehicles in the travel lane to parked motor vehicles or to the curb in the absence of bicyclists, providing more operating space for bicyclists.

Separate evaluations were conducted in three U.S. cities. In Cambridge, MA, there was interest in experimenting with the placement of sharrows 10 ft from the curb to prevent dooring from parked motor vehicles. In Chapel Hill, NC, sharrows were placed on a busy five-lane corridor with wide outside lanes and no street parking. In Seattle, WA, sharrows were placed in the center of the lane on a downhill portion of a busy bicycle commuting street. Prior to the sharrows, a 5-ft bicycle lane was added to the uphill portion of the street, and the center line of the street was shifted.

METHODOLOGY

The experimental design was to collect data on bicycles and motor vehicles operating in the traffic stream before and after sharrow installation. While it would have been desirable to have used an experimental design with comparison data, no adequate comparison sites were available. This is often the case in bicycle safety studies where slight differences in traffic flow, grade,

pavement surface, or some other variable can greatly influence outcomes. One way to possibly obtain a comparison site is to install a treatment on part of a route and to use the remainder as a comparison. However, when a community is installing a treatment, almost invariably, the intention is to install the treatment along the entire route.

Local staff collected videotape data before and after sharrow placement. The bicycle was the basic unit of analysis. A number of measures of effectiveness and other attributes were examined. Videotape coding was performed to obtain information about the bicyclist and to examine the operations of bicycles and motor vehicles when a motorist was following or passing a bicyclist. In Cambridge, MA, and Seattle, WA, events related to the presence of parked motor vehicles were also examined, such as existing open doors and near dooring events, as well as motorists pulling into or out of parking spaces.

The following spacing data were also obtained from images extracted from the videotapes:

- Distance between bicycles and parked motor vehicles (tire to tire).

- Distance between bicycles and the curb at the edge of the road (tire to curb) where there was no parking.

- Distance between bicycles and passing motor vehicles (tire to tire).

- Distance between motor vehicles in the travel lane and parked motor vehicles (tire to tire) or the curb (tire to curb) when no bicycles were present.

Chi-square tests were used to examine the distributions of variables before and after sharrow placement. Analysis of variance models were used to study the effect of sharrows on spacing and other performance measures. In these models, the independent variables included site characteristics, type of treatment, and a dummy variable indicating whether it was a before or after condition. The sign and significance of the coefficient of this dummy variable were used to assess the effectiveness of the markings. None of the data were combined across sites because of differences in the uses of the sharrows in each city.

Cambridge, MA, Experiment

Cambridge, MA, has many street cross sections where the recommended 11-ft spacing from the curb would not be feasible. Sharrows were placed 10 ft from the curb for about 2,500 ft on Massachusetts Avenue, which is a 4-lane divided street with approximately 29,000 vehicles per day, parallel parking on both sides, and a speed limit of 30 mi/h. Figure 7 shows Massachusetts Avenue before sharrows were placed on the street. Figure 8 shows a sketch of the before and after conditions. The intent was to determine whether the sharrows would improve spacing of bicycles and motor vehicles while also helping to prevent dooring.

Figure 7. Photo. Massachusetts Avenue condition in the before period.

Before Sharrow

21'   11'   5'   11'   21'

After Sharrow

10'

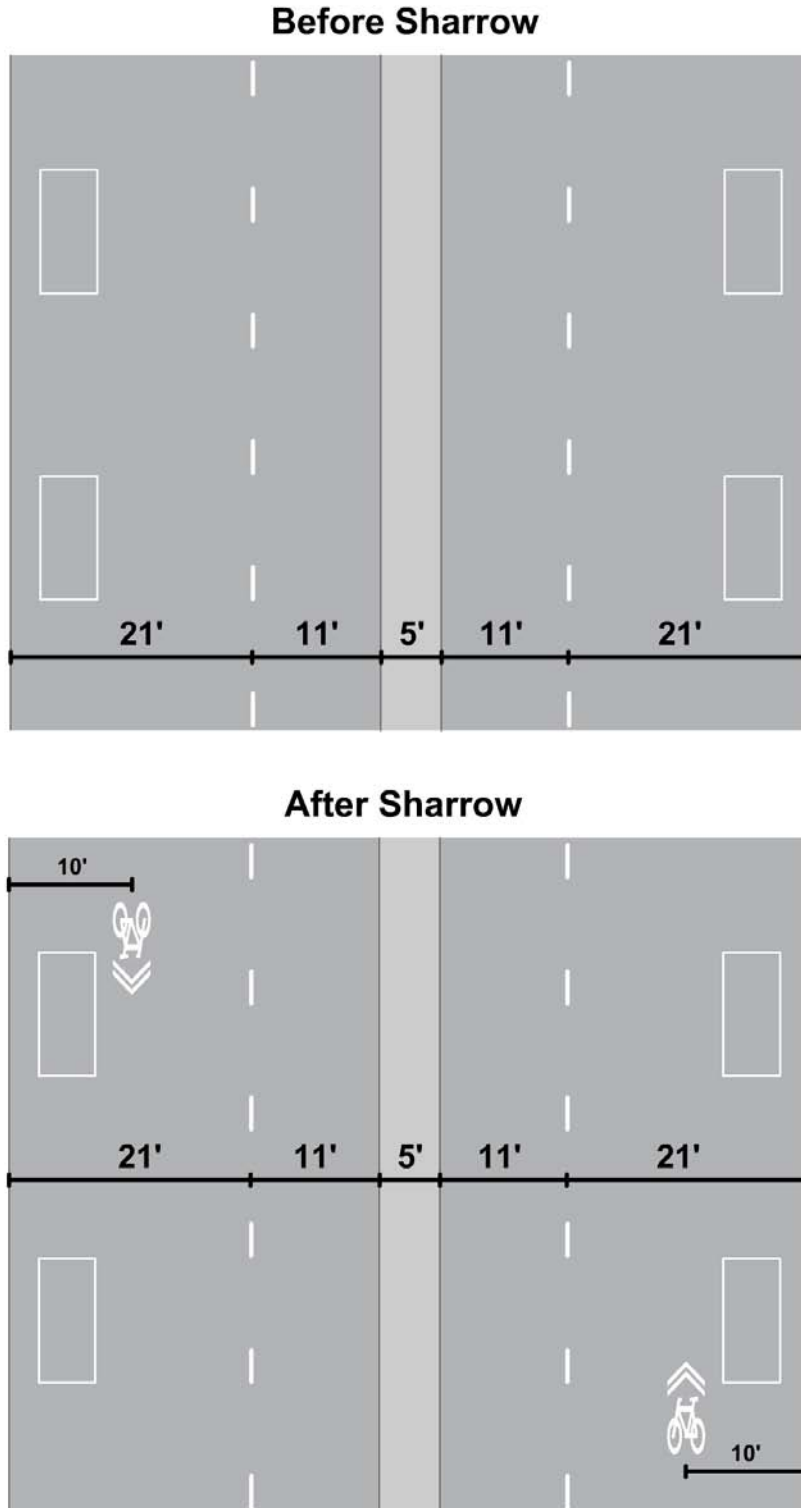21'   11'   5'   11'   21'

10'

Figure 8. Illustration. Cross section view of Massachusetts Avenue before and after sharrow installation.

