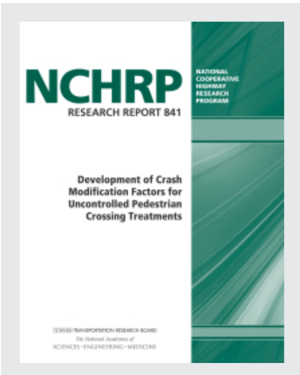

Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments

DETAILS

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP RESEARCH REPORT 841

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research is the most effective way to solve many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation results in increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

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The needs for highway research are many, and NCHRP can make significant contributions to solving highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement, rather than to substitute for or duplicate, other highway research programs.

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The research report authors appreciate the assistance of all of the city officials throughout the United States who were contacted regarding information on the status of pedestrian treatments that have been implemented. The authors are particularly grateful for the support and cooperation of officials from the 14 cities where treatments were selected. This includes officials from Arlington and Alexandria, VA; Cambridge, MA; Charlotte, NC; Chicago, IL; Milwaukee, WI; New York, NY; Eugene and Portland, OR; Miami and St. Petersburg, FL; and Phoenix, Scottsdale, and Tucson, AZ. Also, officials from the respective state DOTs were very helpful in providing crash data for the sites within their cities. This research could not have been conducted without assistance from those city and state DOT officials.

FOREWORD

By Lori L. Sundstrom
Staff Officer
Transportation Research Board

This report quantifies the safety benefits of four types of pedestrian crossing treatments—rectangular rapid flashing beacons, pedestrian hybrid beacons, pedestrian refuge islands, and advanced YIELD or STOP markings and signs—and presents a recommended crash modification factor (CMF) for each treatment type. This information, which is suitable for inclusion in the AASHTO *Highway Safety Manual*, FHWA's CMF Clearinghouse, and other guidance, will be valuable to transportation agencies in choosing the appropriate crossing treatment for uncontrolled pedestrian crossings.

There is considerable uncertainty surrounding the use of pedestrian crossing treatments at uncontrolled crossing locations. Research shows that marking crosswalks without making additional improvements is associated with higher pedestrian crash rates under certain roadway configurations and operating characteristics, such as on high-volume multi-lane roads (Zegeer, C.V., Stewart, J.R., Huang, H.H., and Lagerwey, P.A. *Safety Effects of Marked vs. Unmarked Crosswalks at Uncontrolled Locations,* Federal Highway Administration, 2001). However, failing to provide crossing opportunities, installing inappropriate roadway treatments, or over-improving an area are all undesirable solutions. Where a crosswalk alone might lead to increased pedestrian crashes, Zegeer et al. recommend enhanced crossing treatments, noting that "pedestrian crossing problems and needs should be routinely identified, and appropriate solutions should be selected to improve pedestrian safety and access." While several studies have examined pedestrian safety at uncontrolled crossing locations, robust CMFs are generally lacking.

Under NCHRP Project 17-56, the University of North Carolina Highway Safety Research Center (HSRC) was asked to (1) quantify the relationships between pedestrian safety and crossing treatments at uncontrolled locations (excluding roundabouts) and (2) develop CMFs by crash type and severity for (a) unsignalized pedestrian crosswalk signs and pavement markings, including advanced YIELD markings; (b) pedestrian hybrid beacons; (c) rectangular rapid flashing beacons; (d) pedestrian refuge areas; (e) curb extensions; (f) in-pavement warning lights; and/or (g) high-visibility crosswalk marking patterns.

The HSRC conducted an extensive literature review, collected and evaluated data for numerous uncontrolled pedestrian crossing locations in a number of cities, and narrowed the list of crossing treatments for full evaluation to four: rectangular rapid flashing beacons, pedestrian hybrid beacons, pedestrian refuge islands, and advanced YIELD or STOP markings and signs. The research team analyzed before and after crash data and developed crash prediction models for those four treatment types at nearly 1,000 locations in 14 cities and developed CMFs for each treatment. To facilitate implementation of the research results, the findings of this research are appropriate for inclusion in the AASHTO *Highway Safety Manual*, the Federal Highway Administration's CMF Clearinghouse, design guidance for uncontrolled pedestrian crossings, and other documents.

CONTENTS

SUMMARY

Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments

There continues to be a problem in the United States related to safety for pedestrians who attempt to cross streets, particularly on high-speed, high-volume, multi-lane roads. Furthermore, there is a need to better understand the safety effects of some of the more promising treatments on pedestrian crashes. The purpose of this study was to develop crash modification factors (CMFs) for selected types of pedestrian treatments at unsignalized pedestrian crossings. After considering numerous treatment options related to geometric design and traffic control devices, the four unique treatment types selected for evaluation in this study included rectangular rapid flashing beacons (RRFBs), pedestrian hybrid beacons (PHBs), pedestrian refuge islands, and advanced YIELD or STOP markings and signs. A total of approximately 1,000 treatment and comparison sites were selected from 14 different cities throughout the United States. Most of the study sites selected were intersections on urban, multi-lane streets, since there is a high risk for pedestrian crashes at these sites and countermeasures are typically most needed. Based on detailed information obtained from each city regarding available treatments of interest for this study, U.S. geographic distribution of cities, and other factors, the 14 cities selected for data collection for this study were Alexandria and Arlington, Virginia; Cambridge, Massachusetts; Chicago, Illinois; New York, New York; Miami and St. Petersburg, Florida; Tucson, Scottsdale, and Phoenix, Arizona; Portland and Eugene, Oregon; Charlotte, North Carolina; and Milwaukee, Wisconsin.

For each study site, relevant data were collected on the treatment characteristics, pedestrian and motor vehicle volumes, geometric features, roadway variables, and pedestrian crashes and other crash types that occurred at each site. Efforts were also made to determine the changes in signs, markings, and geometry that occurred at the treatment and comparison sites over the analysis period so such changes could be accounted for in the analysis and modeling phase of the study.

Data analysis involved the development of cross-sectional models and before/after Empirical Bayesian analysis techniques to determine the crash effects (i.e., CMFs) of each treatment type. The data analysis revealed that all four of the treatment types were associated with reductions in pedestrian crash risk, compared to the comparison (untreated) sites. The CMFs for pedestrian crashes are the following: PHBs (CMF of 0.453) and PHBs with advanced YIELD or STOP signs and markings (CMF of 0.432) were associated with the greatest benefit to pedestrian crash risk, followed by RRFBs (CMF of 0.526), pedestrian refuge islands (CMF of 0.685), and advanced YIELD or STOP signs and markings (0.75). The CMFs for PHBs and PHBs with advanced YIELD or STOP markings and signs were statistically different from 1.0 at the 0.05 significance level. CMFs for some other crash types (e.g., rear-end, sideswipe, and total crashes) were also found for some of the four pedestrian treatments. The CMF for the RRFB was based on a very limited sample (i.e., 50 treatment sites) and hence should be used with caution.

Table S-1. Recommended CMFs.

Treatment	Crash Type	Recommended CMF Estimate	Recommended CMF Standard Error	Study Basis
Refuge Island	Pedestrian	0.685	0.183	Median from two studies
	Total	0.742	0.071	Cross-section
	All Injury	0.714	0.082	Cross-section
	Rear-End/Sideswipe Total	0.741	0.093	Cross-section
	Rear-End/Sideswipe Injury	0.722	0.106	Cross-section
Advanced YIELD or STOP Markings and Signs	Pedestrian	0.750	0.230	Median from two studies
	Total	0.886	0.065	Before-after
	Rear-End/Sideswipe Total	0.800	0.076	Before-after
PHB	Pedestrian	0.453	0.167	Median from two studies
PHB + Advanced YIELD or STOP Markings and Signs	Pedestrian	0.432	0.134	Median from two studies
	Total	0.820	0.078	Before-after
	Rear-End/Sideswipe Total	0.876	0.111	Before-after
RRFB	Pedestrian	0.526	0.377	Cross-section

A summary of recommended CMFs developed in this study is given in Table S-1. As a general caution, in the application of the CMFs, users should consider the summary statistics in Chapter 4 of this report to see how closely the site under consideration for one of these treatments resembles the sites used to develop the CMF. Specifically, the CMFs developed in this study are most appropriate for urban, multi-lane intersection and midblock locations in urban (and suburban) areas.

Attempts were also made to develop reliable *crash modification functions* (CMFunctions), that is, equations that allow for determining differences in crash effects as a function of vehicle or pedestrian volumes, number of travel lanes, vehicle speeds, and/or other roadway features. The development of such CMFunctions was considered desirable by local and state agency officials for use in making decisions on which sites would be most or least appropriate for installing various pedestrian treatment types. Unfortunately, these CMFunctions did not provide useful results. Future research could not only develop more robust CMFs, but also investigate whether these treatments are more or less effective under different conditions. To these ends, and given the challenges of acquiring large samples of pedestrian crash and exposure data, it is recommended that the data from this project remain accessible for future research that could also include development of enhanced safety performance functions for pedestrians.

As a result of the CMFs developed in this study, there are several potential resources in which research results from NCHRP Project 17-56 could be integrated to facilitate implementation of the findings in practice. These include the following:

- AASHTO's *Highway Safety Manual* (HSM) (*67*);
- AASHTO's *Guide for the Planning, Design, and Operation of Pedestrian Facilities* (*69*);
- FHWA Pedestrian Safety Guide and Countermeasure Selection System (PEDSAFE) website;

- FHWA CMF Clearinghouse;
- FHWA Proven Safety Countermeasures website;
- *NCHRP Report 600: Human Factors Guidelines for Road Systems, Second Edition* (*68*);
- *Manual on Uniform Traffic Control Devices* (MUTCD) (*62*); and
- Design guidance for uncontrolled pedestrian crossings.

At the end of this report, specific details are provided on how the study results can best be incorporated into each of these guides. As with any proposed safety improvements, it should be remembered that countermeasure selection is a case-specific process, so safety treatments should be based on the specific safety problems and site conditions of the pedestrian location and not just based on the treatment with the best overall CMF.

CHAPTER 1

Project Overview

There continues to be a problem in the United States related to safety for pedestrians who attempt to cross streets, particularly on high-speed, high-volume, multi-lane roads. Furthermore, there is a need to better understand the safety effects of some of the more promising treatments. Numerous studies have been conducted in the United States and abroad in recent years on the effects of various geometric and traffic control treatments at unsignalized crossings. However, most of those evaluations have relied on behavioral and operational measures of effectiveness (e.g., pedestrian/vehicle conflicts, vehicle speeds, and driver yielding behavior) instead of crashes as the measure of effectiveness. The lack of crash-based evaluations for such pedestrian treatments results largely from sample size issues, that is, pedestrian crashes usually do not cluster to the same degree at specific sites, so a larger number of treatment and comparison sites may be needed to obtain sufficient statistical power to detect a change in crashes due to the treatment, compared to the evaluation of countermeasures for vehicle/vehicle crashes, which occur at a higher frequency.

Thus, there is a need to conduct evaluations over a wider region and over a longer time period in order to obtain an adequate sample size to allow for the development of crash modification factors (CMFs) or Functions (CMFunctions) that can provide guidance as to the most effective pedestrian crossing treatments to use. This project sought to develop CMFs for selected pedestrian crossing treatments for various traffic and roadway conditions, to the extent possible. An attempt was made to develop CMFunctions that would allow a CMF to be estimated based on specific site conditions.

The original objective of this project was to develop CMFs for several different types of pedestrian treatments at unsignalized pedestrian crossings. Candidate treatments that were considered for possible evaluation in this study were the following:

- Unsignalized pedestrian crosswalk signs and pavement markings, including advanced YIELD or STOP markings and signs;
- Pedestrian hybrid beacons (PHBs);
- Rectangular rapid flashing beacons (RRFBs);
- Pedestrian refuge islands;
- Curb extensions;
- In-pavement warning lights;
- High-visibility crosswalk marking patterns; and
- Raised crosswalks.

Of the potential candidate treatments listed above, it was not possible to find a sufficient sample of sites with raised crosswalks and/or in-pavement warning lights to develop reliable CMFs. Also, consideration was given to selecting treatments for evaluation that were thought to be of particular interest to local and state traffic and safety officials. Finally, available project funds and the importance of each treatment in terms of CMF development were taken into consideration in choosing treatments for evaluation. Ultimately, four treatments were selected for evaluation:

- RRFBs
- PHBs
- Pedestrian refuge islands
- Advanced YIELD or STOP markings and signs

The selection of these four treatments (see Appendix A for descriptions of the treatments) was approved by the project panel. Data were collected for locations having one of these treatments and for appropriate non-treated comparison (reference) sites. Some of the treatment sites selected for field study had more than one of these four treatments. The study sampling was focused on sites on multi-lane, high-volume roads, since these are the types of sites where pedestrians are at the greatest risk, and therefore, where there is a greater need for the types of countermeasures evaluated in this study.

Data collection efforts included following:

- Identifying suitable treatment and comparison sites for analysis;
- Collecting basic site characteristics data at select sites;
- Collecting pedestrian count data at the treatment and comparison sites for use in computing estimated pedestrian average annual daily traffic (AADT);
- Collecting vehicle AADT numbers at the treatment and comparison sites; and
- Collecting crash summaries for pedestrian and total crashes.

CHAPTER 2

Literature Review

The following sections summarize the available research for each of the eight pedestrian treatments initially considered for evaluation in this study. A more comprehensive literature review is provided in Appendix H. Additionally, a set of summary tables are provided at the end of Appendix H, which provide an overview of the studies for each of the eight treatments. The primary source used to compile Appendix H was a University of North Carolina (UNC) Highway Safety Research Center (HSRC) draft of the 2013 *Evaluation of Pedestrian-Related Roadway Measures: A Summary of Available Research* (*1*).

Unsignalized Pedestrian Crosswalk Signs and Pavement Markings, Including Advanced YIELD or STOP Markings and Signs

This treatment consists of signs or markings designed to improve the visibility of pedestrians to motorists, increase motorist yielding, and prevent multiple-threat crashes (see Figure 2-1). These treatments occur at midblock crossings or uncontrolled crosswalks at multi-lane locations located at intersections with minor stop-controlled roads.

Signing—In-Street Pedestrian Signs

Nine studies were reviewed. All were behavioral studies (not crash based) and generally found in-street pedestrian signs to be an effective means of improving pedestrian safety. Results typically indicated an increase in driver yielding behavior and the number of pedestrians using the crosswalk and a decrease in mean speeds. One study concluded that in-street pedestrian signs were more effective at intersections than they were at midblock locations (*2–10*).

Signing—Other Signs

Evaluation of pedestrian signs has shown them to be of moderate efficacy in increasing pedestrian safety, with some variation across treatments and site characteristics. Some factors that influenced driver yielding at sign locations included the speed and volume of the roadway and whether the motorists perceived yielding as a courtesy or the law (*11*). Signs which are enhanced with flashing beacons or lights have been shown to be more effective when activated manually or automatically by pedestrians than those that blink continuously (*11*).

Of the eight studies reviewed, seven indicated that the installation of various signs increased motorist yielding behavior and decreased speeding (*2*, *9*, *11–17*).

Source: www.wichita.gov

Figure 2-1. Example of advance STOP line and sign **(left)*****, advance YIELD line (shark's teeth) and sign*** **(right)*****, and a continental crosswalk.***

Marked Crosswalks and Enhancements

Marked crosswalks are typically installed at signalized intersections, in school zones, and at unsignalized intersections. The *Manual on Uniform Traffic Control Devices* (MUTCD) defines three types of crosswalk markings: standard parallel lines, ladder or continental stripes, and diagonal stripes.

Recent research has found no safety benefit associated with various types of crosswalk markings, and the inappropriate use of marked crosswalks alone (without other substantial safety measures) can increase crash risk for pedestrians (*18*, *19*). For example, a 2002 study (*18*) found that having a marked crosswalk on two-lane roads or on multi-lane (three or more lanes) roads with AADTs below 12,000 made no difference in pedestrian crash rates, compared to having no marked crosswalks. However, on multi-lane roads with AADTs above 12,000 (or above 15,000 if raised medians are present), having a marked crosswalk without other substantial treatments was associated with an increase in pedestrian crash risk, compared to having no marked crosswalk. In that study, substantial treatments were considered to be such measures as a traffic signal with pedestrian signals, roadway lighting, enhanced traffic calming, and so forth. The authors of the 2002 study (*18*) concluded that it is important to not just remove marked crosswalks, but also to analyze each pedestrian crossing and determine what measures are needed to help pedestrians more safely cross the road.

Advanced YIELD or STOP Markings and Signs

Advanced YIELD or STOP markings are a type of pavement marking placed before a crosswalk to increase the distance at which drivers stop or yield to allow pedestrians to cross. Increasing the distance between yielding vehicles and pedestrians increases the ability of motorists in other lanes to see the pedestrian as the pedestrian crosses and to yield accordingly. The visibility of oncoming traffic to pedestrians is likewise improved.

Eleven studies were reviewed. Ten studies indicated that advanced YIELD or STOP markings and signs reduced pedestrian–vehicle conflicts and increased motorist yielding (*15*, *20–29*).

High-Visibility Crosswalk Marking Patterns

High-visibility crosswalks, when compared to the standard parallel-line crosswalks, have wider lines or additional lines to improve the conspicuity of the crosswalk to approaching drivers (see Figure 2-2). That is, the amount of white marking visible to the driver is increased by having wider longitudinal lines or by having lines parallel and perpendicular to the driver's path.

Source: FHWA

Figure 2-2. Example of a high-visibility "ladder" crosswalk.

Two of the studies reviewed reported crash reduction factors for installing high-visibility crosswalks. One reported a statistically significant reduction in collisions of 37 percent (*30*). The other reported a reduction in pedestrian collisions of 48 percent at treatment sites, significant at the 0.05 level (*31*).

Pedestrian Hybrid Beacons

PHBs, also known as HAWK beacons (short for high-intensity activated crosswalk beacon), were developed by a Tucson traffic engineer, Dr. Richard Nassi, in the late 1990s as a means for providing safe pedestrian crossings where minor streets intersected with major arterials (*32*, *33*). A PHB is a special type of beacon used to warn and control traffic at an unsignalized location to assist pedestrians crossing a street or highway at a marked crosswalk. The PHB signal head consists of two red lenses over a single yellow lens (see Figure 2-3). It displays a red indication to drivers when activated, which creates a gap for pedestrians to use to cross a major roadway. The PHB signal indication for motorists is not illuminated until it is activated

Source: PBIC

Figure 2-3. Example of a PHB.

by a pedestrian, triggering the warning flashing yellow lens on the major street. After a set amount of time, the traffic signal 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 to drivers, and pedestrians are shown an upraised hand symbol with a countdown display informing them the time left to cross. The first PHB was installed in Tucson in 2000. The PHB was considered an experimental treatment until 2009, when it was included in the MUTCD. PHBs are now widely used in Tucson and have since been installed in Georgia, Minnesota, Florida, Michigan, Virginia, Arizona, Alaska, and Delaware (*34*).

One study reviewed reported crash reduction factors for installing PHBs in Tucson, Arizona. Results of the analysis showed a statistically significant reduction in total crashes of 29 percent as well as a statistically significant reduction in pedestrian crashes of 69 percent. There was a 15 percent reduction in severe crashes; however, this result was not statistically significant (*32*).