A total of 94 percent of the bicyclists rode over the sharrows. Further results pertaining to the interaction of bicycles and motor vehicles included the following changes from before to after. All of the differences were from before-after distributions, and p-values are shown to denote statistical significance. The after period results were as follows:

- The percentage of bicyclists who took the lane decreased from 13 to 8 percent ($p = 0.019$).

- The percentage of avoidance maneuvers (i.e., changing speed or direction to avoid another party) decreased from 76 to 37 percent ($p < 0.0001$).

- The percentage of bicyclists who yielded (i.e., gave way to a motorist) decreased from 23 to 7 percent ($p < 0.0001$).

- The percentage of motorists who yielded (i.e., gave way to a bicyclist) increased from 5 to 9.5 percent ($p < 0.0001$).

- The percentage of motorists who made no change while following a bicyclist increased from 44 to 65 percent ($p < 0.0001$).

Results pertaining to the spacing of bicycles and motor vehicles in the presence of a following motor vehicle in the after period included the following:

- The distance from a bicyclist riding beside a parked motor vehicle increased from 40.1 to 42.3 inches when both directions were combined ($p = 0.025$) and increased from 37.4 to 41.5 inches for the inbound direction ($p = 0.002$).

- Outbound spacing was 42.7 inches in the before period and 43.1 inches in the after period, which was a nonsignificant (n.s.) change ($p = 0.791$).

- The percentage of bicyclists who rode within 40 inches (i.e., near the door zone) of parked motor vehicles decreased ($p < 0.0001$). Most of the effect was in the inbound direction with a decrease from 73 to 44 percent ($p < 0.0001$). Comparable outbound values were 44 percent in the before period and 38 percent in the after period (n.s., $p = 0.791$).

- The percentage of bicyclists who rode within 30 inches (i.e., within the door zone) remained unchanged at 13 percent (n.s., $p = 0.893$).

Results pertaining to the spacing of bicycles and motor vehicles in the absence of a following motor vehicle in the after period included the following:

- The change in distance between a bicyclist and a parked motor vehicle was negligible, approximately 45 inches before and after (n.s., $p = 0.553$).

- The percentage of bicyclists who rode within 40 inches of parked motor vehicles increased from 37.5 to 45 percent (n.s., $p = 0.143$), although this may reflect the high percentage of bicyclists who rode over the sharrows.

- When motorists drove past parked motor vehicles in the absence of bicycles in the after period, the spacing increased 16 inches (from 77.4 to 93.6 inches) in the inbound direction, 12 inches (from 84.5 to 96.5 inches) in the outbound direction, and 14 inches (from 80.9 to 95.0 inches) combined (($p < 0.0001$ for all differences).

Overall results from Cambridge, MA, indicated the following:

- A total of 94 percent of bicyclists rode over the sharrows.

- There was more operating space for bicycles as motor vehicle spacing from parked motor vehicles increased.

- A number of variables related to the operations of bicycles and motor vehicles showed positive effects.

- Placement of the sharrows 10 ft from the curb (instead of 11 ft) was not a problem.

Chapel Hill, NC, Experiment

Sharrows were placed 43.5 inches from the curb along Martin Luther King, Jr. Boulevard (MLK) for 1.25 miles. MLK has a 5-lane cross section (4 travel lanes and a center 2-way left turn lane) with no parking, 27,000 vehicles per day, a speed limit of 35 mi/h, and periodic sunken drain grates next to the curb. There was a 3 to 4 percent grade where the videotape data were collected. The street had previously been resurfaced, and the outside lanes were marked nominally as 15-ft-wide lanes. The spacing of bicycles and motor vehicles from the curb and in situations where motorists passed bicyclists was of primary interest. Figure 9 shows MLK in the before period, and figure 10 provides a sketch of the before and after conditions.
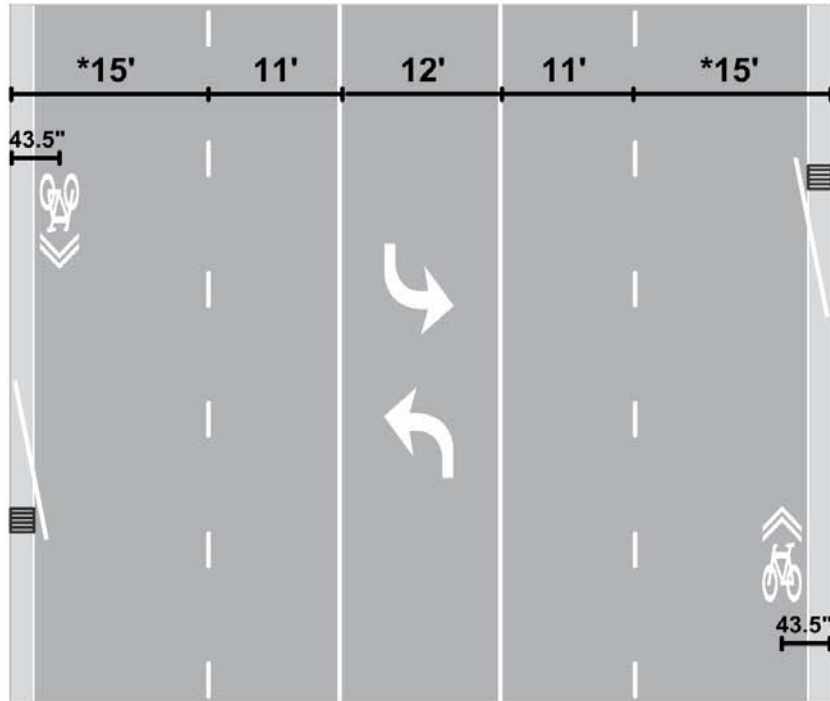

Figure 9. Photo. MLK in the before period.

Before Sharrow

*15'   11'   12'   11'   *15'

After Sharrow

*15'   11'   12'   11'   *15'

43.5"

43.5"
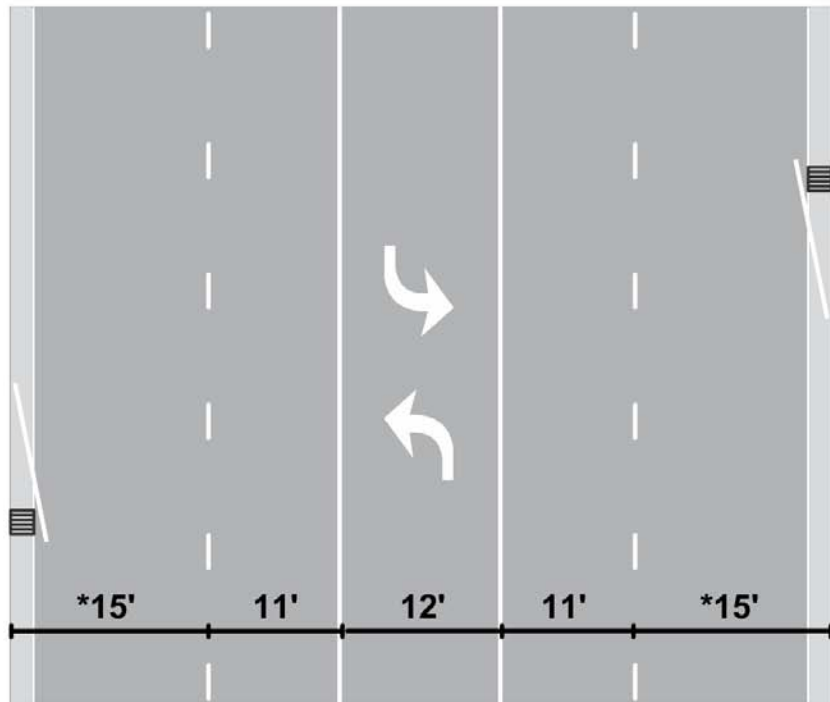
* Indicates that a 2-ft gutter pan was included.

Figure 10. Illustration. Cross section of MLK before and after sharrow installation.

A total of 91 percent of the bicyclists rode over the sharrows—97 percent in the downhill direction and 88 percent in the uphill direction. Bicyclists riding uphill traveled slower and tended to ride closer to the curb. Further results pertaining to the interaction of bicycles and motor vehicles included changes from the before to the after period. All of the differences were from before-after distributions, and p-values are shown to denote statistical significance. The after period results were as follows:

- The percentage of motorists who made no movement to change lanes when overtaking a bicyclist increased from 24 to 32 percent ($p = 0.0409$).

- There was no statistically significant difference in the proportion of bicyclists riding near the curb (approximately 98 percent) or taking the lane (approximately 2 percent).

- The percentage of avoidance maneuvers decreased from 81 to 71 percent ($p < 0.0001$).

- The percentage of motorists staying in the lane when following bicyclists increased from 20 to 29 percent ($p = 0.0110$).

- There was no statistically significant difference in the percentage of bicyclists or motorists who yielded.

Results pertaining to the spacing of bicycles and motor vehicles included the following:

- In the presence of a following motor vehicle in the after period, bicyclists rode closer to the curb after the sharrows by about 2.5 inches (from 40.1 to 37.7 inches (n.s., $p = 0.165$)). The effect was more pronounced downhill (4.6 inches closer, $p = 0.049$) versus uphill (2.9 inches closer, n.s., $p = 0.233$). Similar to Cambridge, MA, this was likely a reflection of bicyclists tracking over the sharrows.

- There were slight increases in the percentages of bicyclists who rode within 30 and 40 inches of the curb. The percentage within 30 inches increased from 12.5 to 15 percent downhill (n.s., $p = 0.653$) and 47.3 to 50.5 percent uphill (n.s., $p = 0.656$).

- When motorists passed bicyclists in the after period, there was a small decrease in the passing distance overall from 82 to 79 inches (n.s., $p = 0.1128$). In the downhill direction, motorists passed 7 inches closer to bicycles from 84.7 to 77.7 inches ($p = 0.012$). There was a small increase in the uphill direction from 80.0 to 81.1 inches (n.s., $p = 0.661$).

- The percentage of passing motor vehicles within 50 inches showed only small differences from 2.0 to 2.6 percent (n.s., $p = 0.975$).

- When the distance of the right front tires of motor vehicles from the curb in the absence of bicycles was examined in the after period, the spacing increased 8.3 inches in the uphill direction (from 64.4 to 72.7 inches, $p < 0.001$), 4.7 inches in the downhill direction (from 76.6 to 81.3 inches, $p = 0.017$), and 7 inches overall (from 70.5 to 77.0 inches, $p < 0.001$).

- The percentages of motor vehicles within 50 and 60 inches of the curb were also significantly lower in the after period. The effect was most pronounced in the uphill direction from 16 to 4 percent within 50 inches ($p = 0.010$) and from 46 to 17 percent within 60 inches ($p < 0.001$).

- Bicyclist sidewalk riding significantly decreased from 43 percent in the before period to 23 percent in the after period ($p < 0.001$). In the downhill direction, sidewalk riding decreased from 39 to 10 percent ($p < 0.001$) with no significant change in the uphill direction.

- Wrong-way riding by bicyclists was 11 percent in the before period and 8 percent in the after period (n.s.).

Overall results from Chapel Hill, NC, indicated the following:

- A total of 91 percent of bicyclists tracked over the sharrows and rode at a safe distance from the edge of curb with more of an effect in the downhill direction.

- Motorists moved away from the sharrows, providing more operating space for bicyclists.

- Several variables related to the operations of bicycles and motor vehicles showed positive effects.

- Bicyclist sidewalk riding decreased in the downhill direction.

- There was no change in the percentage of bicyclist wrong-way riding.

Seattle, WA, Experiment

Sharrows were placed in the center of the lane 12.25 ft from the curb on a downhill section of Fremont Street, which is a 2-lane street that has a speed limit of 30 mi/h, 10,000 vehicles per day, a 3.6 percent grade, and parking on both sides of the street. The placement was meant to encourage bicyclists to take the lane while traveling downhill. Data were collected in two additional after periods following the before period. The centerline of the street was repositioned to allow a 5-ft bicycle lane and parking line to be installed on the uphill section of the street (after period 1). Sharrows were then added in the downhill direction (after period 2) since there was not enough width for bicycle lanes on both sides of the streets. Figure 11 shows a section of Fremont Street in the before period, and figure 12 provides a sketch of the before and after conditions.