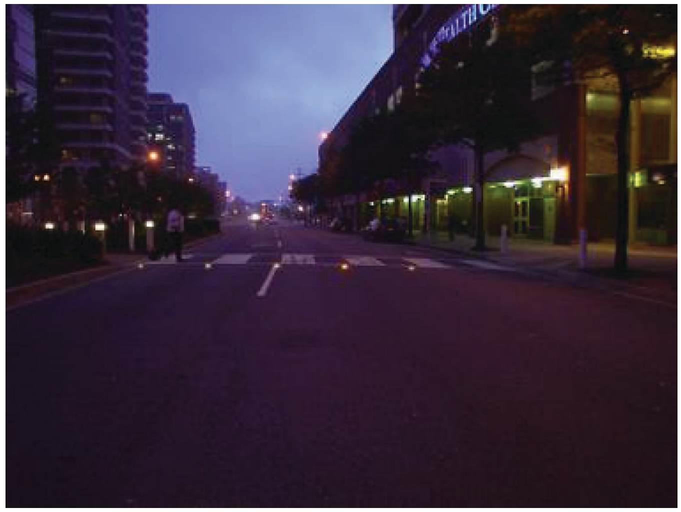
Rectangular Rapid Flashing Beacons

The RRFB is a type of amber light-emitting diode (LED) installed to enhance pedestrian crossing signs at midblock crossings or unsignalized intersections (see Figure 2-4). RRFBs can be automated or pedestrian actuated and feature an irregular, eye-catching flash pattern to call attention to the presence of pedestrians. The RRFB was given interim approval as a crossing sign enhancement by FHWA in 2008 (*35*).

Nine studies were reviewed. All of them indicated that RRFBs increased motorist yielding, thereby helping to reduce pedestrian–vehicle conflicts (*36–44*).

Source: FHWA

Figure 2-4. Example of an RRFB.



Source: FHWA

Figure 2-5. Example of in-pavement warning lights.

In-Pavement Warning Lights

In-pavement lighting, which is activated by pedestrian push buttons, is sometimes used to alert motorists to the presence of a crosswalk at uncontrolled locations. Both sides of the crosswalk are lined with encased raised pavement markers, which sometimes contain LED strobe lighting (see Figure 2-5). In-pavement lighting has shown positive results such as increasing driver compliance and motorist yielding to pedestrians in Washington State, but not in Florida (*45*, *46*). Despite some positive results with in-pavement lighting, there are several drawbacks to this method. For example, the whole system must be replaced whenever road surfacing or utility repairs occur. Also, in-pavement lights are generally visible to only the first car in a platoon. Headlights from oncoming traffic may obscure a driver's view of the entire crossing. Furthermore, in-pavement lighting does not indicate the direction of a pedestrian's travel or whether people are crossing simultaneously from both sides of the road. Finally, the in-pavement flashers may be difficult to see during bright daylight hours (*45*, *46*).

Pedestrian Refuge Islands

Median refuge islands, sometimes referred to as center islands, refuge islands, or pedestrian islands, are raised areas that help protect pedestrians who are crossing the road at intersections and midblock locations (See Figure 2-6). The presence of a median refuge island in the middle of a street or intersection allows pedestrians to focus on one direction of traffic at a time as they cross and gives them a place to wait for an adequate gap between vehicles. Islands are appropriate for use at both uncontrolled and signalized crosswalk locations. Where the road is wide enough and on-street parking exists, center islands can be combined with curb extensions to further enhance pedestrian safety (*47*).

Three studies reviewed reported crash reduction factors for constructing raised medians or pedestrian islands. One study found that replacing a 6-foot painted median with a wide raised median reduced pedestrian crashes by 23 percent (*49*), which was consistent with findings from another study that showed pedestrian crash rates for roads with 10-foot medians were 33 percent lower than for roads with 4-foot painted medians (*48*). Finally, a before-after study was conducted to evaluate the safety effectiveness of raised pedestrian refuge islands. Researchers

Source: walkinginfo.org

Figure 2-6. Example of pedestrian refuge island.

found that there was a 73-percent reduction in midblock pedestrian crashes, but a 136-percent increase in total crashes. It was noted that the decrease in safety related to vehicle-island crashes might be helped by better island design and lane alignment (*50*).

Curb Extensions

Curb extensions are a way of narrowing the roadway width by extending the curb line or sidewalk into the street, which results in reduced vehicle speeds, improved visibility for pedestrians and oncoming motorists, and reduced crossing distance for pedestrians (see Figure 2-7).

Results of the four studies reviewed were mixed. Three of the studies indicated improvements in the form of reduced wait times to cross, a decreased percentage of vehicles that pass before yielding, and an increase in the distance at which vehicles yield in advance of

Source: FHWA

Figure 2-7. Example of an intersection approach with a curb extension.

Source: www.pedbikeinfo.org

Figure 2-8. Example of raised crosswalk with an advanced STOP marking.

the crosswalk (*51*, *53*, *54*). One study did not find any such positive effects of installing curb extensions (*52*).

Raised Pedestrian Crossings

Raised pedestrian crossings consist of a crosswalk that is raised above the level of the street, often at grade (see Figure 2-8). Raised pedestrian crossings tend to be applied most often on two-lane business streets in urban environments and are applied both at intersections and midblock locations. They are generally installed on lower speed roads because they are designed for speeds less than 35 mph and would not be appropriate on higher speed roads.

Only one study was reviewed that considered the effect of raised pedestrian crossings on driver and pedestrian behavior. The study considered three sites in North Carolina and Maryland. Results indicated that the use of raised crosswalks resulted in lower overall vehicle speeds. The researchers also evaluated a raised crosswalk in Cambridge, Massachusetts. Results indicated an increase in the percentage of pedestrians who crossed in the crosswalk and an increase in the percentage of motorists who yielded to pedestrians in the crosswalk (*55*).

CHAPTER 3

Data Collection

Site Identification

The NCHRP Project 17-56 research team used multiple methods for identifying cities and states that had installed pedestrian crossing treatments at unsignalized intersections:

- Identifying agencies using the team's experience and knowledge from managing the Walk Friendly Communities program;
- Contacting pedestrian coordinators at state and local agencies to request lists of specific sites or suggestions for jurisdictions to contact;
- Soliciting agencies through the Association of Pedestrian and Bicycle Professionals (APBP) listserv;
- Communicating with other research teams involved in ongoing projects related to pedestrian safety treatments;
- Contacting vendors to obtain indications of cities with specific treatments;
- Making personal telephone calls to selected agencies known or suspected to have treatments of interest; and
- Conducting exploratory field work to identify specific treatment and comparison sites in multiple cities across the United States, including Portland, Oregon; Tucson, Arizona; and Miami, Florida.

The research team received approximately 80 emails in response to advertisements on various email lists. Additionally, the team developed and circulated a flyer to request information on locations where the pedestrian safety treatments of interest were installed. The descriptions were intended to help potential participating cities and state departments of transportation (DOTs) to better understand the types of treatments that were included in the evaluation. With this information, the project team identified agencies that looked promising in terms of number of sites and types of treatments installed. The team undertook follow-up interview calls with each promising agency.

Approximately 35 agencies were further contacted by phone or email to gain their willingness to participate in the project, to get more information about the number and types of treatments available in their locality, and to determine the availability of their data. The research team developed a matrix of available sites by treatment type as the basis for deciding which agencies to pursue for detailed information. Cities were grouped for possible inclusion in this study into the following priority groups:

- Priority 1—these cities were definitely eligible to be included in the study, based on large numbers of treatment sites or installations of hard-to-find treatments.
- Priority 2—these cities could be included in the study if needed for sample size considerations.

- Priority 3—these cities were unlikely to be included in the study since they have low numbers of potential treatment sites and would add little benefit (additional treatment installations) for the cost (logistics of incorporating another agency into the data collection process).

Based on detailed information obtained from each city regarding available treatments of interest for this study, U.S. geographic distribution of cities, and other factors, the 14 cities selected for data collection for this study were Alexandria and Arlington, Virginia; Cambridge, Massachusetts; Chicago, Illinois; New York, New York; Miami and St. Petersburg, Florida; Tucson, Scottsdale, and Phoenix, Arizona; Portland and Eugene, Oregon; Charlotte, North Carolina; and Milwaukee, Wisconsin.

The data collection activities began with finding the treatments of interest in the 14 selected cities and also finding suitable sites for comparison. Site selection focused on pursuing treatment (and comparison) sites on higher volume, multi-lane streets and/or two-lane roads at busy downtown crossings where pedestrian crash problems are more likely to be a problem and, therefore, where treatments are more likely to be needed.

Compiling Site Data

Given the number of potential issues when obtaining and combining data from multiple agencies, the project team identified treatment details, site characteristics, and crash data variables that were needed for developing CMFs and CMFunctions (see Table 3-1).

Site Characteristics

Most of the study sites selected are intersections on urban, multi-lane streets, since these are sites with a high risk of pedestrian crashes and where countermeasures are typically most needed. Relevant information on geometric and volume characteristics was needed for each site. Google Earth aerial and street-view photographs were used to identify relevant site characteristics, as listed in Table 3-1. Dates were associated with the Google imagery, which allowed for recording of site characteristic changes over time (going back as far as 10 years).

Treatment Characteristics

In addition to site characteristics, it was crucial to collect data specifically on pedestrian safety treatments. Knowledge of where and when the treatment was installed was important. In many cases, treatments were found in combination with other treatments. For example, advanced YIELD or STOP markings and signs are often used in conjunction with the RRFB. Median islands or a refuge island are often used in combination with both the PHB and the RRFB at sites with a high AADT. These data have been gathered largely from agency installation records, from knowledge of agency contacts, and/or from Google Earth aerial and street-view photographs over a multi-year time frame.

Crash Data

The project team collected data on pedestrian crashes and other crashes for each treatment and comparison study site. All agencies had crash data available electronically, but not all agencies had hard copy police crash reports available for the full time frame of crash history. Therefore, the research team obtained electronic crash data files for use in this study. Information was also obtained on the distance from the intersection or midblock crossing where each crash occurred.

Table 3-1. Data elements collected for NCHRP Project 17-56.

Category	Data Elements
Treatment	Description of countermeasure
Treatment	Before condition (baseline)
Treatment	Midblock vs. intersection
Treatment	Other treatments installed at same time
Treatment	Date of installation (to the extent possible)
Treatment	Other changes during study period
Treatment	Photo of installation (to the extent possible)
Site Characteristics	Vehicle volume (AADT)
Site Characteristics	Pedestrian volume
Site Characteristics	Speed limit
Site Characteristics	Number of through lanes
Site Characteristics	Presence of median
Site Characteristics	Crosswalk presence
Site Characteristics	Urban vs. rural
Site Characteristics	One-way vs. two-way
Site Characteristics	Number of right turn lanes
Site Characteristics	Number of left turn lanes
Site Characteristics	Median width
Site Characteristics	Median type
Site Characteristics	Crosswalk type
Site Characteristics	Pedestrian signs
Site Characteristics	Presence of transit stop
Crash	Date
Crash	Time
Crash	Location
Crash	Injury severity
Crash	Weather
Crash	Lighting
Crash	Road/surface condition
Crash	Type of crash (e.g., rear-end, angle)
Crash	Pre -crash maneuvers (first or most harmful event)

Summary of Site Characteristics

Overview of Treatment and Comparison Sites

A summary is given in Table 3-2 of the number of treatment and comparison sites that were found and coded into the database. Approximately 950 potential treatment and 800 potential comparison sites were originally identified. Using Google Earth aerial and street-view imagery, almost half of the original sites were eliminated for numerous reasons. Treatment sites were eliminated most commonly because they had unusual characteristics at the site, had the wrong type of traffic control signal, were too close to a signalized intersection, had unusual intersection or road geometry, were undergoing construction that precluded a pedestrian count, had a treatment that was installed too recently, or lacked good, available, crash or traffic AADT data. Comparison sites were eliminated most commonly because they had recently installed traffic control signals or non-studied treatment types, were too close to a signalized intersection, had unusual intersection or road geometry, were undergoing construction that precluded a pedestrian count, or lacked good, available, crash or traffic AADT data.

A total of 499 treatment sites and 476 comparison sites were included in the final database. The number of treatment sites includes 313 refuge islands, 292 advanced YIELD or STOP markings and signs, 96 PHBs, and 50 RRFBs. Cities with the largest number of treatment sites include St. Petersburg (115 treatment sites), Tucson (85 treatment sites), and Portland (61 sites). Charlotte

Table 3-2. Treatment and comparison site totals by city.

City	Advanced YIELD or STOP Markings and Signs	Refuge Island	RRFB	PHB	Total Treated Sites	Total Comparison Sites
Arlington & Alexandria, VA	2	22	0	0	**23**	**22**
Cambridge, MA	10	17	0	0	**19**	**25**
Charlotte, NC	2	34	0	2	**36**	**112**
Chicago, IL	3	33	3	0	**36**	**37**
Eugene, OR	3	28	6	0	**29**	**27**
Miami, FL	3	27	5	0	**30**	**36**
Milwaukee, WI	0	12	1	0	**12**	**18**
New York, NY	0	17	0	0	**17**	**24**
Phoenix, AZ	16	11	1	5	**18**	**16**
Portland, OR	53	40	2	2	**61**	**33**
Scottsdale, AZ	4	17	0	2	**18**	**16**
St. Petersburg, FL	113	19	32	3	**115**	**45**
Tucson, AZ	83	36	0	82	**85**	**65**
TOTAL	*292*	*313*	*50*	*96*	**499**	**476**

had the most comparison sites (112), primarily because of the availability of a large sample of unsignalized crossings with existing 12-hour pedestrian counts. The number of treatment types is illustrated in Figure 3-1.

Treatment Type Combinations

Treatment sites often had combinations of two or more of the studied treatments. Table 3-3 describes the existing treatment combination possibilities and the number of sites with those combinations, ranging from one treatment per site to three treatments per site. Table 3-3 shows that 300 sites had only one treatment. A total of 146 sites had two treatments, including 57 sites with PHBs plus advanced YIELD or STOP markings and signs. There are 60 sites in the database

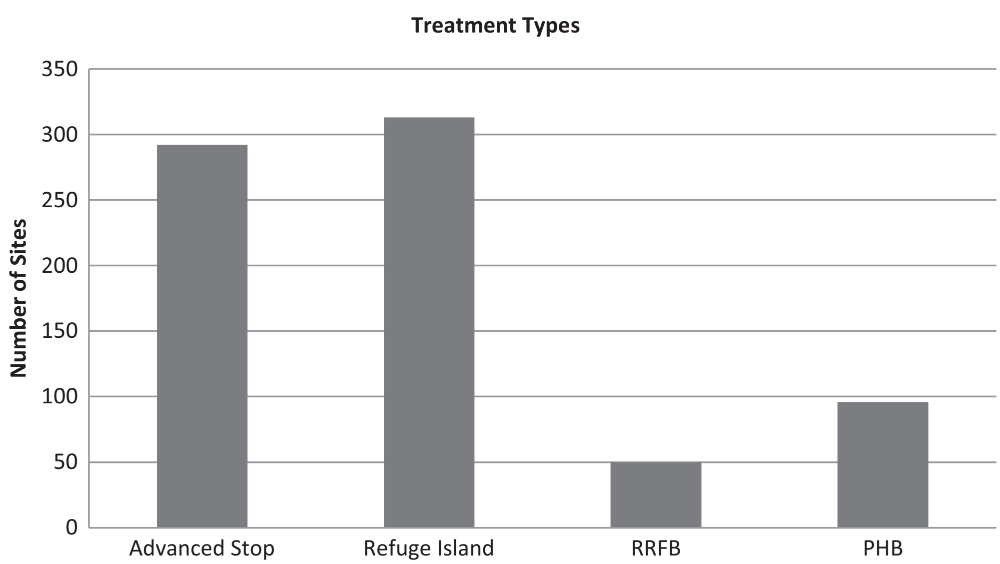


Figure 3-1. Treatment type totals.

Table 3-3. Treatment site combinations.

Single Treatment	Advanced YIELD or STOP Markings and Signs (AS)	Refuge Island (RI)	Rectangular Rapid Flashing Beacon (RRFB)	Pedestrian Hybrid Beacon (PHB)			300
	97	196	5	2			
Two Combined Treatments	AS+RI	AS + RRFB	AS+PHB	RI + RRFB	RI + PHB	RRFB+ PHB	146
	60	25	57	4	0	0	
Three Combined Treatments	AS + RI + RRFB	AS + RRFB + PHB	AS + RI + PHB	RI + RRFB + PHB			53
	16	0	37	0			
Four Combined Treatments	AS + RI + RRFB + PHB						0
	0						
							499

that have advanced YIELD or STOP markings and signs plus refuge islands. There are 53 sites that have three treatment types: either RRFBs or PHBs in combination with advanced YIELD or STOP markings and signs and refuge islands. As discussed in Chapter 4, CMF development was not possible for all of these countermeasure combinations because of small sample sizes that would not have produced reliable CMFs.

Database

After valid treatment and comparison sites were selected, the locations (streets and latitude/longitude) and the site and treatment characteristics for each site were entered into the final database. Pedestrian volume, vehicular traffic volume, and crash data were then compiled and added for each site. As relevant data were collected and received from each city, they were also entered into the existing database, as appropriate.

In addition to the pedestrian volume counts that were available from a few cities, pedestrian volume was also collected in the field by Kittelson & Associates, Inc., and Quality Counts (QC) for 915 of the 975 total sites (discussed in the next section). These pedestrian volume counts were accompanied by site photographs. These photographs, in combination with Google Earth current and historical overhead imagery and the most current Google Earth street-view imagery, allowed for a historical analysis of site characteristics over time. Often, sites had changes in crosswalk types or numbers of lanes over the last 10 years. Additionally, sites with multiple treatments sometimes had those treatments installed in different years. For example, sites sometimes had refuge islands installed and then, several years later, advanced YIELD or STOP markings and signs plus a new crosswalk marking type installed. These types of changes over time were recorded in the final database using the historical and date-stamped imagery tools in Google Earth.

For all sites, important characteristics recorded in the final database included those described in Appendix G of this research report ("NCHRP Project 17-56 Database Creation and Data Entry Methodology Notes"), intersection and midblock locales, road features, signage, area type (urban or suburban), bike lanes, trails, intersection characteristics, crosswalk types, crossing distances, and other pertinent attributes.

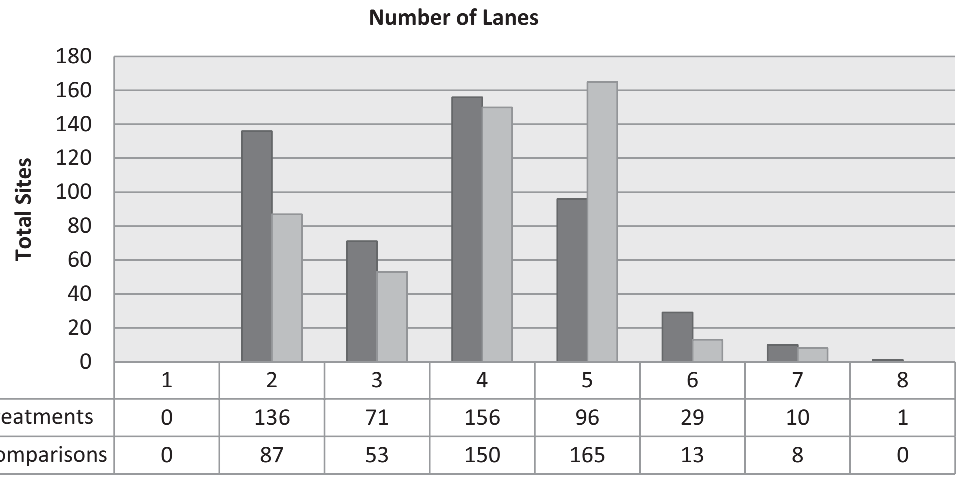


Figure 3-2. Sample site distribution by number of lanes.