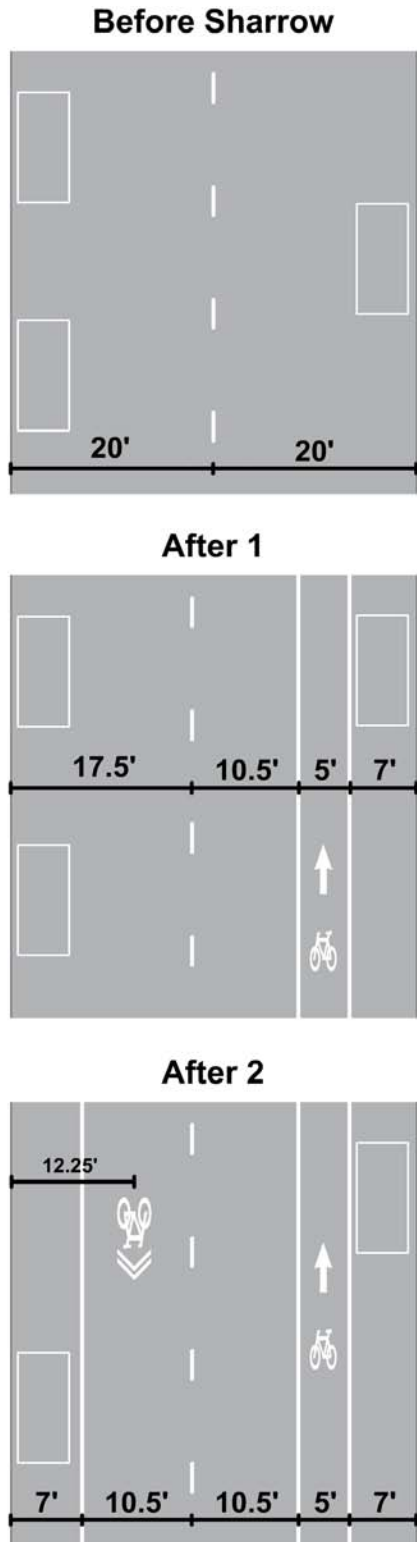**Figure 11. Photo. Fremont Street in the before period.**

Figure 12. Illustration. Cross section view of Fremont Street before and after sharrow installation.

A total of 15 percent of the bicyclists rode over the sharrow during after period 2. Further results pertaining to the interaction of bicycles and motor vehicles included the following changes from before-after distributions, with *p*-values denoting statistical significance:

- There was no statistically significant difference in the safety of the manner in which motorists were following and passing bicyclists. Overall, 97 percent of these maneuvers were considered to be performed safely (i.e., without an abrupt movement by either party).

- A significantly higher percentage (51 versus 27 percent) of bicyclists shifted toward the center of the lane and took the lane during after period 1 when the lane was narrowed to accommodate the addition of the bicycle lane in the uphill direction ($p < 0.0002$).

- The percentage of bicyclists who yielded (i.e., changed direction or speed to give way to a motor vehicle) decreased from 3.3 percent in the before period to 2.8 percent in after period 1 and 0.7 percent in after period 2 ($p = 0.0487$).

- The percentage of motorists who yielded (i.e., changed direction or speed to give way to a bicycle) decreased from 13 percent in the before period to 6.5 percent in after period 1 and 5 percent in after period 2 ($p = 0.0487$).

Results pertaining to the spacing of bicycles and motor vehicles included the following:

- In the absence of following motor vehicles, the average spacing between bicycles and parked motor vehicles did not significantly change across periods (45.8 inches in the before period, 47.5 inches in after period 1, and 44.5 inches in after period 2, $p = 0.217$).

- The percentage of bicyclist spacing values within 30 inches (i.e., within the door zone) increased from about 6 percent in the before period to about 12 percent in the two after periods ($p = 0.054$).

- The percentage of bicyclist spacing values within 40 inches increased from 36 percent in the before period to 39 percent in after period 1 and 44 percent in after period 2 (n.s., $p = 0.348$).).

- When motorists drove past parked motor vehicles in the absence of bicycles in both after periods, the average spacing decreased about 18 inches ($p < 0.001$) due to the change in the roadway configuration (the lane had been narrowed by 2.5 ft).

Overall results from Seattle, WA, indicated the following:

- Sharrow placement alone did not seem to result in an increase in the percentage of bicyclists taking the lane.

- Bicyclists were already riding out of the door zone in the before period and stayed in this location in both after periods. Sharrows had previously been installed 11 ft from the curb

next to parked cars over a 2,000-ft, four-lane section of Fremont Street leading into the section studied in the current project.

- It is possible that narrowing the travel lanes and adding the uphill bike lane had more of an effect on operations and spacing than the addition of sharrows.

- Bicyclists riding in the street seemed experienced and showed that it was not necessary to ride in the middle of the lane to control the lane.

CONCLUSIONS

Sharrows can be used in a variety of situations, and it is assumed that increased use should enhance motorist awareness of bicyclists, or the possibility of bicyclists, in the traffic stream. Results indicate that sharrows increased operating space for bicyclists. Sharrows have reduced sidewalk riding not only in the current study but also in a previous study in Gainesville, FL.[25] As communities continue to experiment with various uses of sharrows, it is recommended that researchers continue to create similar trials in other locations and traffic settings. Additionally, it is important to evaluate and report those experiments so that more data can be examined to provide improved guidance to users.

CHAPTER 6. CROSSWALK MARKING FIELD VISIBILITY STUDY

This chapter summarizes the FHWA report, *Crosswalk Marking Field Visibility Study,* FHWA-HRT-10-068.[26]

OBJECTIVE

The objective of this study was to investigate the relative daytime and nighttime visibility of three crosswalk marking patterns: transverse lines, continental markings, and bar pair markings.

BACKGROUND

Crosswalk markings provide guidance for pedestrians crossing roadways by defining and delineating paths on approaches. These markings are used in conjunction with signs and other measures to alert road users of a designated pedestrian crossing point. Part 3 of the 2009 MUTCD contains basic information about crosswalk markings.[2] Because some States adopt their own supplement or manual on traffic control devices and some develop policies and practices for subjects not discussed in MUTCD, differences in markings can occur among States, cities, and other jurisdictions.

While greater emphasis has recently been placed on researching pedestrian treatments, there is insufficient research to determine the relative visibility and driver behavior effects of the many different styles and patterns of crosswalk markings being used in the United States and abroad. Previous research studies focused on whether the presence of the markings (rather than a specific pattern) was effective.[27–29] The lack of information of the relative visibility of different marking patterns has inhibited the development of a consensus on whether more uniformity is needed in the form of tighter MUTCD standards or more comprehensive guidance on crosswalk markings.

STUDY APPROACH

Participants drove an instrumented vehicle on a route through the Texas A&M University campus in College Station, TX. The route provided an open road environment for the drivers that included portions in a typical college setting (e.g., sidewalks, buildings, basketball arena, etc.) and roads through the agricultural area of the campus (e.g., roadways that are more rural). Roadway lighting was present at all crosswalk locations. The study vehicle was equipped with instrumentation that allowed the researchers to measure and record various driving performance data. However, the vehicle operated and drove like a normal vehicle. The study was conducted during the day and at night.

The 78 participants were nearly evenly divided by gender and age (younger than 55 years old and 55 years old or older). Existing markings (six intersection and two midblock locations) and new markings installed for this study (nine midblock locations) were tested. Figure 13 shows an example of bar pairs installed for this study, figure 14 shows an example of continental markings, and figure 15 shows an example of transverse markings.

Figure 13. Photo. Example of bar pair markings.

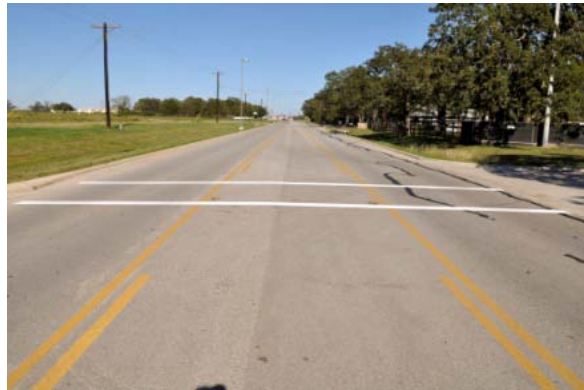**Figure 14. Photo. Example of continental markings.**

Figure 15. Photo. Example of transverse markings.

Once each participant was comfortable in the instrumented vehicle and had driven to a parking lot near the start of the route, he or she was reminded to indicate when one of the following items was seen: crosswalk markings, two-way left-turn arrows, or speed limit signs. The arrows and signs were included to ensure that the driver utilized a normal eye glance pattern and was not exclusively searching for crosswalks. As soon as the driver said "crosswalk," the rear seat experimenter pressed the appropriate button to place a mark in the computer file to indicate detection. Detection distances were adjusted by an experimenter response-time factor determined

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through pretesting. For the nine crosswalks installed for this study, the adjustments to the participant's detection distance ranged between 3 and 13 percent.

After completing the initial route, each participant was given additional instructions and asked to drive the same route again to rate each crosswalk marking on how easy it was to see using a scale of A (excellent, very easy to see) to F (completely unacceptable, it would have missed if not looking for it).

RESULTS

The prime objective of this study was to determine the detection distance of a crosswalk and to identify the variables that affect this distance. The differences in detection distances were evaluated with consideration of variables grouped into the following classes:

- Light (day or night).

- Site characteristics.

  - Marking type (transverse, continental, and bar pairs).

  - Location (study, existing intersection, and existing midblock).

  - Street characteristics (crossing width, posted speed limit, sidewalk presence, and rural or urban feel).

  - Retroreflectivity.

- Traffic characteristics.

  - Traffic presence that could affect detection distance.

  - Pedestrian or bicyclist presence.

  - Driver speed.

- Vehicle type (sedan or SUV).

- Driver characteristics.

  - Driver eye height.

  - Gender.

  - Age group (younger than 55 years old or 55 years old and older).

Initially, the statistical model contained all main effects and possible two-way interactions (termed the extended model). Not all variables could be included in the extended model due to exact linear dependency issues for some of the factors (i.e., a linear combination of one or more

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factors' values can exactly duplicate another factor's values). Next, several models with a subset of variables in the extended model were explored to determine the best model for identifying the variables that influence detection distance (termed the reduced model). Interactions were dropped from the reduced models when the p-value was less than 0.05 (i.e., not statistically significant).

The evaluations were conducted separately for the study sites (where new markings were installed at midblock locations) and the existing sites (where markings were already present at an intersection or were already present midblock and had pedestrian warning signs). The preliminary evaluations clearly showed a difference in detection distance for day and night. Because the nighttime condition had the additional variable retroreflectivity to consider and some of the variables were believed to have different effects during the night (i.e., marking type, vehicle type, and driver eye height), separate analyses were performed for daytime and nighttime conditions. In all combinations, daytime detection distances were longer than nighttime detection distances.

For the study sites, the marking type (bar pair, continental, or transverse) was statistically significant. The detection distances for bar pairs and continental markings were statistically similar, and they were both statistically different from and longer than the detection distance to the transverse markings both during the day and at night (see figure 16).
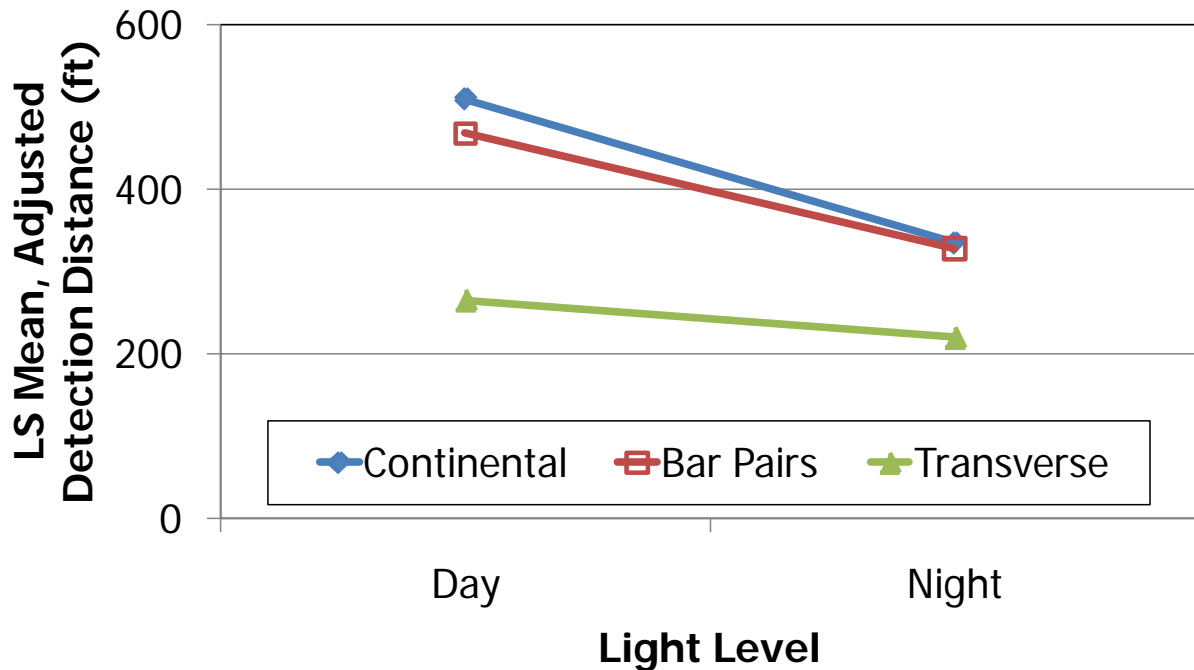

Figure 16. Graph. Least square mean detection distance by marking type and light level for study sites.