Appendix A provides descriptions and examples of treatment installations. Samples of pedestrian counts and site photographs are given in Appendix B.

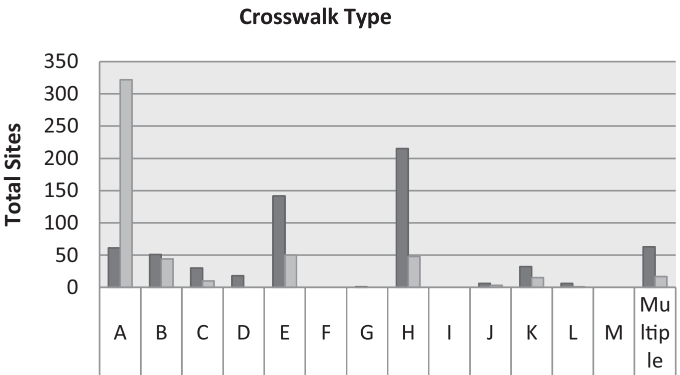
Treatment and Comparison Site Characteristics

Most of the sample sites are on roads with four or more lanes (see Figure 3-2). However, 136 of the 499 treatment sites (27%) and 87 of the 476 comparison sites (18%) are on two-lane roads (see Table 3-4). The research team decided to focus more on sites with four or more lanes and pedestrian crossings on arterial streets and at transit stops, since these are the types of sites where pedestrian crashes are more likely to occur (compared to local, two-lane streets) and where pedestrian safety treatments are more likely needed.

Figure 3-3 provides a summary of crosswalk types. The most common types are crosswalks with no markings, continental-style crosswalks, and ladder crosswalks. Standard (parallel-line)

Table 3-4. Study site distribution by number of lanes, city, and treatment or comparison site.

		Treatment Sites					Comparison Sites				
City	State	Total Number of Sites	≤ 2 Lanes		≥ 3 Lanes		Total Number of Sites	≤ 2 Lanes		≥ 3 Lanes	
Alexandria	VA	3	0	0%	3	100%	2	0	0%	2	100%
Arlington	VA	20	12	60%	8	40%	20	15	75%	5	25%
Cambridge	MA	19	11	58%	8	42%	25	19	76%	6	24%
Charlotte	NC	36	5	14%	31	86%	112	2	2%	110	98%
Chicago	IL	36	16	44%	20	56%	37	8	22%	29	78%
Eugene	OR	29	9	31%	20	69%	27	7	26%	20	74%
Miami	FL	30	3	10%	27	90%	36	2	6%	34	94%
Milwaukee	WI	12	1	8%	11	92%	18	9	50%	9	50%
New York	NY	17	4	24%	13	76%	24	9	38%	15	63%
Phoenix	AZ	18	0	0%	18	100%	16	0	0%	16	100%
Portland	OR	61	12	20%	49	80%	33	3	9%	30	91%
Scottsdale	AZ	18	1	6%	17	94%	16	3	19%	13	81%
St. Petersburg	FL	115	58	50%	57	50%	45	7	16%	38	84%
Tucson	AZ	85	4	5%	81	95%	65	3	5%	62	95%
Grand Total		**499**	**136**	**27%**	**363**	**73%**	**476**	**87**	**18%**	**389**	**82%**



	A	B	C	D	E	F	G	H	I	J	K	L	M	Multiple
Treatment	61	51	30	18	142	0	1	215	0	6	32	6	0	63
Comparison	322	44	10	0	50	0	0	48	0	3	15	1	0	17

Type	Identifier
No Markings	A
White Std	B
Yellow	C
Staggered	D
Ladder	E
Zebra	F
Piano	G
Continental	H
Dbl. Cont	I
Diagonal	J
Brick/Stp/Blk	K
Unknown	L
Raised	M
Combined	Multiple

Figure 3-3. Sample site distribution by crosswalk type.

crosswalks were found at about 100 crossing sites. Multiple crosswalk types (80 sites) are those that have two or more descriptive codes (combined): for example, a yellow crosswalk with standard markings, a staggered crosswalk with continental markings, or a diagonal crosswalk with ladder markings.

The number of treatment sites and comparison sites is shown in Figure 3-4 and Table 3-5 by intersection and midblock configuration for each city. Most of the treatment (75%) and comparison (76%) sites are at intersections. Furthermore, a great majority of treatment and comparison sites are in suburban areas (see Figure 3-5).

In terms of transit use, 41% of treatment sites are at transit stops, and approximately half (50%) of the comparison sites are at transit stops (see Figure 3-6).

Collection of Pedestrian Count Data

The previous section summarized the site characteristics of all of the treatment and comparison sites currently in the database. This section describes the process used to collect pedestrian count data at the majority (915) of those sites where pedestrian counts were not available from city data files.

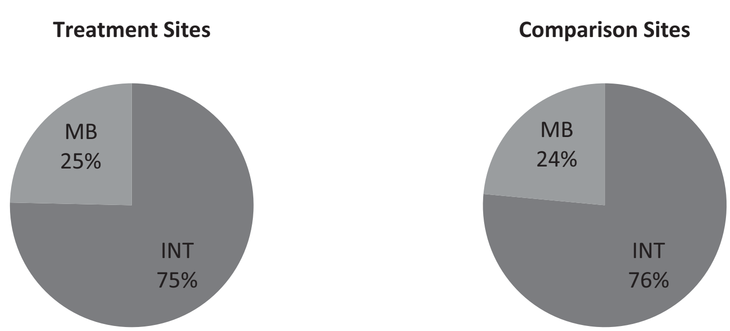


Figure 3-4. Sample site distribution by intersection (INT) and midblock (MB) (all sites).

Table 3-5. Study site distribution data including city, treatment or comparison site, and intersection or midblock site.

City	State	Treatment Sites					Comparison Sites				
		Total Number of Sites	Intersection		Midblock		Total Number of Sites	Intersection		Midblock	
Alexandria	VA	3	3	100%	0	0%	2	1	50%	1	50%
Arlington	VA	20	17	85%	3	15%	20	16	80%	4	20%
Cambridge	MA	19	17	89%	2	11%	25	21	84%	4	16%
Charlotte	NC	36	20	56%	16	44%	112	82	73%	30	27%
Chicago	IL	36	28	78%	8	22%	37	30	81%	7	19%
Eugene	OR	29	16	55%	13	45%	27	22	81%	5	19%
Miami	FL	30	19	63%	11	37%	36	27	75%	9	25%
Milwaukee	WI	12	10	83%	2	17%	18	16	89%	2	11%
New York	NY	17	11	65%	6	35%	24	20	83%	4	17%
Phoenix	AZ	18	12	67%	6	33%	16	11	69%	5	31%
Portland	OR	61	53	87%	8	13%	33	21	64%	12	36%
Scottsdale	AZ	18	11	61%	7	39%	16	8	50%	8	50%
St. Petersburg	FL	115	78	68%	37	32%	45	29	64%	16	36%
Tucson	AZ	85	81	95%	4	5%	65	60	92%	5	8%
	Total	499	376	75%	123	25%	476	364	76%	112	24%

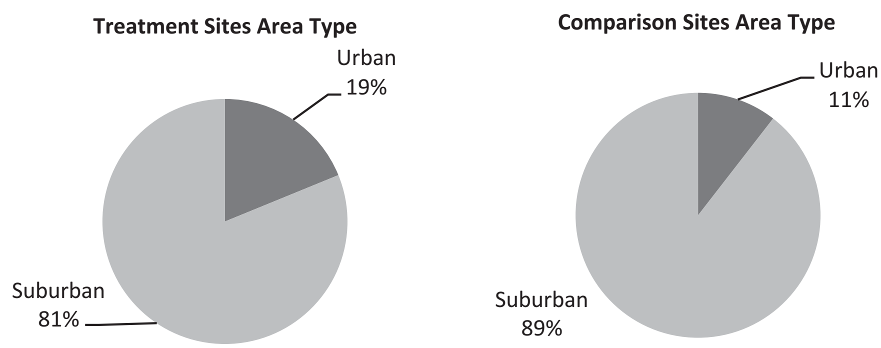


Figure 3-5. Sample site distribution by area type (all sites).

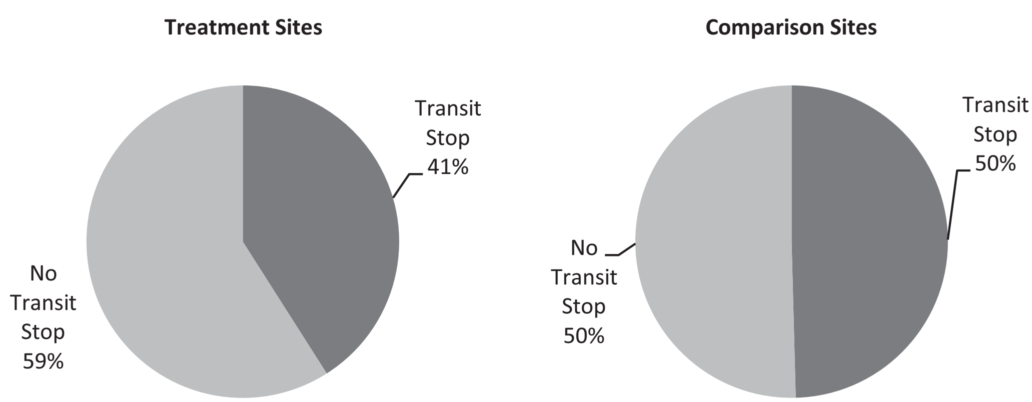


Figure 3-6. Sample site distribution at locations with and without transit stops (all sites).

Approach

The data collection followed a consistent and pre-established process for collecting pedestrian counts. Several key steps are the following:

1. Confirmed list of treatment sites and comparison sites.
   a. Confirmed identified treatment(s) at treatment site.
   b. Eliminated sites with a traffic signal.
2. Due to limitations in the project budget, pedestrian volumes for 24-hour periods could not be compiled. The project team investigated the option of collecting pedestrian volumes for 1 hour versus 2 hours. Collecting data for 1 hour would allow for data collection at more sites, but the team needed to determine whether a 1-hour data collection period would provide sufficient accuracy. To make this determination, the team
   a. Filmed/recorded pedestrians crossing at the site for a 2-hour period generally between noon and 6:00 pm for first city (Portland, Oregon).
   b. Viewed the 2-hour period from 3:00 to 5:00 pm by intersection leg in 15-minute increments (this time period was chosen because this was usually the 2-hour period with the most number of pedestrian crossings).
   c. Compared the results of the Portland 2-hour counts to the 12-hour counts from Charlotte, North Carolina (from city records). This comparison of 1-hour to 2-hour counts showed that 1-hour counts were essentially as good as 2-hour counts for developing estimates of daily pedestrian volumes. Typically, 1-hour counts were conducted between 4:00 and 5:00 pm. Details of this analysis are given in Appendix C. Appendix D describes the method for adjusting these short counts into day-long pedestrian volumes.
3. Filmed or recorded pedestrian counts for a 1-hour period at most sites in subsequent cities studied for estimating pedestrian AADT.

The team provided QC with specific location information (e.g., intersection or midblock street names, and latitude and longitude of each site), a link to a Google map location, and an indication of which treatments were expected to be present at the location. QC used this information to locate the sites, confirm the expected conditions were present, document differences between what the team expected and the actual conditions, and document other circumstances that seemed potentially inconsistent with the needs of NCHRP Project 17-56.

A summary of the treatment and comparison sites and the status of the pedestrian volume data collection, by city, follows.

Number of Treatment and Comparison Sites

The initial list of sites in need of pedestrian counts was reduced for several reasons. For some sites in Charlotte, North Carolina, and St. Petersburg, Florida, pedestrian counts were already available from city records. Other sites were eliminated for reasons such as ongoing construction during data collection periods and the presence of a newly added traffic signal.

As data collection commenced in the field, additional sites were removed because the locations were controlled by a signal and no longer qualified as uncontrolled crossing locations; there was construction at or adjacent to the site; and/or the treatments that were expected to be installed were not present. Table 3-6 summarizes the number of sites by city at which data collection was attempted (sites listed), and successfully completed (sites counted). The pedestrian volume data collection commenced in July 2014 in Portland, Oregon, and concluded in November 2014 with the three Arizona cities (Phoenix, Scottsdale, and Tucson).

Table 3-6. Summary of treatment and comparison sites for pedestrian volume data collection.

	Sites Listed		Sites Counted	
City	Treatment Sites	Comparison Sites	Treatment Sites	Comparison Sites
Arlington & Alexandria, VA	32	33	30	30
Cambridge, MA	23	28	19	26
Charlotte, NC	36	35	36	35
Chicago, IL	40	40	37	37
Eugene, OR	30	30	30	28
Miami, FL	34	38	29	39
Milwaukee, WI	18	25	12	18
New York, NY	20	25	17	24
Phoenix, AZ	22	20	20	17
Portland, OR	86	39	66	36
Scottsdale, AZ	19	18	19	18
St. Petersburg, FL	90	54	90	47
Tucson, AZ	86	69	86	69
TOTAL	**536**	**454**	**491**	**424**

Summary

In summary, pedestrian volumes were collected at a total of 491 treatment sites and 424 comparison sites in 14 cities from July through November 2014. The pedestrian counts were used to estimate the pedestrian AADT for each of these sites. Please note that the number of sites presented in Table 3-6 only represents sites where new pedestrian counts needed to be collected. It does not include the approximately 100 sites (from Charlotte and St. Petersburg) where pedestrian counts were already available from the city files and provided to the project team.

Collection of Crash and Average Annual Daily Traffic Data

Crash Data

To develop CMFs, it is necessary to collect crash data for each treatment and comparison site. It is also important to understand how the crash data for each agency are collected so that the appropriate crashes are included in the query for analysis. Agencies in each of the 14 cities were contacted to obtain the necessary information to understand and subsequently request crash data for each study site. Information gathered included but was not limited to:

- Number of years of available crash data;
- Any major changes that occurred to the crash databases or recording systems in the last 10 years;
- An explanation of how crashes are assigned to intersection and midblock locations; and
- Whether hard copies of the crash reports were available.

Once an appropriate contact was identified, steps were made to obtain crash data. Table 3-7 gives an indication of which agency provided data for each city involved in the study, the range of years of available data, and whether hard copies of the crash reports were available.

It is important to note that the research team was not able to obtain any hard copy reports from any agency, primarily due to privacy laws. This means that crash diagrams and

Table 3-7. Crash data availability and summary for study sites.

City	Agency to Provide Crash Data	Years of Data Available	Total Years	Hard Copies Available
Alexandria, VA	Virginia DOT	2004–2013	10	No
Arlington, VA	Virginia DOT	2004–2013	10	No
Cambridge, MA	Cambridge DOT	2004–2013	10	No
Charlotte, NC	HSIS*	2004–2013	10	No
Chicago, IL	Chicago DOT	2008–2012	5	No
Eugene, OR	Oregon DOT	2004–2013	10	No
Miami, FL	Florida DOT	2006–2012	7	No
Milwaukee, WI	Wisconsin DOT	2004–2013	10	No
New York, NY	New York DOT	2008–2012	5	No
Phoenix, AZ	Arizona DOT	2004–2013	10	No
Portland, OR	Oregon DOT	2004–2013	10	No
St. Petersburg, FL	Florida DOT	2006–2012	7	No
Scottsdale, AZ	Arizona DOT	2004–2013	10	No
Tucson, AZ	Arizona DOT	2004–2013	10	No

*HSIS = Highway Safety Information System

narratives of each crash could not be used to locate the crashes relative to the treatment(s) of interest.

The majority of agencies had crash data available electronically; however, much work was needed to identify crashes at particular sites. For instance, some cities maintained crash data in a spatial format, so queries in a GIS environment were used to associate crashes to sites. In most cases, the research team was given the full crash record for the entire desired city. In a few cases, the agency pulled the full crash record for applicable crashes only for the sites provided by the research team.

Average Annual Daily Traffic Data

It was also necessary to obtain traffic volume data for the road segments surrounding each leg of the treatment or comparison site. In addition to obtaining crash data from each agency, the research team also sought contacts for AADT data. In most cases, AADT data were obtained from local agencies, unlike the crash data, which came primarily from state DOTs. Efforts were made to obtain multiple years of AADT records where possible.

Develop Crash Modification Factors

The original objectives of this research were to (1) quantify the relationships between pedestrian safety and crossing treatments at uncontrolled locations and (2) develop CMFs or CMFunctions by crash type and severity for four treatments.

CHAPTER 4

Data Analysis

Crash Modification Factor Development for Pedestrian Treatments

The aim of the analytical work was to use the most appropriate techniques for estimating CMFs or CMFunctions for pedestrians involved and all crashes, by type, for various treatments and treatment combinations.

As defined in the FHWA's *Guide to Developing Quality Crash Modification Factors* (*64*), a crash modification *factor* (CMF) is a multiplicative factor used to compute the expected number of crashes *after* implementing a given countermeasure at a specific site. The CMF is multiplied by the expected crash frequency without treatment. A CMF greater than 1.0 indicates an expected increase in crashes, while a value less than 1.0 indicates an expected reduction in crashes after implementation of a given countermeasure. For example, a CMF of 0.8 indicates an expected safety benefit, specifically, a 20 percent expected reduction in crashes. A CMF of 1.2 indicates an expected degradation in safety, specifically, a 20 percent expected increase in crashes.

A crash modification *function* (CMFunction) is a formula used to compute the CMF for a specific site based on its characteristics. It is not always reasonable to assume a constant reduction in crashes for all sites with different characteristics (e.g., safety improvements may be greater for high traffic volumes). A countermeasure may also have several levels or potential values (e.g., improving intersection skew angle). A crash modification *function* allows the CMF to change over the range of a variable or combination of variables. Where possible, it is preferable to develop CMFunctions as opposed to a single CMF value since safety effectiveness most likely varies based on site characteristics, at least to some extent. In practice, however, this is often difficult since more data are required to detect such differences. This is particularly so for pedestrian countermeasures. It is also possible that the CMF for all pedestrian crashes might be different than the CMF for fatal and incapacitating pedestrian crashes. The same limitation related to the need for a larger crash set also applies to this issue.

It was quickly realized that the preferred before-after study would be limited in scope and robustness because of the relatively small sample sizes, especially for pedestrian crashes. Thus, considerable effort was made to assemble a database for the alternative methodology, cross-sectional regression analysis, while recognizing the well-known limitations of this approach. Because of those limitations, it was still necessary to conduct a before-after study, however limited, to corroborate the results of the cross-sectional analysis. The results of the before-after study could also be used to reinforce the results of the cross-sectional regression analysis by providing combined results that could be used with more confidence.

This chapter is organized as follows. The before-after study is described, followed by a section on the cross-sectional analysis. Each of these main sections provides information on the data and methodology used, followed by a presentation and discussion of the results. The chapter closes with a section that compares the results of the two sets of analyses and a final section with conclusions and recommendations.

Before-After Evaluation

The intent of the study was to conduct a before-after evaluation for the following treatments (initially, it appeared there were sufficient samples to facilitate such a study):

- Refuge island alone (68 sites)
- Advanced YIELD or STOP markings and signs alone (69 sites)
- Refuge island with advanced YIELD or STOP markings and signs (9 sites)
- PHB alone (10 sites)
- PHB with advanced YIELD or STOP markings and signs (27 sites)
- RRFB alone (9 sites)
- RRFB with advanced YIELD or STOP markings and signs (7 sites)

However, it was clear that samples of sites for PHB alone, RRFB alone, and the refuge island and advanced YIELD or STOP markings and signs and RRFB and advanced YIELD or STOP markings and signs combinations were limited (less than or equal to 10 sites). These samples were too small to obtain any reliable CMFs for pedestrian crashes. Hence, the before-after evaluation was pursued for refuge islands, advanced YIELD or STOP markings and signs, and PHB and advanced YIELD or STOP markings and signs.

Four crash types were investigated in the before-after evaluation: total, rear-end, sideswipe, and pedestrian.

Before-After Study Methodology

The Empirical Bayes (EB) methodology for observational before-after studies was used to develop CMFs. In the EB approach, the CMF is estimated based on the parameters π and λ, where π is the expected number of crashes that would have occurred in the after period without the treatment and λ is the number of reported crashes in the after period. This methodology is rigorous in that it properly accounts for regression to the mean and has been included in the first edition of the *HSM* as the state-of-the-art for conducting observational before-after studies (*67*).

To estimate π (expected number of crashes), the research team

1. Identified a group of untreated sites that were otherwise similar to the treatment group. This is called the reference group.
2. Using data from the reference group, estimated safety performance functions (SPFs) (mathematical equations) relating crashes to the characteristics of the site including traffic volume, pedestrian volume, number of through lanes, location type (intersection or non-intersection), area (urban or suburban), presence and type of crosswalk, one-way or two-way street, and presence or absence of school crossing. The SPFs are documented in Appendix E of this report.
3. Calibrated annual SPF multipliers, in estimating SPFs, to account for the temporal effects (e.g., variation in weather, demography, and crash reporting) on safety.
4. Estimated the number of crashes that would be expected in each year of the before period for each treatment site using the SPFs, the annual SPF multipliers, and data on the site characteristics for each year in the before period for each treatment site. The sum of these annual estimates was called P. The year of the treatment installation was not included in the before and after periods.

5. Used the following equations to calculate the EB estimate of the expected crashes in the before period at each site, where x is the count of crashes in the before period at a treatment site and m is the expected number of crashes in the before period after correcting for possible bias due to RTM:

$$m = w_1(x) + w_2(P), \tag{1}$$

where the weights w_1 and w_2 were estimated from the mean and variance of the SPF estimate as:

$$w_1 = \frac{Pk}{Pk+1}, \tag{2}$$

$$w_2 = \frac{1}{Pk+1}, \tag{3}$$

where k was estimated from the SPF calibration process with the use of a maximum likelihood procedure. In that process, a negative binomial distributed error structure was assumed with k being the overdispersion parameter of this distribution.

6. Estimated π as the product of m and the sum of the annual SPF predictions for the after period divided by P, the sum of these predictions for the before period (for each treatment site). The EB procedure also produced an estimate of the variance of π.

The estimate of π was then summed over all sites in treatment groups of interest (to obtain π_{sum}) and compared with the count of crashes during the after period in that group (λ_{sum}). The variance of π was also summed over all sites in the strategy group.

The CMF was estimated as:

$$CMF = \frac{\lambda_{sum} / \pi_{sum}}{1 + \left(Var(\pi_{sum}) / \pi_{sum}^2 \right)} \tag{4}$$

The standard deviation of the estimated CMF was the following:

$$StDev(CMF) = \sqrt{\frac{\theta^2 \left(\frac{Var(\pi_{sum})}{\pi_{sum}^2} + \frac{Var(\lambda_{sum})}{\lambda_{sum}^2} \right)}{\left(1 + \frac{Var(\pi_{sum})}{\pi_{sum}^2} \right)^2}} \tag{5}$$

The percent change in crashes is calculated as 100(1 − CMF); thus a value of CMF = 0.7 with a standard deviation of 0.12 indicates a 30 percent reduction in crashes with a standard deviation of 12 percent. Further discussion of the EB procedure can be found in Hauer (*65*).

Data for Before-After Study

The before-after evaluation included data from the following cities:

- Alexandria and Arlington, Virginia
- Cambridge, Massachusetts
- Charlotte, North Carolina
- Chicago, Illinois
- Eugene and Portland, Oregon
- Miami and St. Petersburg, Florida

Table 4-1. Summary statistics for sites with refuge islands (68 sites).

Variable	Minimum	Maximum	Mean	Standard Deviation
Major road AADT	1245	46000	12599	9897
Pedestrian volume (24 hours)	3	5354	434	935
Years before	1	5	2.37	1.2
Years after	1	8	5.84	1.7
Total crashes per site-year before	0	21.5	1.61	3.14
Total crashes per site-year after	0	15.75	1.52	2.71
Rear-end crashes per site-year before	0	9	0.63	1.4
Rear-end crashes per site-year after	0	9	0.50	1.34
Sideswipe crashes per site-year before	0	3	0.20	0.58
Sideswipe crashes per site-year after	0	1.25	0.12	0.24
Pedestrian crashes per site-year before	0	1.5	0.04	0.2
Pedestrian crashes per site-year after	0	0.67	0.04	0.11

- Milwaukee, Wisconsin
- New York, New York
- Phoenix, Scottsdale, and Tucson, Arizona

Tables 4-1 through 4-3 show the summary statistics for the following treatment groups:

- Refuge island (68 sites)
- Advanced YIELD or STOP markings and signs (69 sites)
- PHB in combination with advanced YIELD or STOP markings and signs (27 sites)

Tables 4-1 through 4-3 show summary statistics on the following variables: AADT on the major road, pedestrian volumes, number of years before and after, and crashes per site-year before and

Table 4-2. Summary statistics for sites with advanced YIELD or STOP markings and signs (69 sites).

Variable	Minimum	Maximum	Mean	Standard Deviation
Major road AADT	340	52892	15735	14271
Pedestrian volume (24 hours)	5	6812	644	1224
Years before	1	5	1.9	1.23
Years after	1	8	4.51	1.88
Total crashes per site-year before	0	27	2.92	5.17
Total crashes per site-year after	0	21.5	2.08	3.02
Rear-end crashes per site-year before	0	20	1.49	3.46
Rear-end crashes per site-year after	0	9	0.80	1.43
Sideswipe crashes per site-year before	0	1.5	0.17	0.36
Sideswipe crashes per site-year after	0	3	0.22	0.45
Pedestrian crashes per site-year before	0	3	0.13	0.47
Pedestrian crashes per site-year after	0	1.5	0.09	0.27

Table 4-3. Statistics for sites with PHBs and advanced YIELD or STOP markings and signs (27 sites).

Variable	Minimum	Maximum	Mean	Standard Deviation
Major road AADT	6634	48791	20673	12221
Pedestrian volume (24 hours)	6	1647	334	353
Years before	1	5	3.26	1.72
Years after	3	8	5.41	1.93
Total crashes per site-year before	0.2	11.8	3.62	3.6
Total crashes per site-year after	0	7.25	2.14	1.89
Rear-end crashes per site-year before	0	7	1.43	2.15
Rear-end crashes per site-year after	0	3.88	0.92	0.91
Sideswipe crashes per site-year before	0	2.2	0.41	0.63
Sideswipe crashes per site-year after	0	1.5	0.18	0.36
Pedestrian crashes per site-year before	0	1	0.10	0.22
Pedestrian crashes per site-year after	0	0.33	0.03	0.07

after for the four different crash types that were considered. These statistics are included to provide the reader with some basic information about the sample size and the range of the different variables. The before and after crash statistics from Tables 4-1 through 4-3 are for information only and cannot be directly used to estimate CMFs because such a comparison does not take account into the possible bias due to RTM and other trends. This comparison can be done with the EB estimates presented later.

Before-After Study Results—Estimates of Crash Modification Factors

Table 4-4 shows the estimated CMFs for refuge island, advanced YIELD or STOP markings and signs, and the PHB and advanced YIELD or STOP markings and signs combination. The columns that are included in Table 4-4 are as follows:

- **Treatment and number of sites.** This is the number of treated sites included in the evaluation. Only sites that had at least 1 year of before period data and 1 year of after period data were included in the before-after evaluation. The number of sites includes both intersections and non-intersections. The sample size was not sufficient to provide reliable CMFs for intersections and non-intersections separately.
- **Crash type**. As mentioned earlier, four crash types were included. The results for sideswipe and rear-end crashes were combined to be consistent with the approach used in the cross-sectional modeling method and other CMF evaluations conducted in recent times.
- **Number (#) of crashes per year (before).** This is the actual number of crashes per year in the before period at the treatment sites.
- **Number (#) of crashes per year (after).** This is the actual number of crashes per year in the after period at the treatment sites.
- **Number (#) of crashes (before).** This is the actual number of crashes in the before period at the treated sites.
- **Number (#) of crashes (after).** This is the actual number of crashes in the after period at the treated sites.

Table 4-4. Estimated crash modification factors from the before-after evaluation.

Treatment and number of sites	Crash type	# of crashes per year (before)	# of crashes per year (after)	# of crashes (before)	# of crashes (after)	EB estimates (before)	Variance of EB (before)	EB estimates (after)	Variance of EB (after)	CMF	S.E. of CMF	p-value
Refuge island: 68 sites	Pedestrian	2.53	2.23	6	13	7.9	2.0	18.8	11.2	0.671	0.215	0.126
Advanced YIELD or STOP markings and signs: 69 sites	Total	163.16	148.78	310	671	304.6	233.7	754.7	2254.5	0.886	0.065	0.079
	Rear-end and Sideswipe	83.68	74.28	159	335	155.5	101.0	416.2	1068.8	0.800	0.076	0.008
	Pedestrian	9.47	4.66	18	21	14.3	5.4	32.2	27.4	0.636	0.169	0.031
Pedestrian hybrid beacons & Advanced YIELD or STOP markings and signs: 27 sites	Total	87.73	63.03	286	341	275.1	232.3	413.2	1078.5	0.820	0.078	0.021
	Rear-end and Sideswipe	38.65	33.64	126	182	117.5	84.0	205.4	460.9	0.876	0.111	0.264
	Pedestrian	3.07	0.74	10	4	8.0	2.9	15.6	13.3	0.244	0.128	<0.001

- **EB estimates (before).** This is the EB estimate of the crashes in the before period after correcting for RTM. Generally, this is expected to be lower than the actual number of crashes in the before period if sites with high accidents had been selected for treatment.
- **Variance of EB (before).** This is the variance of the EB estimates for the before period.
- **EB estimates (after).** This is the estimate of the crashes in the after period had the treatment not been implemented.
- **Variance of EB (after).** This is the variance of the EB estimates for the after period.
- **CMF.** This column shows the CMF.
- **S.E. of CMF.** This is the standard error of the CMF.
- **p-value.** This indicates the level of significance for the CMF. With lower p values (or the level of significance), we have more confidence that the CMF is truly statistically different from 1.0. Typically, most researchers use p values of 0.05 (i.e., 5%) or lower as a benchmark. However, due to the relative rarity of pedestrian crashes (compared to vehicle crashes), CMFs associated with pedestrian treatments have p values that are higher than 0.05. Hence, we also discuss p values higher than 0.05 in the discussion below.

The following observations can be made based on the results in Table 4-4:

- **Refuge islands.** For pedestrian crashes, the results indicate a reduction of approximately 33%, which was significant at about the 13% level. The results for the vehicle-vehicle involved crash types were not considered reliable enough for inclusion.
- **Advanced YIELD or STOP markings and signs.** The results indicate, approximately, an 11 percent reduction in total crashes, a 20 percent reduction in rear-end and sideswipe crashes, and a 36 percent reduction in pedestrian crashes. The reduction in total crashes is statistically significant at about the 8 percent level, and the reduction in the other two crash types is statistically significant at the 5 percent level or lower.
- **PHB and Advanced YIELD or STOP markings and signs.** The results indicate, approximately, an 18 percent reduction in total crashes and a 76 percent reduction in pedestrian crashes. Both these results are statistically significant at the 5 percent level or lower. The changes in rear-end and sideswipe crashes are not statistically significant at any reasonable significance level. The result for pedestrian crashes is quite consistent with the 69 percent reduction reported by Fitzpatrick and Park (*32*) for the same treatment at intersections in Tucson. Fitzpatrick and Park (*32*) also used the EB before-after evaluation method.

It should be mentioned that two of the columns in Table 4-4 indicate the pedestrian crashes per site per year that occurred on average before and after the various countermeasures were installed. Even though there is a reduction in pedestrian crashes/site/year in the after period (compared to the before period) for each countermeasure, these crash rates do not account for possible bias due to RTM, overall trends, and changes in traffic volume between the before and after periods. For this reason, the rates shown in Table 4-4 alone should not be used to determine the precise level of the CMF. The CMFs were estimated based on the EB procedure, which accounts for the possible variation in crashes due to RTM, overall trends, and changes in traffic volumes. Table 4-4 also provides the total sample of crashes that was included in the before and after periods. The greater number of crashes in the after period as compared to the before period is the result of there being a larger time frame in the after period than the before period.

Crash Modification Factor Estimation from Cross-Sectional Regression Analysis

As mentioned earlier, although the EB before-after methodology is preferred for estimating CMFs, and it was possible to do a limited EB study for this research, a cross-sectional analysis was necessary because the data before and after a treatment was actually implemented were too limited for a robust before-after study. The results from the two approaches are compared in a later section.

Analysis Purpose

The purpose of the cross-sectional regression analysis, as for the before-after study, was to estimate CMFs or CMFunctions for each of the four pedestrian treatments under study. These four treatments are:

- Refuge islands
- Advanced YIELD or STOP markings and signs
- PHBs
- RRFBs

It was also of interest to estimate CMFs for combinations of treatments. In fact, at many of the sites one treatment was installed initially, followed by installation of one or more additional treatments in later years. For most combination treatments, however, the sample size was too limited to provide robust results. The exceptions were PHBs and RRFBs—most sites with these treatments also have advanced YIELD or STOP markings and signs present.

Several crash types were analyzed separately for each treatment, including

- Pedestrian crashes
- Rear-end plus sideswipe crashes
- Total crashes
- (KABC) injury rear-end plus sideswipe crashes
- (KABC) injury total crashes

KABC refers to crashes classified as K (fatal), A (incapacitating injury), B (non-incapacitating injury) or C (possible injury) on the KABCO injury severity scale (O stands for property damage only).

While the target crash of the four pedestrian treatments is the small subset of vehicle-pedestrian crashes, vehicle-vehicle crashes were added to the analysis to investigate whether they were affected as well. If the treatments alter driver behavior, this is a logical possibility. Rear-end and sideswipe crashes were combined as it was hypothesized that these types of vehicle-vehicle crashes may be the crash types most likely to be affected by pedestrian treatments and would be similar in this regard. The combined category was considered the target vehicle-vehicle crash category.

Approach for Crash Modification Factor Cross-Sectional Regression Analysis

CMFs derived from cross-sectional panel data are based on a single time period under the assumption that the ratio of average crash frequencies for sites with and without a feature is an estimate of the CMF for implementing that feature. Known confounding factors, such as traffic volume or geometric characteristics, can be controlled for in principle by estimating a multiple variable regression model and/or matching sites based on these variables. However, the basic problem with the cross-sectional design is that an unknown portion of the observed difference in crash experience can be due to factors that cannot be controlled for (e.g., if data are non-existent) or are unknown. For this reason, caution needs to be exercised in making inferences about CMFs on the basis of cross-sectional designs. Corroboration with insights from before-after studies, however limited, other cross-section studies and/or logical reasoning tends to mitigate this difficulty.

The cross-sectional analysis applied Generalized Linear Modeling (GLM). Because each site-year of data was used as an observation, it was necessary to resolve the issue of repeated measures of the data in specifying the models. This is termed "repeated measures" because for each site multiple observations of crash counts are used, and the errors between these observations are correlated. In addition, the model specification considered that the data are nested both by site location (multiple years of observed data for each site) and by city. The approach taken within the GLM framework to account for the repeated measures and the nested nature of the data was Generalized Estimation Equations (GEE). This ensures that the correlation between within-site observations is accounted for as well as allowing for unobserved heterogeneity between cities.

Regression models for crash data typically adopt an error distribution from the Poisson family, which is suited for non-negative count data. The negative binomial model has been used extensively for crash data modeling because these data are frequently overdispersed, meaning the variance of observed crash frequencies is greater than the mean. In preliminary model development, it was observed that the pedestrian crash data were not overdispersed. For this reason, the regression models for pedestrian crashes used a Poisson error distribution with repeated measures. For the other crash types considered, the negative binomial distribution with repeated measures specification was found to be appropriate because those data did exhibit overdispersion.

Cumulative Residual (CURE) plots and the Integrate-Differentiate (ID) method (discussed in Appendix F) were used to investigate different model forms. The assessment of model fit included, in addition to the CURE plot, several goodness-of-fit statistics and considerations, including:

- The logic of the direction of effect and magnitude of estimated parameters
- The p values of estimated parameters
- For negative binomial models, the value of the overdispersion parameter
- CURE plots for each variable included in the model
- Akaike's Information Criteria (AIC)

When comparing two or more potential models, the AIC penalizes for the addition of parameters and thus selects a model that fits well but has a minimum number of parameters. AIC is not typically used as a goodness-of-fit measure in itself, but can be used to compare the relative fit of alternate models. The lower value of AIC is preferred.

AIC = −2(log-likelihood) + 2K, where K is the number of estimated parameters included in the model (i.e., number of variables + the intercept).

The log-likelihood of the model, given the data, is readily available in statistical output and reflects the overall fit of the model (smaller values indicate worse fit).

Description and Data Preparation Considerations for Cross-Sectional Model Databases

This section describes the preparation of the datasets used to develop the regression models for each of the four treatments and provides summary statistics. Definitions of the variables are given in Table 4-5.

Data Preparation Considerations

Data Observations for Modeling. The structure of the data used to estimate the regression models included each individual site-year of data as an observation. Each site-year was used instead of aggregating all years of data for each site because many sites experienced changes over time other than the treatment of interest. For example, at one midblock site in Phoenix, a refuge island was installed in 2003, an advanced STOP sign with markings was installed in 2005, and

Table 4-5. Definitions for analysis variables.

Variable	Definition
Lanes	Number of lanes on road being crossed
Crosswalk Length	Crosswalk length in feet
AADT	Average annual daily traffic on mainline road
PEDAADT	Pedestrian average annual daily volume
Midblock_Int	M if midblock location I if unsignalized intersection
BusStop	Y if bus stop is present N if bus stop is not present
Lighting	Y if lighting is present N if lighting is not present
Refuge Island Presence	Y if refuge island is present N if refuge island is not present
School Crossing	Y if school crossing is present N if school crossing is not present
Median	Y if median is present on road being crossed N if median is not present on road being crossed
AreaType	Suburban or urban area type
TraffDir	One-way or two-way traffic on road being crossed
PEDCRASH	Frequency of pedestrian–vehicle crashes
TOTCRASH	Frequency of total crashes
INJCRASH	Frequency of fatal+injury crashes
TARGETCRASH	Frequency of rear-end plus sideswipe crashes
INJTARGETCRASH	Frequency of fatal+injury rear-end plus sideswipe crashes

a PHB was installed in 2009. Because of the multiple changes, the data for all years cannot be combined. Data for any year in which one of the four treatments of interest was installed were discarded from the calibration dataset so that a full year of data could be used where no changes took place. Additionally, for a few sites, one or more years of data were discarded when major construction took place, e.g., a lane addition.