The presence of traffic had an impact on detection distance at the study sites, which limited the ability to see the markings farther upstream in most cases, as expected (see figure 17). The impact of traffic on the transverse markings was minimal, as the detection distances to these markings were already relatively small compared to the detection distances for bar pairs or continental markings.
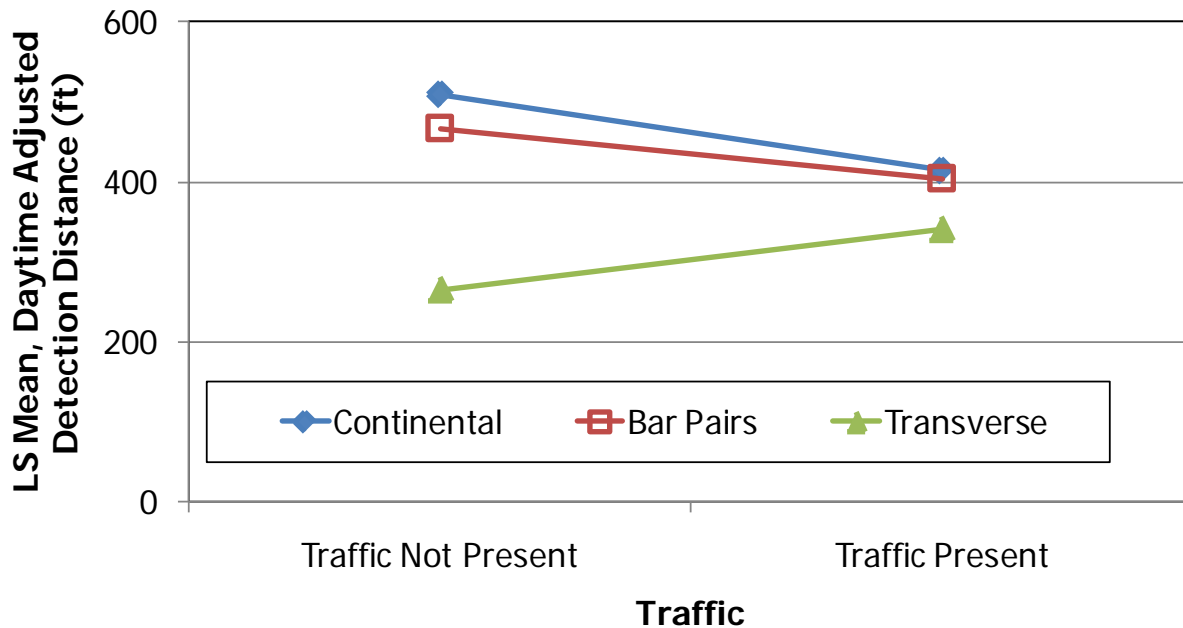
Figure 17. Graph. Least square mean daytime adjusted detection distance by marking type and traffic presence at study sites.

Overall, shorter detection distances were associated with higher operating speeds; however, in most cases, the detection distances were only slightly shorter. The characteristics of the streets also influenced the detection of the crosswalk markings. An unexpected result was that the street group with a posted speed limit of 45 mi/h had longer nighttime adjusted detection distances than the 30-mi/h roadway sections. This finding was opposite the finding for daytime conditions. Daytime adjusted detection distances were slightly shorter for higher speeds.

Age (younger versus older) was only a significant factor during the day for the existing sites. However, the size of this difference was small and was not considered to be meaningful by the research team. Variables that included gender, driver eye height, and vehicle type as part of an interaction term were found to be statistically significant, but closer examination found them to not be of practical significance.

For the existing sites, marking type had a significant effect on detection distance. Figure 18 illustrates the least square mean daytime adjusted detection distance by marking type and location. There were no existing sites with bar pair markings. As a result, only continental and transverse markings were compared. During the day, the detection distances to the continental and transverse markings at intersections were not significantly different. The detection distance to midblock continental was statistically different (longer) from the detection distance to midblock transverse markings.
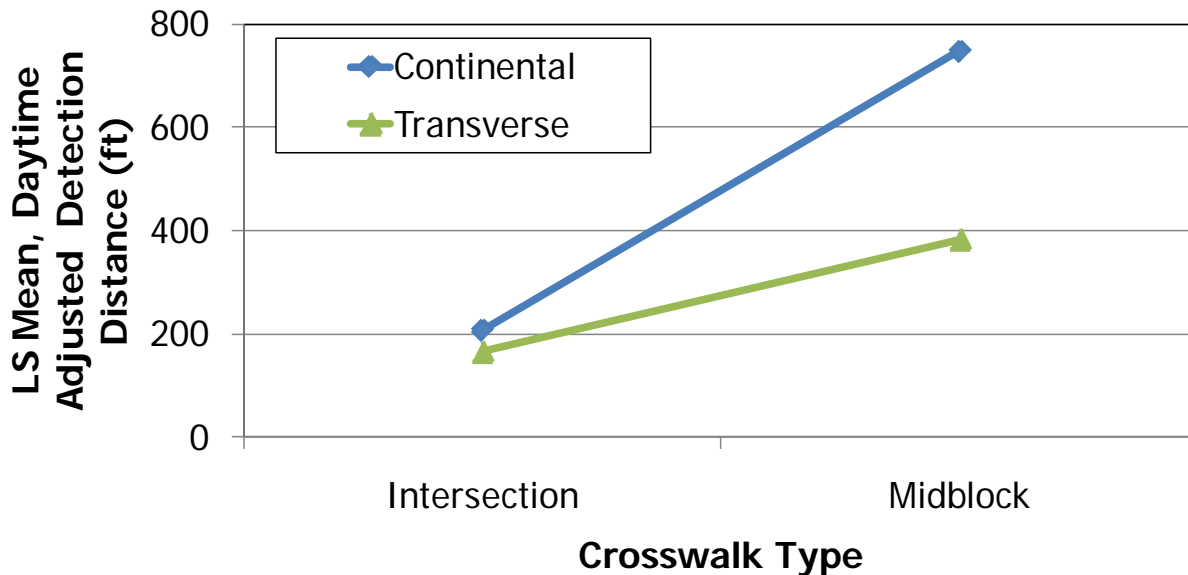
Figure 18. Graph. Least square mean daytime adjusted detection distance by marking type and location at existing sites.

During nighttime conditions at existing sites, variables, in addition to marking type, had an effect on detection distances, including location (midblock or intersection) and driver speed. Driver speed had mixed effects on detection distance depending on location (intersection or midblock) and light level (day or night). For intersections, an increase in driver speed was associated with longer detection distances for both the daytime and nighttime conditions. All of the intersections included in this project were either stop-controlled or signal-controlled. Several drivers appeared to be more focused on the stopping maneuver than the detection task and would not call out the recognition of a crosswalk until close to the stop bar.

For midblock (uncontrolled) approaches, findings were dependent on light level. Nighttime detection distance at midblock crosswalks was similar to those at intersections—longer detection distances were associated with higher speeds. For daytime, the opposite occurred—higher driver speeds were associated with shorter detection distances at the midblock crosswalks. While higher driver speeds were associated with shorter detection distances, the differences were small and were not considered to be of practical significance.