Influence Area. The influence area defines the areas upstream and downstream from each pedestrian crossing within which crashes are included in the crash data for the site. Preliminary models were developed using the full influence area (350 ft) used for each jurisdiction to assign crashes related to the crossing and using areas of 50 ft, 150 ft, and 250 ft in either direction of the treatment. No significant difference was found for varying the size of the influence area, so the full influence area data provided by jurisdictions were used for developing the final models to maximize the number of crashes under study. This is consistent with the strategy adopted for the data used for the before-after study.

Zero Pedestrian Volume Sites. Some sites had a count of zero pedestrians during the time a traffic count was done. It is unlikely that the crossing volume is truly zero for the average daily count, but it is likely that the pedestrian volume is low. In developing preliminary models, it was investigated whether these sites should be dropped from the data or whether a value of 0.5 should be assigned as a daily pedestrian volume so that the GLM approach could be used on these sites in estimating the regression models. It was found that there were no substantial differences in the parameter estimates or goodness-of-fit for the models estimated under either approach. Thus, the sites with a count of zero pedestrians were included with a daily crossing volume of 0.5 in the final dataset used, in order to maximize the data available.

Aggregation/Disaggregation of Data. Because some sites had more than one of the four pedestrian treatments under study, it was considered preferable to eliminate sites with one of the other three treatments present when looking at the safety effects of a single treatment. This approach sought to reduce the number of confounding variables that the regression modeling needed to account for.

Where possible this approach was undertaken. However, for the PHB and RRFB treatments it was not possible to take this approach because it would have left very few site-years of observed data for the single treatment. Where this could not be done, one or more of the other treatments was included in order to increase the sample size. Details on which data were included for each model are discussed in the cross-sectional model results section. The results are presented and interpreted with the appropriate caveats.

Data Summary

Refuge Islands. The dataset for developing CMFs for refuge islands did not include any site that had advanced YIELD or STOP markings and signs, PHB, or RRFB installed at any time during the study period. Table 4-6 and Table 4-7 provide descriptive statistics by treatment and reference group. The reference group sites do not have any of the four main treatments installed.

Advanced YIELD or STOP markings and signs. The dataset used for developing CMFs for advanced YIELD or STOP markings and signs did not include any site that had a refuge island, PHB, or RRFB installed at any time during the study period. Table 4-8 and Table 4-9 provide descriptive statistics by treatment and reference group. The reference group sites do not have any of the four main treatments installed.

PHBs. The dataset for developing CMFs for PHBs did not include any site that had a refuge island or RRFB installed at any time during the study period. Because many sites with a PHB also have an advanced YIELD or STOP marking and sign, sites with these signs were included in the dataset. The sites were also limited to cities in which a PHB existed: Charlotte, Portland, Phoenix, Scottsdale, Tucson, and St. Petersburg. Table 4-10 and Table 4-11 provide descriptive statistics by treatment and reference group. The reference group sites do not have any of the four main treatments installed.

RRFBs. For pedestrian crash models, the dataset for developing CMFs for RRFBs included all locations. This was needed to allow for a sufficient sample of pedestrian crashes. For the other crash types, the dataset for RRFBs did not include any site that had a refuge island or PHB installed at any time during the study period. Because many sites with an RRFB also have an advanced YIELD or STOP marking and sign, sites with these signs were included in the dataset. For the non-pedestrian crash models, the sites were also limited to cities in which an RRFB existed: Chicago, Eugene, Miami, Phoenix, Portland, and St. Petersburg. Table 4-12 and Table 4-13 provide descriptive statistics by treatment and reference group. The reference group sites do not have any of the four main treatments installed.

Cross-Sectional Model Results

This section presents and discusses the final models developed and the CMFs implied by the relevant parameter estimates. The following considerations were applied in making decisions on variables to include in the models and presenting the results:

1. The typical multiplicative crash prediction model form was eventually applied with pedestrian and total AADT as separate power model terms and the categorical variables for each city in which a crossing is located, presence of a treatment, area type (urban or suburban), and crossing location (midblock or intersection) as exponential terms. The exponential model form for categorical variables implies a percent change to the crash prediction for each level of the variable, leading to a CMF for the presence of treatment variables.

Table 4-6. Summary statistics for refuge island dataset.

Site Type	Statistic	Lanes	Crosswalk Length	AADT	PEDAADT	PEDCRASH	TOTCRASH	INJCRASH	TARGET CRASH	INJ TARGET CRASH
Control	N	3867	3867	3867	3867	3867	3867	3867	3867	3867
Control	MIN	2	21	810	0.5	0	0	0	0	0
Control	MAX	7	142	48000	7825	4	31	15	22	8
Control	MEAN	4.0	56.4	17603.2	343.1	0.1	2.4	0.9	1.0	0.3
Control	STD	1.2	13.6	9507.8	721.0	0.3	3.4	1.5	1.9	0.8
Treatment	N	1154	1154	1154	1154	1154	1154	1154	1154	1154
Treatment	MIN	2	22	340	0.5	0	0	0	0	0
Treatment	MAX	7	112	47500	20388	2	19	7	8	4
Treatment	MEAN	3.6	60.3	15634.9	607.8	0.1	1.2	0.4	0.5	0.2
Treatment	STD	1.3	17.8	10335.7	1829.9	0.2	2.0	0.9	1.0	0.4

Table 4-7. Frequency tallies for refuge island dataset.

Site Type	Variable	Frequency	Percentage
Reference	Midblock_Int	Intersection – 2,970 Midblock – 897	Intersection – 76.8 Midblock – 23.2
	BusStop	No – 2,047 Yes – 1,820	No – 52.9 Yes – 47.1
	Lighting	No – 840 Yes – 3,027	No – 21.7 Yes – 78.3
	Refuge Island Presence	Yes – 0 No – 3,867	Yes – 0.0 No – 100.0
	SchoolCrossing	No – 3,529 Yes – 338	No – 91.3 Yes – 8.7
	Median	No – 3,867 Yes – 0	No – 100.0 Yes – 0.0
	AreaType	Suburban – 3,522 Urban – 345	Suburban – 91.1 Urban – 8.9
	TraffDir	One-Way – 97 Two-Way – 3,770	One-Way – 2.5 Two-Way – 97.5
Treatment	Midblock_Int	Intersection – 813 Midblock – 341	Intersection – 70.5 Midblock – 29.5
	BusStop	No – 626 Yes – 528	No – 54.3 Yes – 45.7
	Lighting	No – 135 Yes – 1,019	No – 11.7 Yes – 88.3
	Refuge Island Presence	No – 0 Yes – 1,154	No – 0.0 Yes – 100.0
	CrossingGuard	No – 1,147 Yes – 7	No – 99.4 Yes – 0.6
	SchoolCrossing	No – 1,079 Yes – 75	No – 93.5 Yes – 6.5
	Median	No – 492 Yes – 662	No – 42.6 Yes – 57.4
	AreaType	Suburban – 956 Urban – 198	Suburban – 82.8 Urban – 17.2
	TraffDir	One-Way – 49 Two-Way – 1,105	One-Way – 4.2 Two-Way – 95.8

Table 4-8. Summary statistics for advanced YIELD or STOP markings and signs dataset.

Site Type	Statistic	Lanes	Crosswalk Length	AADT	PEDAADT	PEDCRASH	TOTCRASH	INJCRASH	TARGET CRASH	INJ TARGET CRASH
Ref	N	3867	3867	3867	3867	3867	3867	3867	3867	3867
Ref	MIN	2	21	810	0.5	0	0	0	0	0
Ref	MAX	7	142	48000	7824.6	4	31	15	22	8
Ref	MEAN	4.0	56.4	17603.2	343.1	0.1	2.4	0.9	1.0	0.3
Ref	STD	1.2	13.6	9507.8	721.0	0.3	3.4	1.5	1.9	0.8
Treat	N	540	540	540	540	540	540	540	540	540
Treat	MIN	2	20	533	0.5	0	0	0	0	0
Treat	MAX	8	122	49402.0	5128.8	2	14	10	13	9
Treat	MEAN	3.4	53.2	12979.0	494.5	0.1	1.1	0.4	0.4	0.2
Treat	STD	1.4	19.7	12364.6	937.0	0.3	1.7	1.0	1.2	0.7

Table 4-9. Frequency tallies for advanced YIELD or STOP markings and signs dataset.

Site Type	Variable	Frequency	Percentage
Reference	Midblock_Int	Intersection – 2,970 Midblock – 897	Intersection – 76.8 Midblock – 23.2
	BusStop	No – 2,047 Yes – 1,820	No – 52.9 Yes – 47.1
	Lighting	No – 840 Yes – 3,027	No – 21.7 Yes – 78.3
	Presence of Advanced YIELD or STOP Markings and Signs	Yes – 0 No – 3,867	Yes – 0 No – 100.0
	SchoolCrossing	No – 3,529 Yes – 338	No – 91.3 Yes – 8.7
	Median	No – 3,867 Yes – 0	No – 100.0 Yes – 0.0
	AreaType	Suburban – 3,522 Urban – 345	Suburban – 91.1 Urban – 8.9
	TraffDir	One-Way – 97 Two-Way – 3,770	One-Way – 2.5 Two-Way – 97.5
Treatment	Midblock_Int	Intersection – 417 Midblock – 123	Intersection – 77.2 Midblock – 22.8
	BusStop	No – 347 Yes – 193	No – 64.3 Yes – 35.7
	Lighting	No – 32 Yes – 508	No – 5.9 Yes – 94.1
	Presence of Advanced YIELD or STOP Markings and Signs	Yes – 540 No – 0	Yes – 100.0 No – 0
	CrossingGuard	No – 537 Yes – 3	No – 99.4 Yes – 0.6
	SchoolCrossing	No – 517 Yes – 23	No – 95.7 Yes – 4.3
	Median	No – 413 Yes – 127	No – 76.5 Yes – 23.5
	AreaType	Suburban – 388 Urban – 152	Suburban – 71.9 Urban – 28.1
	TraffDir	One-Way – 30 Two-Way – 510	One-Way – 5.6 Two-Way – 94.4

Table 4-10. Summary statistics for PHB dataset.

Site Type	Statistic	Lanes	Crosswalk Length	AADT	PEDAADT	PEDCRASH	TOTCRASH	INJCRASH	TARGET CRASH	INJ TARGET CRASH
Ref	N	3129	3129	3129	3129	3129	3129	3129	3129	3129
Ref	MIN	2	20	533	0.5	0	0	0	0	0
Ref	MAX	8	122	49402	7824.6	3	31	15	22	9
Ref	MEAN	4.2	56.4	18446.6	240.0	0.1	2.6	1.0	1.2	0.4
Ref	STD	1.1	14.5	10334.2	592.1	0.3	3.6	1.6	2.0	0.9
Treat	N	366	366	366	366	366	366	366	366	366
Treat	MIN	2	20	510	0.5	0	0	0	0	0
Treat	MAX	7	130	46000	1647.2	1	27	13	21	9
Treat	MEAN	3.9	60.8	17625.7	303.2	0.1	2.9	1.3	1.6	0.6
Treat	STD	1.5	22.5	11766.1	262.7	0.2	3.5	1.6	2.4	1.1

Table 4-11. Frequency tallies for PHB dataset.

Site Type	Variable	Frequency	Percentage
Reference	Midblock_Int	Intersection – 2,349 Midblock – 780	Intersection – 75.1 Midblock – 24.9
	BusStop	No – 1,828 Yes – 1,301	No – 58.4 Yes – 41.6
	Lighting	No – 630 Yes – 2,499	No – 20.1 Yes – 79.9
	PHB Presence	Yes – 0 No – 3,129	Yes – 0.0 No – 100.0
	SchoolCrossing	No – 2,979 Yes – 150	No – 95.2 Yes – 4.8
	Median	No – 3,012 Yes – 117	No – 96.3 Yes – 3.7
	AreaType	Suburban – 2,920 Urban – 209	Suburban – 93.3 Urban – 6.7
	TraffDir	One-Way – 105 Two-Way – 3,024	One-Way – 3.4 Two-Way – 96.6
Treatment	Midblock_Int	Intersection – 345 Midblock – 21	Intersection – 94.3 Midblock – 5.7
	BusStop	No – 274 Yes – 92	No – 74.9 Yes – 25.1
	Lighting	No – 4 Yes – 362	No – 1.1 Yes – 98.9
	PHB Presence	Yes – 359 No – 7	Yes – 98.1 No – 1.9
	CrossingGuard	No – 344 Yes – 22	No – 94.0 Yes – 6.0
	SchoolCrossing	No – 211 Yes – 155	No – 57.7 Yes – 42.3
	Median	No – 356 Yes – 10	No – 97.3 Yes – 2.7
	AreaType	Suburban – 312 Urban – 54	Suburban – 85.3 Urban – 14.7
	TraffDir	One-Way – 27 Two-Way – 339	One-Way – 7.4 Two-Way – 92.6

Table 4-12. Summary statistics for RRFB dataset.

Site Type	Statistic	Lanes	Crosswalk Length	AADT	PEDAADT	PEDCRASH	TOTCRASH	INJCRASH	TARGET CRASH	INJ TARGET CRASH
Ref	N	1798	1798	1798	1798	1798	1798	1798	1798	1798
Ref	MIN	2	20	533	0.5	0	0	0	0	0
Ref	MAX	8	142	49402	7824.6	3	19	12	16	9
Ref	MEAN	4.1	56.0	15958.2	322.0	0.1	1.4	0.6	0.6	0.2
Ref	STD	1.3	16.8	10477.8	739.7	0.3	2.1	1.1	1.2	0.6
Treat	N	130	130	130	130	130	130	130	130	130
Treat	MIN	2	34	1386.5	9.99	0	0	0	0	0
Treat	MAX	6	108	46000	1403.8	1	6	3	4	1
Treat	MEAN	3.5	56.7	16250.2	235.2	0.0	0.9	0.3	0.3	0.1
Treat	STD	1.3	14.3	12112.7	323.9	0.2	1.3	0.6	0.7	0.2

Table 4-13. Frequency tallies for RRFB dataset.

Site Type	Variable	Frequency	Percentage
Reference	Midblock_Int	Intersection – 1,325 Midblock – 473	Intersection – 73.7 Midblock – 26.3
	BusStop	No – 801 Yes – 997	No – 44.6 Yes – 55.4
	Lighting	No – 289 Yes – 1,509	No – 16.1 Yes – 83.9
	RRFB Presence	Yes – 0 No – 1,798	Yes – 0.0 No – 100.0
	SchoolCrossing	No – 1,695 Yes – 103	No – 94.3 Yes – 5.7
	Median	No – 1,681 Yes – 117	No – 93.5 Yes – 6.5
	AreaType	Suburban – 1,587 Urban – 211	Suburban – 88.3 Urban – 11.7
	TraffDir	One-Way – 61 Two-Way – 1,737	One-Way – 3.4 Two-Way – 96.6
Treatment	Midblock_Int	Intersection – 87 Midblock – 43	Intersection – 66.9 Midblock – 33.1
	BusStop	No – 49 Yes – 81	No – 37.7 Yes – 62.3
	Lighting	No – 18 Yes – 112	No – 13.9 Yes – 86.2
	RRFB Presence	Yes – 115 No – 15	Yes – 88.5 No – 11.5
	CrossingGuard	No – 90 Yes – 40	No – 69.2 Yes – 30.8
	SchoolCrossing	No – 62 Yes – 68	No – 47.7 Yes – 52.3
	Median	No – 74 Yes – 56	No – 56.9 Yes – 43.1
	AreaType	Suburban – 117 Urban – 13	Suburban – 90.0 Urban – 10.0
	TraffDir	One-Way – 5 Two-Way – 125	One-Way – 3.9 Two-Way – 96.1

2. Interaction terms were attempted to account for, for example, the effect of presence of treatment and crossing location, but these did not improve the model's ability to explain the variation in crashes between sites.
3. Multi-level models were attempted to develop CMFunctions by investigating whether the implied CMFs for presence of treatment varied by vehicle and pedestrian AADT and other variables, but these too did not improve the results.
4. The "City" factor variable was included in the models to account for differences in expected crashes between jurisdictions that are not related to the treatment, which could include crash reporting practices, weather, cultural issues, etc. Inclusion of this variable estimates a unique intercept term for each city in a model. The same logic applies to the inclusion of the area type variable. Models with and without the city variable and the area type were attempted before deciding to include these variables in the final models. (For the most part, these variables were included.) Cities were also grouped according to the coefficients when they were used individually, but the groups did not result in improvements and in any case did not have logical characteristics to define them.
5. For PHB and RRFB, almost all site-years of data had advanced YIELD or STOP markings and signs as well. For pedestrian crashes, where a satisfactory CMF was estimated for advanced YIELD or STOP markings and signs, a model with separate coefficients for each treatment was first estimated. The results for advanced YIELD or STOP markings and signs presence were consistent with the previous results, so the model for PHB or RRFB was then run using the advanced YIELD or STOP markings and signs presence parameter estimated for that treatment on its own as an offset. In the modeling process, the value of the offset is subtracted from the value of the dependent variable (crashes). This approach was adopted only for the pedestrian crash models since the models for the other crash types did not support the estimation of CMFs.
6. With the exception of refuge islands, CMFs are not reported for non-pedestrian crash types since the estimated models do not support the estimation of a valid CMF for those crash types. In such cases, an effect for non-pedestrian crashes also cannot be logically or anecdotally supported.
7. The estimates for the city variable are not provided in the interest of brevity and because, in any case, they do not impact the estimated CMFs.

Refuge Islands

The following model forms pertain to each crash type. The models predict the expected number of crashes per year.

$$\begin{aligned}
PEDCRASH &= exp^{(a+City+b*Refuge\ Island\ Presence+c*AreaType)}AADT^{e}PEDAADT^{f}\\
TOTCRASH &= exp^{(a+City+b*Refuge\ Island\ Presence+d*Midblock_int)}AADT^{e}PEDAADT^{f}\\
INJCRASH &= exp^{(a+City+b*Refuge\ Island\ Presence+d*Midblock_int)}AADT^{e}PEDAADT^{f}\\
TARGETCRASH &= exp^{(a+City+b*Refuge\ Island\ Presence+d*Midblock_int)}AADT^{e}PEDAADT^{f}\\
INJTARGETCRASH &= exp^{(a+City+b*Refuge\ Island\ Presence+d*Midblock_int)}AADT^{e}PEDAADT^{f}
\end{aligned}$$

Target crashes include rear-end and sideswipe crashes.

where

AADT = total AADT on roadway being crossed
AreaType = 1 if Suburban, 0 if Urban
City = an intercept term specific for each city
Midblock_Int = 1 if intersection, 0 if midblock
PEDAADT = total pedestrian AADT for midblock or intersection
Refuge Island Presence = 1 if present, 0 if not present

Table 4-14. Parameter estimates for refuge island regression models.

	Parameter Estimate (standard error)				
Parameter	Pedestrian	Total	Injury	RE+SS*	Injury RE+SS
a	–10.4246 (1.6409)	–5.5953 (0.7761)	–6.4572 (0.8886)	–8.3157 (0.9754)	9.7130 (1.2009)
b	–0.3578 (0.2153)	–0.2981 (0.0956)	–0.3369 (0.1148)	–0.2999 (0.1258)	–0.3254 (0.1460)
c	–0.5715 (0.3127)	n/a	n/a	n/a	n/a
d	n/a	0.4730 (0.1083)	0.4312 (0.1183)	0.4140 (0.1224)	0.3728 (0.1395)
e	0.6977 (0.1694)	0.5192 (0.0756)	0.5375 (0.0846)	0.7235 (0.0947)	0.7780 (0.1157)
f	0.3295 (0.0486)	0.1224 (0.0247)	0.1141 (0.0260)	0.1041 (0.0237)	0.0986 (0.0263)
overdispersion	n/a	0.7608 (0.0305)	0.7075 (0.0482)	0.9149 (0.0521)	0.9837 (0.1075)

*RE = Rear-end; SS = Sideswipe

Parameter estimates for all models are shown in Table 4-14. As noted above, the estimates for the city variable are not provided in the interest of brevity and because, in any case, they do not impact the estimated CMFs.

With the exception of the parameter estimates for refuge island presence and area type in the pedestrian crash model, all parameter estimates are statistically significant at the 5 percent level (i.e., a value of no effect is not within 1.96 standard errors). Those two estimates are, however, statistically significant at the 10 percent level (a value of zero is not within 1.64 standard errors).

The estimated parameters indicate that fewer crashes of all types are expected when a refuge island is present and, for pedestrian crashes, in suburban areas versus urban areas. Greater numbers of crashes of all types are expected at higher levels of vehicle and pedestrian AADT. With the exception of pedestrian crashes, the models also indicate that more crashes are expected at intersections than at midblock crossings.

The CMFs implied by the parameter estimates for refuge island presence (exp^{b}) are provided in Table 4-15, along with the p values that indicate the level of significance. These indicate crash reductions for all crash types with statistically significant CMFs ($p < 0.10$) consistently of the order of 0.7 (crash reductions of 0.7).

Note that the refuge island may be provided by a continuous median or a smaller island provided at the crossing. Additional models were attempted that allowed the safety effects to differ by continuous median versus short refuge island, but the results were inconclusive.

Table 4-15. CMFs for refuge islands.

Crash Type	CMF (standard error)	p-value
PEDCRASH	**0.699** (0.152)	0.0965
TOTCRASH	**0.742** (0.071)	0.0018
INJCRASH	**0.714** (0.082)	0.0033
TARGETCRASH	**0.741** (0.093)	0.0171
INJTARGETCRASH	**0.722** (0.106)	0.0258

Advanced YIELD or STOP Markings and Signs

The following model forms pertain to each crash type. The models predict the expected number of crashes per year.

$$PEDCRASH = exp^{(a+b*Advance\ Stop\ Yield\ Sign\ Presence+c*AreaType)} AADT^{e} PEDAADT^{f}$$
$$TOTCRASH = exp^{(a+City+b*Advance\ Stop\ Yield\ Sign\ Presence+c*AreaType+d*Midblock\_int)} AADT^{e} PEDAADT^{f}$$
$$INJCRASH = exp^{(a+City+b*Advance\ Stop\ Yield\ Sign\ Presence+d*Midblock\_int)} AADT^{e} PEDAADT^{f}$$
$$TARGETCRASH = exp^{(a+City+b*Advance\ Stop\ Yield\ Sign+d*Midblock\_int)} AADT^{e} PEDAADT^{f}$$
$$INJTARGETCRASH = exp^{(a+City+b*Advance\ Stop\ Yield\ Sign\ Presence+d*Midblock\_int)} AADT^{e} PEDAADT^{f}$$

where

AADT = total AADT on roadway being crossed
AreaType = 1 if Suburban, 0 if Urban
City = an intercept term specific for each city
Midblock_Int = 1 if intersection, 0 if midblock
PEDAADT = total pedestrian AADT for midblock or intersection
Advance Stop Yield Sign Presence = 1 if present, 0 if not present

Parameter estimates for all models are shown in Table 4-16. The estimates for city are not provided in the interest of brevity, and they do not impact the estimated CMFs. The city variable was included in the models to account for differences in expected crashes between jurisdictions that are not related to the treatment. For pedestrian crashes, the city variable was not included in the final model because the parameter estimates became unstable.

The parameter estimates for presence of an advanced YIELD or STOP marking and sign are of low statistical significance, as is the parameter estimate for AADT in the pedestrian crash model. All other parameters are statistically significant at the 5 percent level. The AADT term in the pedestrian crash model is consistent with the other models in terms of the direction of effect, however.

For the presence of advanced YIELD or STOP markings and signs, the estimated parameters indicate that fewer pedestrian, total, and injury crashes are expected when a sign is present, and

Table 4-16. Parameter estimates for advanced YIELD or STOP markings and signs models.

	Parameter Estimate (standard error)				
Parameter	**Pedestrian**	**Total**	**Injury**	**RE+SS***	**Injury RE+SS**
a	–6.5485 (1.6715)	–5.1484 (0.6466)	–5.5571 (0.7427)	–7.8277 (0.7854)	–8.7847 (1.0780)
b	–0.1470 (0.3295)	–0.0195 (0.2240)	–0.1367 (0.2714)	0.3520 (0.3284)	0.2801 (0.4228)
c	–0.9656 (0.4798)	–0.2668 (0.1462)	n/a	n/a	n/a
d	n/a	0.6124 (0.1172)	0.6039 (0.1265)	0.5200 (0.1283)	0.4786 (0.1550)
e	0.2501 (0.2041)	0.5021 (0.0634)	0.4384 (0.0705)	0.6752 (0.0767)	0.6761 (0.1044)
f	0.4003 (0.1011)	0.0949 (0.0257)	0.1006 (0.0270)	0.0880 (0.0248)	0.1026 (0.0287)
overdispersion	n/a	0.7151 (0.0307)	0.6908 (0.0488)	0.9038 (0.0530)	1.1215 (0.1149)

*RE = Rear-end, SS = Sideswipe

more crashes are expected for target and target injury crashes. For total crashes, the estimate is extremely close to 0, which would indicate no effect. For the non-pedestrian crash types, the sample sizes are sufficiently large that the large standard errors of these estimates as well as the inconsistent direction of effect can be used to question their reliability in estimating a CMF. For this reason, it is concluded that the models do not support a CMF for vehicle-vehicle crashes. For pedestrian crashes, which have much smaller sample sizes, regardless of the large standard error, the results appear logical in direction of effect and magnitude.

Greater numbers of crashes of all types are expected at higher levels of vehicle and pedestrian AADT. For pedestrian and total crashes, fewer crashes are expected in suburban areas versus urban areas. With the exception of pedestrian crashes, the models also indicate that more crashes are expected at intersections than are expected at midblock crossings.

The CMF implied for pedestrian crashes by the parameter estimate for advanced YIELD or STOP markings and signs is provided in Table 4-17. As calculated, the p-value is large, implying low significance. However, because the direction of the effect is intuitive (CMF < 1), the point estimate of the CMF for pedestrian crashes is still recommended for application since the high p-value is likely to be a result of the scarcity of these crashes. For the other crash types, for which the sample size of crashes is not small, the large p values and, in some cases, illogically large magnitudes of effect implied led to no CMF being recommended.

Pedestrian Hybrid Beacons

The following model forms pertain to each crash type. The models predict the expected number of crashes per year. For the PEDCRASH model, the CMF estimated for advanced YIELD or STOP markings and signs was included in the model as an offset.

$$PEDCRASH = exp^{(a+City+b*PHB\ Presence+d*AreaType)} AADT^{f} PEDAADT^{g}$$
$$TOTCRASH = exp^{(a+City+b*PHB\ Presence+c*Advance\ Stop\ Yield\ Sign\ Presence+d*AreaType+e*Midblock\_int)} AADT^{f} PEDAADT^{g}$$
$$INJCRASH = exp^{(a+City+b*PHB\ Presence+c*Advance\ Stop\ Yield\ Sign\ Presence+e*Midblock\_int)} AADT^{f} PEDAADT^{g}$$
$$TARGETCRASH = exp^{(a+City+b*PHB\ Presence+c*Advance\ Stop\ Yield\ Sign\ Presence+e*Midblock\_int)} AADT^{f} PEDAADT^{g}$$
$$INJTARGETCRASH = exp^{(a+City+b*PHB\ Presence+c*Advance\ Stop\ Yield\ Sign\ Presence+e*Midblock\_int)} AADT^{f} PEDAADT^{g}$$

where

AADT = total AADT on roadway being crossed
Advance Stop Yield Sign Presence = 1 if present, 0 if not present
AreaType = 1 if Suburban, 0 if Urban
City = an intercept term specific for each city
Midblock_Int = 1 if intersection, 0 if midblock
PEDAADT = total pedestrian AADT for midblock or intersection
PHB Presence = 1 if present, 0 if not present

Table 4-17. CMFs for advanced YIELD or STOP markings and signs.

Crash Type	CMF (standard error)	p-value
PEDCRASH	0.863 (0.290)	0.6555
TOTCRASH	Models do not support the recommendation of a CMF.	
INJCRASH		
TARGETCRASH		
INJTARGETCRASH		

Table 4-18. Parameter estimates for PHB models.

	Parameter Estimate (standard error)				
Parameter	Pedestrian	Total	Injury	RE+SS*	Injury RE+SS
a	–7.1959 (1.2593)	–3.5996 (0.6295)	–4.1974 (0.7043)	–5.8685 (0.7804)	–7.9532 (0.93400
b	–0.3930 (0.3013)	0.5446 (0.3288)	0.6080 (0.2510)	0.6450 (0.5089)	0.5600 (0.4275)
c	n/a	–0.4191 (0.2341)	–0.4275 (0.2313)	–0.3189 (0.4036)	–0.1172 (0.4124)
d	–0.5695 (0.3110)	–0.2967 (0.1640)	n/a	n/a	n/a
e	n/a	0.7576 (0.1287)	0.6913 (0.1400)	0.5589 (0.1448)	0.4390 (0.1505)
f	0.3802 (0.1337)	0.3436 (0.0645)	0.2945 (0.0669)	0.4779 (0.0761)	0.5948 (0.0907)
g	0.3141 (0.0522)	0.1003 (0.0269)	0.1126 (0.0282)	0.1107 (0.0260)	0.1266 (0.0283)
overdispersion	n/a	0.7213 (0.0319)	0.6791 (0.0477)	0.9983 (0.0555)	1.1413 (0.1063)

*RE = Rear-end, SS = Sideswipe

Parameter estimates for all models are shown in Table 4-18. The estimates for city are not provided in the interest of brevity, and they do not impact the estimated CMFs. The city variable was included in the models to account for differences in expected crashes between jurisdictions that are not related to the treatment.

The parameter estimates for presence of PHB are of low statistical significance with the exception of the estimate for injury crashes. With the exception of the parameter estimate for area type in the pedestrian crash model and the estimates for advanced YIELD or STOP markings and signs, all parameters are statistically significant at the 5 percent level. The area type term in the pedestrian crash model is consistent with the other models in terms of the direction of effect, however, and is statistically significant at the 10 percent level.

For the presence of PHB, the estimated parameters indicate that fewer pedestrian crashes are expected when a PHB is present, and all other crash categories increase. Greater numbers of crashes of all types are expected with increases in vehicle and pedestrian AADT. With the exception of pedestrian crashes, the models also indicate that more crashes are expected at intersections than at midblock crossings.

The CMF implied for pedestrian crashes by the parameter estimates for PHBs is provided in Table 4-19. The p-value for pedestrian crashes is on the high side, but, as with advanced YIELD or STOP markings and signs, because the direction of the effect is intuitive (CMF < 1), the point estimate of the CMF for pedestrian crashes is still recommended for application. No CMFs are recommended for the other crash types due to the statistical significance and/or illogical effects implied.

Table 4-19. CMFs for PHBs.

Crash Type	CMF (standard error)	p-value
PEDCRASH	0.675 (0.206)	0.1921
TOTCRASH	Models do not support the recommendation of a CMF.	
INJCRASH		
TARGETCRASH		
INJTARGETCRASH		

Rectangular Rapid Flashing Beacons

The following model forms pertain to each crash type. The models predict the expected number of crashes per year. The model for pedestrian crashes used the CMFs estimated for pedestrian refuge islands, advanced YIELD or STOP markings and signs, and PHBs as offsets in the PEDCRASH model because the data included sites with these treatments. For the other crash types, the data did not include sites with pedestrian refuge islands or PHBs, and the presence of advanced YIELD or STOP markings and signs was also included in the model.

$$PEDCRASH = exp^{(a+City+b*RRFB\ Presence)} AADT^{f} PEDAADT^{g}$$
$$TOTCRASH = exp^{(a+City+b*\ RRFB\ Presence+c*Advance\ Stop\ Yield\ Sign\ Presence+d*AreaType+e*Midblock\_int)} AADT^{f} PEDAADT^{g}$$
$$INJCRASH = exp^{(a+City+b*PHB\ Presence+c*Advance\ \ Stop\ Yield\ Sign\ Presence+e*Midblock\_int)} AADT^{f} PEDAADT^{g}$$
$$TARGETCRASH = exp^{(a+City+b*RRFB\ Presence+c*Advance\ \ Stop\ Yield\ Sign\ Presence+e*Midblock\_int)} AADT^{f} PEDAADT^{g}$$
$$INJTARGETCRASH = exp^{(a+City+b*RRFB\ Presence+c*Advance\ \ Stop\ Yield\ Sign\ Presence+e*Midblock\_int)} AADT^{f} PEDAADT^{g}$$

where

AADT = total AADT on roadway being crossed
Advance Stop Yield Sign Presence = 1 if present, 0 if not present
AreaType = 1 if Suburban, 0 if Urban
City = an intercept term specific for each city
Midblock_Int = 1 if intersection, 0 if midblock
PEDAADT = total pedestrian AADT for midblock or intersection
RRFB Presence = 1 if present, 0 if not present

Parameter estimates for all models are shown in Table 4-20. The estimates for city are not provided in the interest of brevity and they do not impact the estimated CMFs. The city variable was included in the models to account for differences in expected crashes between jurisdictions that are not related to the treatment.

Table 4-20. Parameter estimates for RRFB models.

	Parameter Estimate (standard error)				
Parameter	**Pedestrian**	**Total**	**Injury**	**RE+SS***	**Injury RE+SS**
a	–7.0997 (1.5901)	–3.5339 (0.6395)	–3.9171 (0.7733)	–5.0199 (0.7179)	–5.5874 (1.1623)
b	–0.6427 (0.6672)	–0.1053 (0.1960)	–0.0661 (0.2183)	0.2145 (0.2044)	–0.6618 (0.5498)
c	n/a	–0.2768 (0.2062)	–0.2855 (0.2662)	0.2899 (0.1835)	–0.0798 (0.4304)
d	n/a	–0.3214 (0.1803)	n/a	n/a	n/a
e	n/a	0.4602 (0.1611)	0.4155 (0.1697)	0.4216 (0.1467)	0.3952 (0.2333)
f	0.2336 (0.1386)	0.3188 (0.0685)	0.2401 (0.0771)	0.2693 (0.0730)	0.2534 (0.1094)
g	0.4198 (0.0876)	0.1111 (0.0442)	0.1029 (0.0451)	0.1041 (0.0366)	0.0947 (0.0598)
overdispersion	n/a	0.8504 (0.0618)	1.0210 (0.1167)	1.3313 (0.1007)	2.0417 (0.3518)

*RE = Rear-end, SS = Sideswipe

Table 4-21. CMFs for RRFBs.

Crash Type	CMF (standard error)	p-value
PEDCRASH	0.526 (0.377)	0.3354
TOTCRASH	Models do not support the recommendation of a CMF.	
INJCRASH		
TARGETCRASH		
INJTARGETCRASH		

The parameter estimates for presence of RRFB are of low statistical significance. With the exception of the parameter estimate for area type in the total crash model and the estimates for advanced YIELD or STOP markings and signs, all parameters are statistically significant at the 5 percent level. The area type term in the total crash model is consistent with the other models in terms of the direction of effect, however, and is statistically significant at the 10 percent level.

The estimated parameters indicate that if RRFB is present, fewer pedestrian, total, and target injury crashes are expected, but at the same time, more target crashes are expected. Greater numbers of crashes of all types are expected at higher levels of vehicle and pedestrian AADT. With the exception of pedestrian crashes, the models also indicate that more crashes are expected at intersections than at midblock crossings. For total crashes, fewer crashes are expected in suburban areas versus urban areas.

The CMF for pedestrian crashes implied by the parameter estimates for RRFBs is provided in Table 4-21. As was the case for advanced YIELD or STOP markings and signs, because the direction of the effect is intuitive (CMF < 1), the point estimate of the CMF for pedestrian crashes is still recommended for application since the high p-value is likely a result of the scarcity of these crashes. No CMFs are recommended for the other crash types due to the statistical significance and/or illogical effects implied. For example, the parameter estimate for presence of RRFBs for target crashes would indicate an increase in crashes of 24 percent, which seems large and hard to explain by logical considerations.

Comparison of Before-After and Cross-Sectional Study Results

Table 4-22 summarizes the results from the before-after and cross-sectional analyses for treatments and crash type cases where the analyses support a CMF recommendation. As is evident, a comparison of results from the two studies is only possible for pedestrian crashes, the main target crash type.

In general, the before-after results, where they could be obtained, corroborate the direction of effect for pedestrian crashes from the cross-sectional analysis and, in the case of refuge islands, the order of magnitude.

For the other treatments, advanced YIELD or STOP markings and signs, PHB, and PHB + advanced YIELD or STOP markings and signs, the CMF point estimates are larger (the benefits smaller) for the cross-sectional study, which might be expected on theoretical grounds as a result of the issues with cross-sectional studies. However, given the large standard errors, in particular for the CMFs for the cross-sectional analysis, it cannot be concluded that the estimates are different statistically.

Table 4-22. CMFs from before-after and cross-sectional analyses.

Treatment	Crash type	Cross-sectional study		Before-after study	
		Estimate	Standard error	Estimate	Standard error
Refuge Island	Pedestrian	0.699	0.152	0.671	0.215
	Total	0.742	0.071		
	All Injury	0.714	0.082		
	Rear-End/Sideswipe Total	0.741	0.093		
	Rear-End/Sideswipe Injury	0.722	0.106		
Advanced YIELD or STOP Markings and Signs	Pedestrian	0.863	0.290	0.636	0.169
	Total			0.886	0.065
	Rear-End/Sideswipe Total			0.800	0.076
PHB	Pedestrian	0.526	0.206	0.38*	n/a
PHB + Advanced YIELD or STOP Markings and Signs	Pedestrian	0.62**	0.140	0.244	0.128
	Total			0.820	0.078
	Rear-End/Sideswipe Total			0.876	0.111
RRFB	Pedestrian	0.526	0.377		

*As mentioned earlier, the sample size for the PHB alone treatment was very limited for conducting a before-after evaluation. However, the before-after evaluation estimated CMFs for advanced YIELD or STOP markings and signs and PHB + advanced YIELD or STOP markings and signs combinations. Using these results and assuming that CMFs are multiplicative for treatment combinations, the CMF for PHB alone was calculated as the CMF for PHB + advanced YIELD or STOP markings and signs divided by the CMF for advanced YIELD or STOP markings and signs, i.e., 0.244/0.636 = 0.38.
**Estimated for comparison purposes

Consolidation of Analysis Results

As presented in Table 4-22, credible CMFs for pedestrian crashes and vehicle-involved crashes were estimated by either cross-sectional or before-after analysis, or both, for refuge islands, advanced YIELD or STOP markings and signs, PHB, and PHB + advanced YIELD or STOP markings and signs. The CMF for RRFB was based on a very limited sample, and hence should be used with caution. As noted above, results from the before-after and cross-sectional analyses are only reported for treatments and crash type cases where the analyses support a CMF recommendation.