The subjective ratings of visibility using the letter-grade system (A, B, C, D, and F) were compared for all the groups/variables identified in the preceding analysis. The ratings for continental and bar pairs were consistent over various comparison groups, with better ratings for bar pairs and continental markings than for transverse markings. Figure 19 shows the overall rating received by each marking type for study sites.
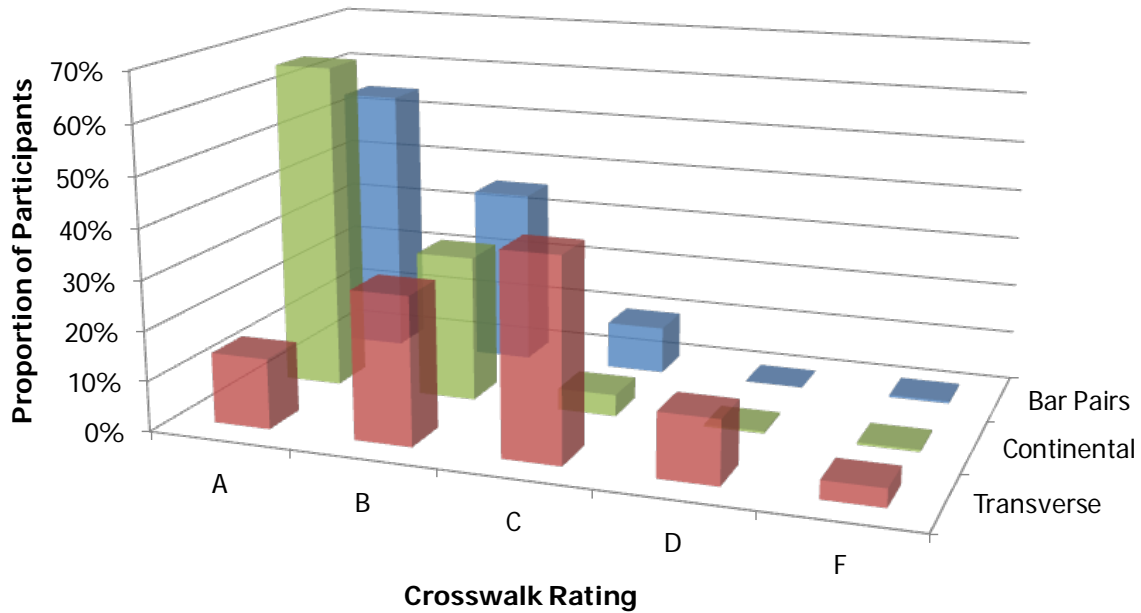
Figure 19. Graph. Rating by marking type for study sites.

CONCLUSIONS

The conclusions from this study were as follows:

- The detection distances to continental and bar pairs are statistically similar and are statistically longer than those for transverse markings.

- For the existing midblock locations, continental markings were detected at about twice the distance upstream as transverse markings during daytime conditions. This increase in distance reflects 8 s of increased awareness of the crossing for a 30-mi/h operating speed.

- The results of the appearance ratings of the markings on a scale of A to F mirrored the findings from the detection distance evaluation. Participants preferred the continental and bar pair markings over the transverse markings.

- Participants gave the continental and bar pair markings similar ratings during both the daytime and nighttime. However, the transverse marking ratings differed based on the light level. The participants gave slightly better ratings (although still worse than continental or bar pair markings) for transverse markings during the nighttime as compared to the daytime. The lower ratings during daylight conditions might be due to sun glare or shadow issues mentioned by the participants.

RECOMMENDATIONS

Based on the findings from this research, it is recommended that consideration be given to revising the 2009 MUTCD as follows:

- Include bar pairs as a usable crosswalk pattern.

- Provide typical dimensions for the marking patterns including spacing that will assist in avoiding wheel paths.

- Consider making bar pairs or continental markings the default for all crosswalks across uncontrolled approaches (i.e., not controlled by signals or stop signs) with exceptions allowing transverse lines where engineering judgment determines that such markings would be adequate, such as a location with low-speed residential streets.

CHAPTER 7. EVALUATION METHODS REPORT

This chapter summaries the FHWA report, *Pedestrian and Bicyclist Traffic Control Device Evaluation Methods,* FHWA-HRT-11-035.[30]

Pedestrians and bicyclists are vulnerable road users when their paths cross vehicular traffic. Traffic control devices are one low-cost safety solution that can be used to better inform, warn, and regulate all road users. FHWA requires evaluations of the effectiveness of traffic control devices that are not in the 2009 MUTCD.[2] When determining whether countermeasures are effective, engineers and planners often rely on anecdotal observations or their professional judgment. In some cases, a limited quantitative safety evaluation is conducted; however, these evaluations are typically limited in terms of scope, experimental design, and statistical rigor. This is often the case because many State and local agencies lack research funds or sufficient knowledge of experimental design and statistics to conduct reliable evaluations of new innovative traffic control devices or other traffic features.

As part of this FHWA project, an evaluation methods report was developed. The report is intended to inform practicing engineers, planners, and public works employees at the local, county, and State levels how to conduct an evaluation of traffic control devices. The guidance provided, though presented in the context of devices associated with pedestrians and bicyclists, can be applied to evaluations of any traffic control device.

The goal of the *Pedestrian and Bicyclist Traffic Control Device Evaluation Methods* report is to improve the quality of those evaluations conducted as part of the MUTCD request for experimentation process.[30] New traffic control device products and applications are constantly being introduced, and quality evaluations are necessary to prove their effectiveness before widespread adoption. The main body of the report presents basic evaluation method steps for traffic engineers to use. More advanced methods involving crash statistical analysis and human factors studies are described in appendices to be used by consultants or university researchers working with practitioners.

The full report consists of the following chapters:[30]

- Chapter 1 presents a brief overview of the evaluation process and discusses the use of surrogate safety measures.

- Chapter 2 provides details on the process used by FHWA to make changes to MUTCD. It discusses the distinction between interpretation and experimentation and details the process to request experimentation.

- Chapter 3 presents a six-step process for planning an evaluation of a new traffic control device.

- Chapter 4 presents information on how to conduct the evaluation and includes basic information on sample size and statistical analysis. It focuses primarily on those traffic engineering measures of effectiveness, such as speed and volume counts, that traffic engineers would be familiar with.

- Chapter 5 describes how to properly document the evaluation effort in a research report.

- Chapter 6 lists additional resources for practitioners to use to conduct, analyze, and report on evaluations.

- Appendix A provides an example of the planning process for an actual evaluation of a pedestrian crossing treatment as follows:

  - Planning step 1: Problem identification—What is the safety or traffic operations issue?

  - Planning step 2: Evaluation question—What is the research question?

  - Planning step 3: Measures of effectiveness—How will you assess performance?

  - Planning step 4: Evaluation designs—What is the study approach?

  - Planning step 5: Evaluation methods—How will you measure user behaviors, traffic, or crashes?

  - Planning Step 6: Selecting components to the evaluation plan—How do you balance time, budget, and practicality to execute the plan?

- Appendix B presents more detailed information on statistical analysis.

- Appendix C provides additional measures that focus more on human behavior.

CHAPTER 8. SUMMARY

The overall goal of the FHWA Pedestrian and Bicycle Safety Research Program is to increase pedestrian and bicycle safety and mobility. From improved crosswalks, sidewalks, and pedestrian technologies to educational and safety programs, the program strives to make it safer and easier for pedestrians, bicyclists, and motorists to share roadways. This report documents an FHWA project to quantify the effectiveness of engineering countermeasures in improving safety and operations for pedestrians and bicyclists. The project focused on existing and new engineering countermeasures for pedestrians and bicyclists that have not yet been comprehensively evaluated in terms of effectiveness. The following sections summarize the methodologies used in this project as well as the findings.