The two methods have strengths and limitations. Although the before-after analysis is preferred, especially the EB approach used for this research, the limited sample size of sites and crashes limits the robustness of the results. By contrast, the well-known limitations of deriving CMFs from cross-sectional regression analysis suggest that results obtained from that analysis, albeit from a substantial sample, should be interpreted and used with caution. It is encouraging, however, that the results of the limited before-after study corroborate those from the cross-sectional study for pedestrian crashes, the main crash type of interest.

On balance, it is difficult to choose one approach over another where two sets of results are obtained, as was the case for pedestrian crashes, which logically suggests that equal weighting of the CMFs is not unreasonable for recommending CMFs for practical application. With this in mind, where there are two CMFs in Table 4-22, the median point values are presented in Table 4-23 as a final recommendation for practical application. Where there is a CMF value from only one study, that value is recommended. In each case, there is an appropriate annotation indicating the basis of the recommendation. For practical applications where a conservative benefit estimate is desired for a contemplated treatment, the higher of two CMF values from Table 4-22 is recommended. However, as a general caution, in the application of the CMFs, users should consider the

Table 4-23. Recommended CMFs.

Treatment	Crash Type	Recommended CMF		Study Basis
		Estimate	Standard Error	
Refuge Island (RI)	Pedestrian	0.685	0.183	Median from two studies
	Total	0.742	0.071	Cross-section
	All Injury	0.714	0.082	Cross-section
	Rear-End/Sideswipe Total	0.741	0.093	Cross-section
	Rear-End/Sideswipe Injury	0.722	0.106	Cross-section
Advanced YIELD and STOP Markings and Signs	Pedestrian	0.750	0.230	Median from two studies
	Total	0.886	0.065	Before-after
	Rear-End/Sideswipe Total	0.800	0.076	Before-after
PHB	Pedestrian	0.453	0.167	Median from two studies
PHB + Advanced YIELD and STOP Markings and Signs	Pedestrian	0.432	0.134	Median from two studies
	Total	0.820	0.078	Before-after
	Rear-End/Sideswipe Total	0.876	0.111	Before-after
RRFB	Pedestrian	0.526	0.377	Cross-section

summary statistics in Tables 4-6 to 4-13 to see how closely the site under consideration for one of the treatments resembles the sites used to develop the CMF.

As mentioned earlier, CMFunctions were explored in order to determine the effectiveness of the treatments under study in relation to different levels of AADT, posted speed limit, area type, number of lanes, and other factors. However, the CMFunctions did not provide useful results. Future research could focus on developing CMFunctions and, at the very least, investigate whether the treatments considered in this study are more or less effective under different conditions.

CHAPTER 5

Summary and Conclusions

Study Objectives and Results

There continues to be a problem in the United States related to the safety for pedestrians who attempt to cross streets, particularly on high-speed, high-volume, multi-lane roads. Furthermore, there is a need to better understand the safety effects of some of the more promising treatments on pedestrian crashes. The objective of this study was to develop CMFs for several different types of pedestrian treatments at unsignalized pedestrian crossings. After considering numerous treatment options, the four unique treatment types selected for evaluation included RRFBs, PHBs, pedestrian refuge islands, and advanced YIELD or STOP markings and signs. A total of approximately 1,000 treatment and comparison sites were selected from 14 different cities throughout the United States. Most of the study sites were selected at intersections on multi-lane streets in urban and suburban areas, since these are sites with a high risk for pedestrian crashes and where countermeasures are typically most needed. For each study site, relevant data were collected regarding the treatment characteristics; traffic, geometric, and roadway variables; and the pedestrian crashes and other crash types that occurred at each site. Cross-sectional models and before/after EB analysis techniques were used to determine the crash effects of each treatment type. Wherever possible, study sites were selected on multi-lane, high-volume roads since pedestrians are at greater risk when crossing such roads, and, therefore, the need for pedestrian crossing enhancements is greater on such roads compared to lower-volume two-lane roads.

All four of the treatment types were found to be associated with reductions in pedestrian crash risk compared to the untreated sites. Pedestrian hybrid beacons (CMF of 0.453) and PHBs with advanced YIELD or STOP markings and signs (CMF of 0.432) were associated with the greatest benefit to pedestrian crash risk, followed by RRFBs (CMF of 0.526), pedestrian refuge islands (CMF of 0.685), and advanced YIELD or STOP markings and signs (0.75). CMFs for some other crash types (e.g., rear-end, sideswipe, and total crashes) were also found for some of the four pedestrian treatments, as given in Table 4-23. As a general caution, in the application of the CMFs, users should consider the summary statistics in Chapter 4 to see how closely the site under consideration compares to sites in the research study when estimating the expected CMF for their new treatment. Specifically, most of the CMFs in this study were based on intersections (and some midblock locations) in urban and suburban areas. Although most of the study sites were on multi-lane (three-, four-, and five-lane) roads, some of the treatment sites were on two-lane roads.

Data Limitations and Recommendations

Although several CMFs were estimated, it is important to note that the expected safety effects of applying the treatments may vary across specific applications. A great majority of the treatment sites selected for inclusion in this study were in urban (and suburban) areas on multi-lane roads. While most of the treatments are at intersections, a substantial number of midblock locations are also represented in the database. For example, it is likely that factors such as operating speed, AADT, roadway width, lane width, and others can be expected to influence the efficacy of any of these interventions. The limited data available did not allow for such a disaggregation of expected effects. Future work is needed to make more precise predictions about how much of a crash reduction should be expected at locations with specific characteristics. Therefore, this investigation should be replicated in several years after more of these treatments have been deployed in order to obtain more specific predictions about crash reductions across different types of roadway, volumes, and speeds. To this end, and given the challenges of acquiring large samples of pedestrian crash and exposure data, it is recommended that the data from this project remain accessible for future research that may also include the enhanced development of safety performance functions for pedestrians.

It is also likely that these treatments may have different effects on number of crashes and the severity of crashes. For example, treatments that slow down drivers and reduce the probability of a crash may also have an effect on the severity of a crash when one occurs. Hence, it may be possible to have a CMF for total crashes and a different CMF for incapacitating and fatal crashes. Another factor that could not be fully assessed is how the use of several of these treatments together would influence crashes. In some cases, two CMFs may sum algebraically and in other cases they may not yield a larger effect than the more effective of the two CMFs. A much larger dataset would be required to address these questions. It should also be remembered that the CMF for the RRFB was based on a very limited sample (i.e., 50 treatment sites), and hence should be used with caution.

One of the data limitations for this study and other pedestrian- and bicycle-related studies is the lack of available exposure data related to walking (and bicycling). As a result of the lack of such data from most of the 14 agencies selected for this study, it was necessary to conduct short-term (i.e., 1- or 2-hour) counts and then to extrapolate those counts to obtain an estimate of the average annual daily pedestrian traffic (i.e., pedestrian AADTs). Developing pedestrian AADTs based on the actual hourly count, the time of day of the count (e.g., 4:00 to 5:00 p.m. was the usual count time), and the type of area within the city required a substantial effort. Pedestrian counts were conducted at a great majority of the selected sites, which was quite costly. Estimating pedestrian daily volume was necessary for use as a control variable in the analysis; however, the accuracy of such estimates (i.e., extrapolating short-term counts) would have been greatly improved if a larger data sample (e.g., 8- or 10-hour counts) was available from city transportation agencies. Unfortunately, only two of the cities (Charlotte and St. Petersburg) had existing pedestrian counts at any of the sites selected for study. Certainly, if more city and state DOTs routinely collected pedestrian (and bicycle) counts, such count data would have value not just for research studies, but also to help determine the need and justification for all types of pedestrian improvements on a routine basis.

It is also important to remember that all four treatment types evaluated in this study did not appear in all (or even most) of the 14 test cities. For example, approximately 90 percent of the PHBs under study were found in Tucson, Arizona, a city that was found to have installed the most PHBs nationwide. Likewise, approximately 75 percent of the RRFB sites in this study were from St. Petersburg, Florida, due to the frequent use of these devices in that city. Therefore, readers should not necessarily assume that the CMFs found in this study for a given treatment will necessarily apply to usage of that treatment in all cities. Individual cities and state jurisdictions have differences in driver and pedestrian behaviors, terrain, laws, weather patterns, and many other factors that can affect the way that any countermeasure will perform. Therefore, it is recommended that agencies select among countermeasures with caution and try to identify and address the specific safety problem(s) at a location and then the countermeasure(s) most likely to address the specific problem(s). Also, after implementation of any countermeasures, it is advisable to routinely monitor crashes and behaviors at treatment sites to ensure that the countermeasure is operating effectively.

Criteria for Treatment Installation

The four treatments of interest are typically installed according to the following recommendations and criteria given below. Please note that reference to the MUTCD is based on the 2009 version, which was in effect when most of the countermeasures included in this study were installed (*62*). Any more current versions of the MUTCD should be considered when these criteria are updated.

Rectangular Rapid Flashing Beacon

Criteria for Countermeasure Installation

1. If the device is side mounted it should be located above the Pedestrian W11-2 sign placed adjacent to the crosswalk location (according to MUTCD "Interim Approval for Optional Use of Rectangular Rapid Flashing Beacons – IA-11)" (*56*).
2. The beacon must meet the J595 Class 1 Beacon luminosity standard. It should also meet the flash rate specified in the interim approval (*56*).
3. The devices evaluated in the FHWA study, *Effects of Yellow Rectangular Rapid-Flashing Beacons on Yielding at Multilane Uncontrolled Crosswalks*, were visible from both directions (*57*, *58*) so consideration should be given to installing them this way on roads that serve two-way traffic. This requirement is not specified in the Notice of Proposed Amendments (for the MUTCD), although it may have influenced the outcome results of Shurbutt et al. (*57*) and Shurbutt and Van Houten (*58*) because it produced a gateway effect for approaching vehicles whose drivers could see the beacons on the opposite side of the street, increasing the visibility of the device.
4. There is also evidence that the device produces higher levels of yielding, particularly at night, when installed on the median or refuge island on roads with multiple lanes in each direction that are separated by a median or refuge island at the crosswalk (*58*).
5. The installation of advanced YIELD or STOP markings and signs at sites with crosswalks has been shown to decrease conflicts related to possible multiple-threat crashes on multi-lane roads (*59–61*). This countermeasure is designed to decrease the risk of a multiple-threat crash. These are more common when the AADT is relatively high. When used, the R1-5 or R1-5a "YIELD HERE FOR PEDESTRIANS" sign or the R1-5b or R1-5c "STOP HERE FOR PEDESTRIANS" sign should be installed adjacent to the advanced YIELD or STOP markings and signs (*59–61*).
6. It is also recommended that high-visibility crosswalk markings be installed at these sites (*59–61*).
7. Signs or foliage should not obstruct the view of the sign or beacons by drivers approaching the crosswalk.

Considerations

1. **Number of lanes**. The more lanes that a pedestrian has to cross, the more likely it is that other vehicles may visually screen the device. Although a device mounted on a mast arm could improve visibility under this condition, data are not available on the efficacy of this type of configuration. The RRFB is ideally suited for four-lane roads with a median or refuge islands because it increases yielding right-of-way to pedestrians and is more effective with beacons on the sides and on the refuge island (*58*).
2. **AADT**. Data show that median and refuge islands are highly desirable when AADT is over 10,000. High AADT is a surrogate measure for the risk of a multiple-threat crash on multi-lane

roads, the use of advanced YIELD or STOP markings and signs is strongly recommended when vehicle AADT is high (*59–61*).

3. **Posted speed limit**. The RRFB has typically been installed on roads with speed limits between 25 and 35 mph. With higher speeds (e.g., 40 mph or higher) the use of a PHB should be considered, particularly when AADT is high (e.g., above approximately 15,000).
4. **Outreach**. Consider public outreach to increase driver understanding of RRFBs when RRFB devices are not in common use in an area.
5. **Direction of vehicle traffic**. Whether the road carries one-way or two-way traffic can influence how and where the RRFB devices are implemented. Roads with one-way traffic typically are easier to cross, but multiple-threat crashes still may be present if there are multiple vehicle lanes.

Pedestrian Hybrid Beacon

Criteria for Countermeasure Installation

1. This device can be installed only at a marked crosswalk. The device should be mounted on a mast arm or, in the case of a four-lane road with a median island, side mounted on both sides of the approach to the crosswalk. If there is no median island or more than two lanes in each direction, the device must be mounted overhead. If the device is mounted on a span wire, an incandescent signal head should be used rather than an LED signal head. The MUTCD specifies that a "CROSSWALK STOP ON RED" (symbolic circular red, R10-23) sign shall be mounted adjacent to a PHB face on each major street approach. If an overhead PHB face is provided, the sign should be mounted adjacent to the overhead signal face (*62*).
2. Stop lines must be installed on each approach to a PHB. Although a specific distance is not recommended in the MUTCD, the MUTCD specifies that stop lines at midblock signalized locations should be placed at least 40 feet in advance of the nearest signal. Although no specification is given for the PHB, it is recommended that the stop line be placed at a similar distance to decrease the multiple-threat crash risk, based on previous research by Van Houten for Michigan DOT (*70*).

Considerations

1. **Warning signs**. Whether to install a Pedestrian (W11-2) warning sign with an AHEAD (W16-9P) supplemental plaque in advance of the PHB.
2. **Experimental signs**. Some jurisdictions have installed an experimental "STOP ON FLASHING RED THEN PROCEED WHEN CLEAR" sign because of poor compliance with the flashing signal.
3. **Outreach**. When PHB devices are not in common use in an area, consider conducting outreach or educational efforts to explain how to respond to the device.
4. **Warning beacon**. Whether a warning beacon was installed to supplement the W11-2.
5. **Supporting signs**. Whether the R1-6 or R1-6a sign is used with the PHB.
6. **Refuge island**. Because the PHB only protects pedestrians when the device is activated, consider installing a refuge island when AADT is high and pedestrian push-button compliance is low.
7. **Crosswalk type**. Consider high-visibility crosswalk markings to increase visibility to approaching drivers.

Advanced YIELD or STOP Markings and Signs

Criterion for Countermeasure Installation

Advanced YIELD or STOP markings and signs may be used to indicate the point behind which vehicles are required to stop or yield in compliance with a "STOP HERE FOR PEDESTRIANS"

(R1-5b or R1-5c) sign, or "YIELD HERE TO PEDESTRIANS" (R1-5 or R1-5a) sign (*62*). Research on these markings at crosswalks with a multi-lane approach indicated that they worked well when placed 30 to 50 feet in advance of the crosswalk (*59–61*). The MUTCD specifies that these markings used at crosswalks on an uncontrolled multi-lane approach should be placed 20 to 50 feet in advance of the nearest crosswalk line, and parking should be prohibited in the area between the yield or stop line and the crosswalk (*62*).

Considerations

1. **State law stop versus yield.** States or communities with laws requiring motorists to stop for pedestrians typically use stop rather than yield markings. States with laws requiring motorists to yield to pedestrians in crosswalks typically use yield markings. However, some states with laws requiring motorists to yield permit the use of stop bars because the statute requires motorists to "yield or stop." Check which is the practice in your jurisdiction.
2. **AADT.** If AADT is high (e.g., 15,000 or above) and a median is not present, consider installing a pedestrian refuge island.
3. **Crosswalk type.** Consider using high-visibility crosswalk markings at sites with high AADT to increase visibility to approaching drivers.
4. **Signs.** Use of R1-6 or R1-6a signs should be considered if AADT is high.

Pedestrian Refuge Island

Criteria for Countermeasure Installation

The refuge island should be raised and of sufficient width that it can serve as a place of refuge for pedestrians who are attempting to cross at a midblock or intersection location. Center islands allow pedestrians to find an adequate gap in one direction of traffic at a time as they are able to stop, if necessary, in the center island or median area and wait for an adequate gap in the other direction of traffic before crossing the second half of the street or highway. The minimum widths for accessible refuge islands and for design and placement of detectable warning surfaces are provided in the "Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities (ADAAG)".

Considerations

1. **Length and width of the island**. If pedestrians are expected to cross in large groups, consider providing adequate pedestrian storage.
2. **Driver yielding behavior.** If yielding levels are low, consider placing R1-6 signs on top of the island curb face in each direction (*63*).
3. **Pedestrian line of sight.** If space exists, consider placing a diagonal refuge or median crossing that orients pedestrians to face traffic as they approach the second half of the roadway.
4. **Stop or yield markings.** If a stop or yield marking is installed, specify the distance in advance of the crosswalk (*59–61*).
5. **Signs.** Consider whether or not to install the R1-5 or R1-5a, "YIELD HERE FOR PEDESTRIANS" sign or the R1-5b or R1-5c "STOP HERE FOR PEDESTRIANS" sign and whether or not to install the R11-2 warning sign with the advance markings (*62*).
6. **AADT.** Raised medians are particularly appropriate for streets where AADT is moderate to high (e.g., above approximately 5,000).
7. **Posted speed limit.** Refuge islands may be particularly effective on multi-lane roads, particularly where vehicle volumes exceed approximately 1,000 vehicles per day.

CHAPTER 6

Incorporation of Study Results into National Guidelines

Research results from NCHRP Project 17-56 could be integrated into the following resources to facilitate implementation of the findings in practice:

- AASHTO's *Highway Safety Manual* (HSM) (*67*);
- AASHTO's *Guide for the Planning, Design, and Operation of Pedestrian Facilities* (*69*);
- FHWA Pedestrian Safety Guide and Countermeasure Selection System (PEDSAFE) website;
- FHWA's CMF Clearinghouse;
- FHWA's Proven Safety Countermeasures website;
- *NCHRP Report 600: Human Factors Guidelines for Road Systems, Second Edition* (*68*);
- MUTCD (*62*); and
- Design guidance for uncontrolled pedestrian crossings.

Each of these opportunities is discussed in greater detail below.

Highway Safety Manual

The HSM is organized into four parts—Part A: Introduction, Human Factors, and Fundamentals; Part B: Roadway Safety Management Process; Part C: Predictive Method; and Part D: Crash Modification Factors. Findings from NCHRP Project 17-56 could inform each part of the HSM.

Part A: Introduction, Human Factors, and Fundamentals

Information and observations from NCHRP Project 17-56 could be integrated into the HSM's Chapter 2: Human Factors and Chapter 3: Fundamentals. This information could include topics such as trends or patterns in crashes involving pedestrians at uncontrolled crossings and key considerations in identifying the appropriate supplemental treatments to reduce crashes at such locations (e.g., posted speed, prevailing speed, and number of vehicle lanes).

Part B: Roadway Safety Management Process

Chapter 6 within Part B of the HSM discusses how to select countermeasures based on crash trends and patterns. A section within Chapter 6 focuses on crashes involving pedestrians and bicyclists. The content of this section could be updated with the findings from NCHRP Project 17-56.

Part C: Predictive Method

Chapter 12 within Part C of the HSM provides crash prediction methodology for urban and suburban arterials. There is a possibility that the CMFs produced in NCHRP Project 17-56 could be incorporated into the Chapter 12 methodology to enable practitioners to consider the potential impact of incorporating these treatments. The limited ability of the Chapter 12 methodology to account for pedestrian crashes is a current gap; it may be feasible to help close this gap with NCHRP Project 17-56 findings.

Part D: Crash Modification Factors

Chapter 13 and 14 within Part D of the HSM include CMFs applicable to roadway segments and intersections, respectively. The CMFs developed for uncontrolled pedestrian crossing treatments from NCHRP Project 17-56 could be directly integrated into these two chapters.

Research results from NCHRP Project 17-56 will be considered by researchers assembling the next edition of the HSM, as part of NCHRP Project 17-71.