IDENTIFICATION OF COUNTERMEASURES

The process of identifying potential countermeasures began with an extensive literature review of bicycle and pedestrian countermeasure evaluations. The experimental requests sent to FHWA for bicycle- and pedestrian-related traffic control devices not specifically addressed by the 2009 MUTCD were also summarized. Based on these evaluations, five candidate bicycle countermeasures and nine candidate pedestrian countermeasures were identified and then reviewed by a panel of practitioners. The final selection of the countermeasures to be evaluated considered the following:

- Priority rankings by a practitioner panel.

- An assessment of the availability of potential evaluation sites.

- The ability to design an effective evaluation study.

- Available funding.

The development of an evaluation methods report for pedestrian and bicycle traffic control devices was also included in the project. The purpose of the evaluation methods report is to educate practicing engineers, planners, and public works employees at the local, county, and State level as to how to conduct an evaluation of traffic control device effectiveness.

RRFB

The RRFB is a pedestrian-activated beacon system located at the roadside below pedestrian crosswalk signs. This study examined the effects of RRFBs at uncontrolled marked crosswalks. Several methods have been examined to increase driver yielding to pedestrians at multilane crosswalks at uncontrolled locations with relatively high ADT. Previously, only treatments that employed a red phase have consistently produced sustained high levels of yielding at high-volume multilane crosswalks. Five experiments examined the efficacy of RRFBs. These studies found that RRFBs produced an increase in yielding behavior at all 22 sites located in 3 cities in the United States. Data collected over a 2-year follow-up period at 18 of these sites also documented the long-term maintenance of yielding behavior produced by RRFBs. A comparison of RRFBs to a traditional overhead yellow flashing beacon and a side-mounted traditional yellow

flashing beacon documented higher driver yielding associated with RRFBs that was both statistically significant and practically important. Data from other experiments demonstrated that mounting additional beacons on pedestrian refuge islands, or medians, and aiming the beacons to maximize its salience at the dilemma zone increased the efficiencies of the system. Two other variants were found to not influence the effectiveness of the system.

HAWK

The HAWK is a pedestrian-activated beacon located on the roadside and on mast arms over the major approaches to an intersection. It was created in Tucson, AZ, and it was used at more than 60 locations throughout the city at the time of this study. The HAWK head consists of two red lenses over a single yellow lens. It displays a red indication to drivers when activated, which creates a gap for pedestrians to use to cross the major roadway. A before-after study of the safety performance of the HAWK was conducted. The before-after evaluation used an EB method to compare the observed crash frequency during the after period (with the treatment installed) to an estimate of what the crash frequency during the after period would have been if the treatment had not been applied. To develop the datasets used in this evaluation, crashes were counted if they occurred within the study period, typically 3 years before HAWK installation and 3 years after HAWK installation or up to the limit of the available crash data for the after period. Two crash datasets were created. The first dataset included ISN crashes, which were all crashes with the same ISNs that matched the intersections used in the study. The second dataset included IR crashes, which were only those ISN crashes that had "yes" for the IR code. The crash types that were examined included total, severe, and pedestrian crashes. From the evaluation that considered data for 21 HAWK sites (treatment sites) and 102 unsignalized intersections (reference group 2), the following changes in crashes were found after the HAWK was installed:

- 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).

SHARROWS

Shared lane markings are intended to inform motorists and bicyclists that they must share the travel way on which they are operating. The purpose of the markings is to create improved conditions for bicyclists by clarifying where they are expected to ride and to notify motorists to expect bicyclists on the road. The purpose of this study was to evaluate the impact of several uses of shared lane pavement markings, specifically the sharrow design, on operational and safety measures for bicyclists and motorists. Experiments were conducted in three cities. In Cambridge, MA, there was interest in experimenting with the placement of sharrows at a 10-ft spacing from the curb to prevent dooring from parked vehicles. In Chapel Hill, NC, sharrows were placed on a busy five-lane corridor with wide outside lanes and no parking. In Seattle, WA, sharrows were placed in the center of the lane on a downhill portion of a busy bicycle commuting street. Prior to the sharrows, a 5-ft bicycle lane was added to the uphill portion of the street in conjunction with shifting the center line of the street. A variety of hypotheses were examined, and a number of variables related to the interaction and spacing of

bicycles and motor vehicles showed positive effects. Sharrows can be used in a variety of situations, and it is assumed that increased use should increase motorist awareness of bicycles, or the possibility of bicycles, in the traffic stream. As communities continue to experiment with various uses of sharrows, it is recommended that researchers continue to create similar trials in other locations and traffic settings. Additionally, it is important to evaluate and report those experiments so that more data can be examined to provide improved guidance to users.

CROSSWALK MARKINGS

The objective of this study was to investigate the relative daytime and nighttime visibility of three crosswalk marking patterns: transverse lines, continental markings, and bar pair markings. This study collected information on the distance from the crosswalk at which the participant verbally indicated its presence. In total, 78 participants were used and were nearly evenly divided between groups by gender and by age (younger than 55 years old and 55 years old or older). The study was conducted in November 2009 using instrumented vehicles on an open road route on the Texas A&M University campus. Data were collected during two periods: daytime (sunny and clear or partly cloudy) and nighttime (street lighting on). Existing markings (six intersection and two midblock locations) and new markings installed for this study (nine midblock locations) were tested.

For the sites where markings were newly installed for this study, the detection distances for bar pairs and continental markings were similar, and they were statistically different from and longer than the detection distance for the transverse markings both during the day and at night. For the existing midblock locations, the continental markings were detected at about twice the distance upstream as the transverse markings during daytime conditions. This increase in distance reflects 8 s of increased awareness of the presence of the crossing for 30-mi/h operating speeds. Drivers also rated the appearance of markings on a scale of A to F. These results mirrored the findings from the detection distance evaluation. Overall, participants preferred the continental and bar pair markings over the transverse markings.

EVALUATION METHODS

An evaluation methods report was developed as part of this FHWA project. The report provides traffic engineering practitioners with information on how to conduct an evaluation of traffic control devices for roadways associated with pedestrians and bicyclists. The evaluation methods report is designed for practitioners (State transportation departments and county/city engineers and planners). Personnel without high-level statistical analysis skills should be able to easily use and understand the report. The first step of any evaluation is to clearly formulate the research question by identifying the motorist, pedestrian, or bicyclist behavior that poses a safety or operations problem. Candidate traffic control devices and other countermeasures can then be identified as potential solutions to that problem. Evaluation methods described in this report include user surveys or interviews, visibility studies, driving performance studies, observational traffic studies, and crash analyses. The selection of the appropriate evaluation methods will weigh monetary cost, time, research aims, and available research equipment and staff.

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