Crash Modification Factor Clearinghouse

The FHWA's CMF Clearinghouse is an online (http://www.cmfclearinghouse.org), searchable database of CMFs produced in safety research literature. It is updated approximately quarterly with the most recent research findings. Users can search the database based on the type of treatment in which they are interested. The potentially applicable CMFs appear with information about the quality of the CMF, source of the CMF, and context in which it was developed and therefore most applicable to apply. The quality of CMFs are rated using a five star scale with five stars representing the highest quality CMF. Quality is based on study design, sample size, standard error, potential bias, and data source. Members of the NCHRP Project 17-56 research team help to review and maintain the database. They will be able to work with others at FHWA to incorporate the findings from NCHRP Project 17-56 into the database, enabling practitioners searching for information related to the treatments at uncontrolled pedestrian crossings to find the results.

Proven Safety Countermeasures Website

FHWA maintains and periodically updates a website focused on highlighting countermeasures to improve safety on roadway networks (http://safety.fhwa.dot.gov/provencounter measures). It currently highlights two countermeasures directly related to the NCHRP Project 17-56 research: (1) medians and pedestrian crossing islands in urban and suburban areas and (2) PHBs. The research results from NCHRP Project 17-56 could be integrated into the treatment-specific information available on the FHWA website for these two countermeasures. FHWA could also choose to highlight other treatments evaluated in NCHRP Project 17-56 (e.g., use of RRFBs and/or advanced YIELD or STOP lines) as proven safety countermeasures on the FHWA website.

NCHRP Report 600: Human Factors Guidelines for Road Systems, Second Edition

Chapter 15 of *NCHRP Report 600: Human Factors Guidelines for Road Systems, Second Edition* is focused on special considerations for urban environments. Two of the special considerations discussed within Chapter 15 are related to human behavior at uncontrolled pedestrian crossings and methods to improve behavior and thereby improve safety. Findings from NCHRP Project 17-56 could be integrated into the next edition of *NCHRP Report 600: Human Factors Guidelines for Road Systems* and specifically used to supplement or update the discussion regarding uncontrolled pedestrian crossings.

Manual on Uniform Traffic Control Devices

Research results from NCHRP Project 17-56 are unlikely to be directly incorporated into the MUTCD simply because the content of the MUTCD is focused on communicating the standardization of the use of traffic control devices (e.g., signs, signals, pavement markings, and beacons). The results of the research may inform discussions that occur at the National Committee on Uniform Traffic Control Devices (NCUTCD). This could, in turn, result in changes to the MUTCD to include increased guidance on when and which specific supplemental treatments at uncontrolled pedestrian crossings should be required or implemented by local or state agencies.

Design Guidance for Uncontrolled Pedestrian Crossings

State and local agencies frequently establish their own guidelines and/or procedures for when to mark an uncontrolled crosswalk and if or what additional supplemental treatments will be installed at a marked crosswalk across an uncontrolled approach. To develop these local or state level guidelines or decision-making trees, agencies frequently use research findings from the FHWA study, *Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations: Final Report and Recommended Guidelines* (*66*). State and local agencies with such guidelines would be able to use the findings from NCHRP Project 17-56 to supplement, update, or revise the guidelines they currently have in place. To facilitate this process, FHWA could create a synthesis report focused on uncontrolled pedestrian crossings that integrated the previous research in *Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations: Final Report and Recommended Guidelines* with findings from NCHRP Project 17-56 to create a single, consistent source for practitioners to use as a reference on the subject.

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APPENDIX A

Selected Treatment Types for Evaluation

Unsignalized Pedestrian Crosswalk Signs and Pavement Markings, Including Advance Yield or Stop Markings

Description

This treatment consists of signs or markings at midblock crossings designed to improve visibility of pedestrians to motorists, increase motorist yielding, and prevent multiple-threat crashes.

Examples

Source: www.wichita.gov

High-Intensity Activated Crosswalk (HAWK)/ Pedestrian Hybrid Beacon

Description

A HAWK signal [also termed pedestrian hybrid beacon in the MUTCD] is a special type of hybrid beacon used to warn and control traffic at an unsignalized location to assist pedestrians in crossing a street or highway at a marked crosswalk. The HAWK signal 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 a major roadway. The HAWK signal indication for motorists is not illuminated until it is activated by a pedestrian, triggering the warning flashing yellow lens on the major street. After a set amount of time, the traffic signal 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 to drivers, and pedestrians are shown an upraised hand symbol with a countdown display informing them of the time left to cross.

Example

Source: PBIC

Rectangular Rapid Flashing Beacons (RRFBs)

Description

RRFBs are user-actuated amber LEDs that supplement warning signs at unsignalized intersections or midblock crosswalks. They can be activated by pedestrians manually by a push button or passively by a pedestrian detection system. RRFBs use an irregular flash pattern that is similar to emergency flashers on police vehicles.

Example

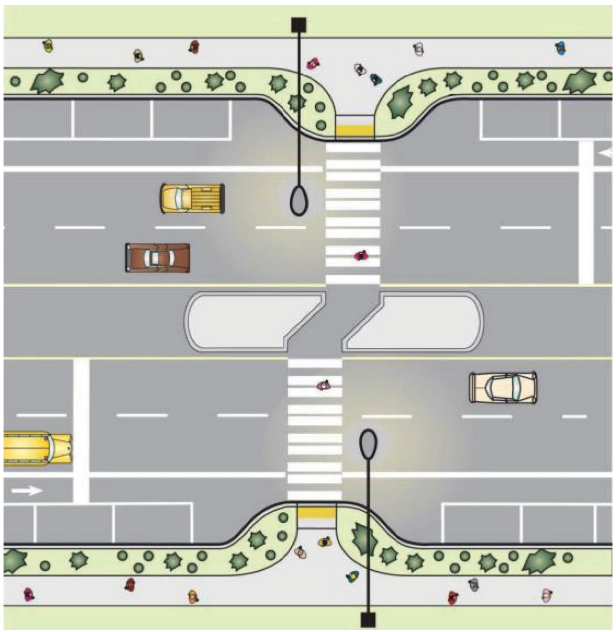
Source: FHWA

Pedestrian Refuge Areas

Description

Pedestrian refuge areas are created when a marked crosswalk is intersected by a median. This provides pedestrians with the option of waiting in this middle area until before beginning the next stage of the crossing. This design breaks a long complex crossing into two simpler crossings. This study will investigate refuge areas on both two-lane and multi-lane roads.

Example



Source: walkinginfo.org

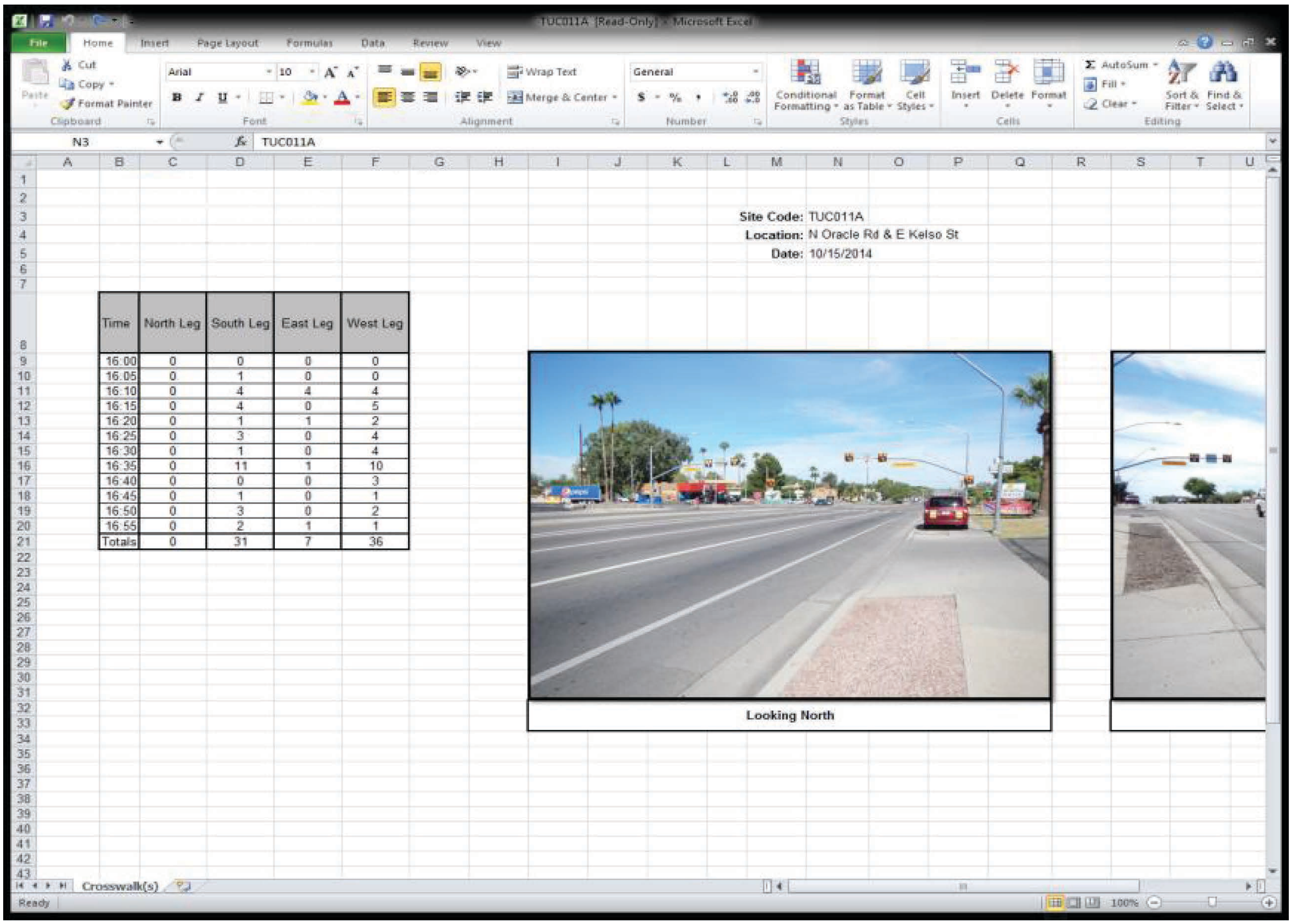
APPENDIX B

Treatment and Comparison Site Examples of Pedestrian Count Summaries

NCHRP Project 17-56 QC Pedestrian Volume Count Report Examples

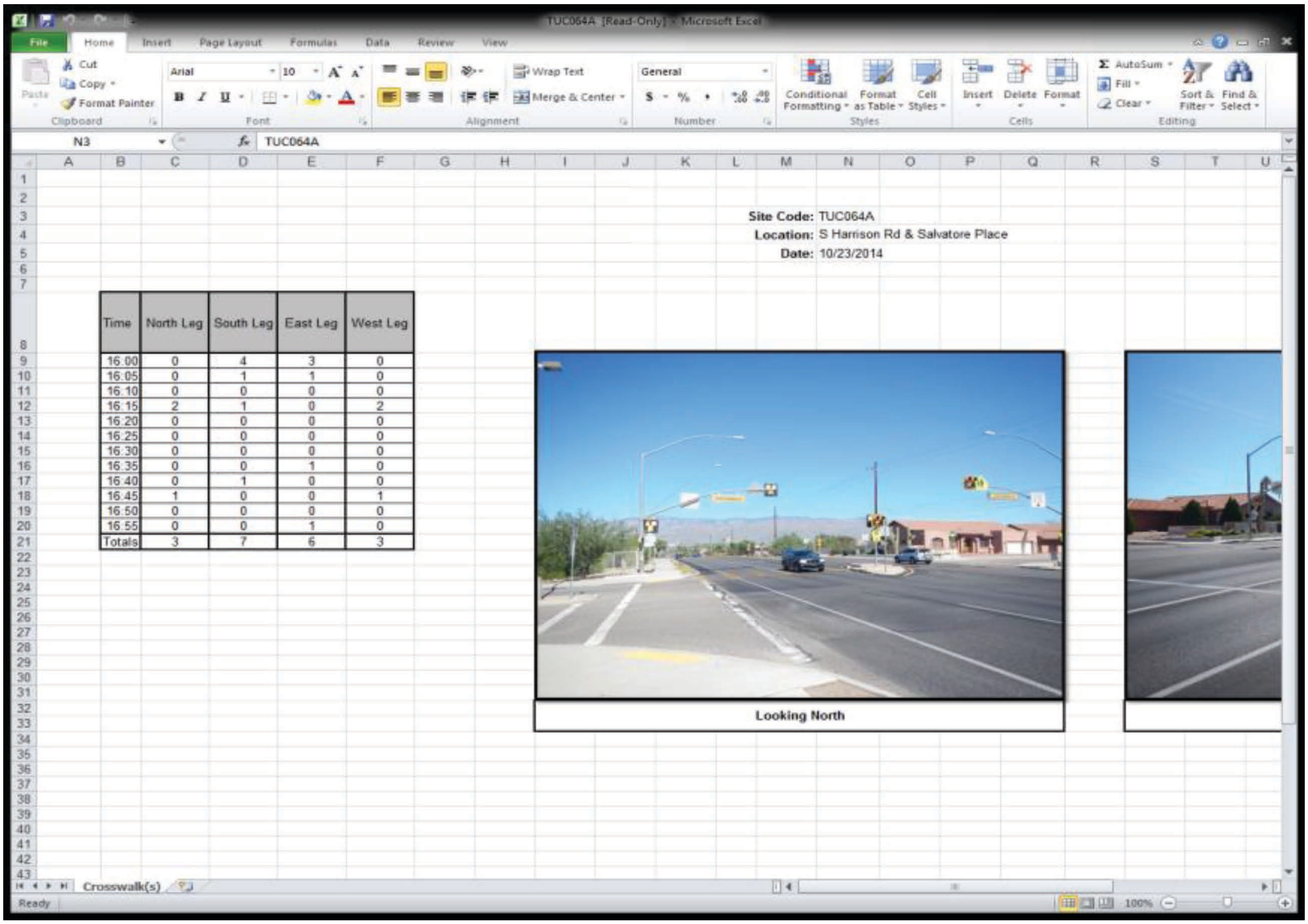
CITY	AS	RI	RRFB	PHB	TREATMENT SITES	COMPARISON SITES
TUCSON, AZ	83	36	0	82	**85**	**65**
ST. PETERSBURG, FL	113	19	32	3	**115**	**45**
PORTLAND, OR	53	40	2	2	**61**	**33**
CHARLOTTE, NC	2	34	0	2	**36**	**112**
TOTAL (14 cities as of 8 Dec 2014)	292	313	50	96	**499**	**476**

AS = Advance Stop, RI = Refuge Island, RRFB = Rectangular Rapid Flashing Beacon, PHB = Pedestrian Hybrid Beacon



Time	North Leg	South Leg	East Leg	West Leg
16:00	0	0	0	0
16:05	0	1	0	0
16:10	0	4	4	4
16:15	0	4	0	5
16:20	0	1	1	2
16:25	0	3	0	4
16:30	0	1	0	4
16:35	0	11	1	10
16:40	0	0	0	3
16:45	0	1	0	1
16:50	0	3	0	2
16:55	0	2	1	1
Totals	0	31	7	36

Figure B-1. Example of a Tucson PHB with AS.



Time	North Leg	South Leg	East Leg	West Leg
16:00	0	4	3	0
16:05	0	1	1	0
16:10	0	0	0	0
16:15	2	1	0	2
16:20	0	0	0	0
16:25	0	0	0	0
16:30	0	0	0	0
16:35	0	0	1	0
16:40	0	1	0	0
16:45	1	0	0	1
16:50	0	0	0	0
16:55	0	0	1	0
Totals	3	7	6	3

Figure B-2. Example of a Tucson PHB with RI and AS.

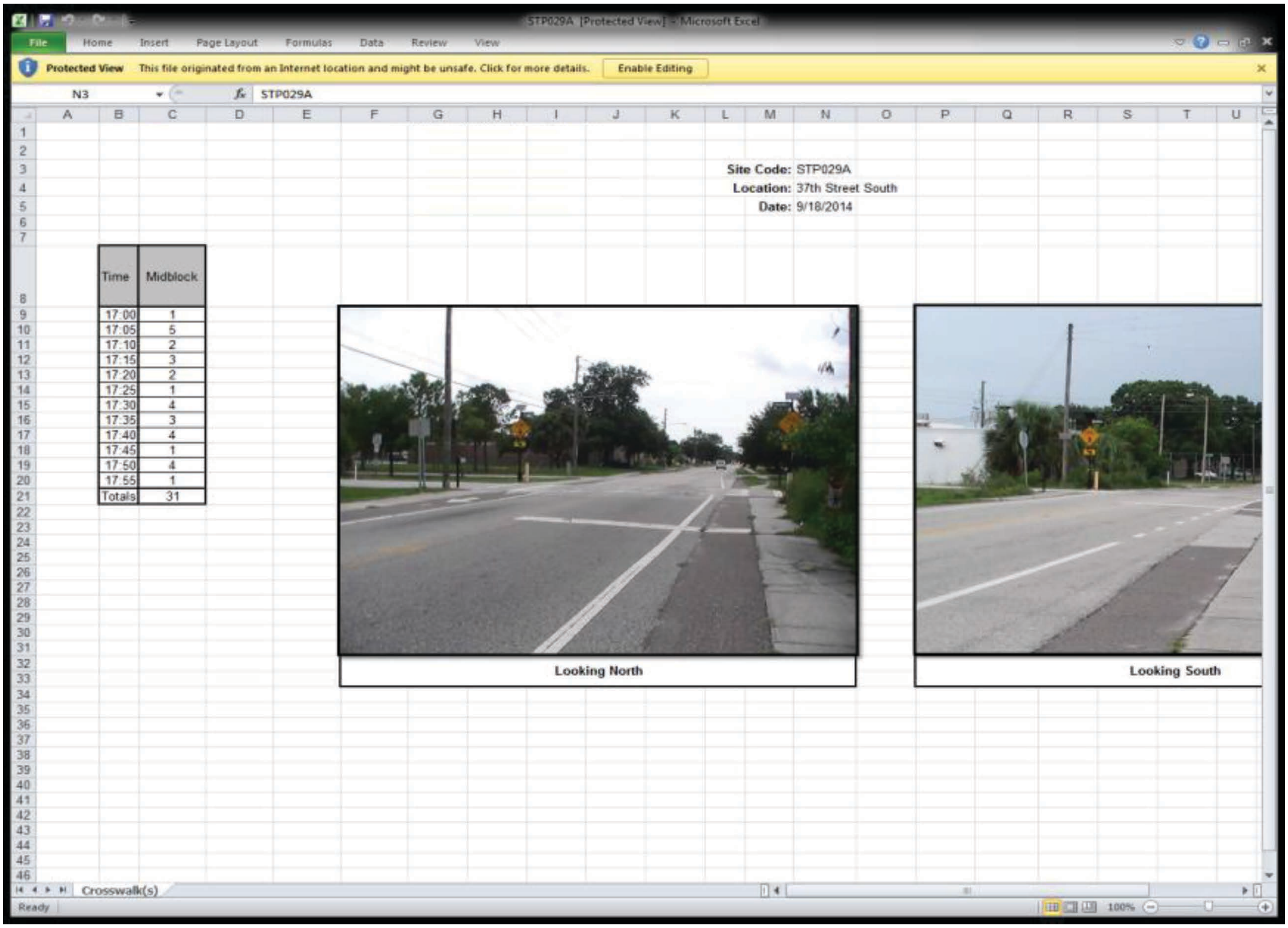
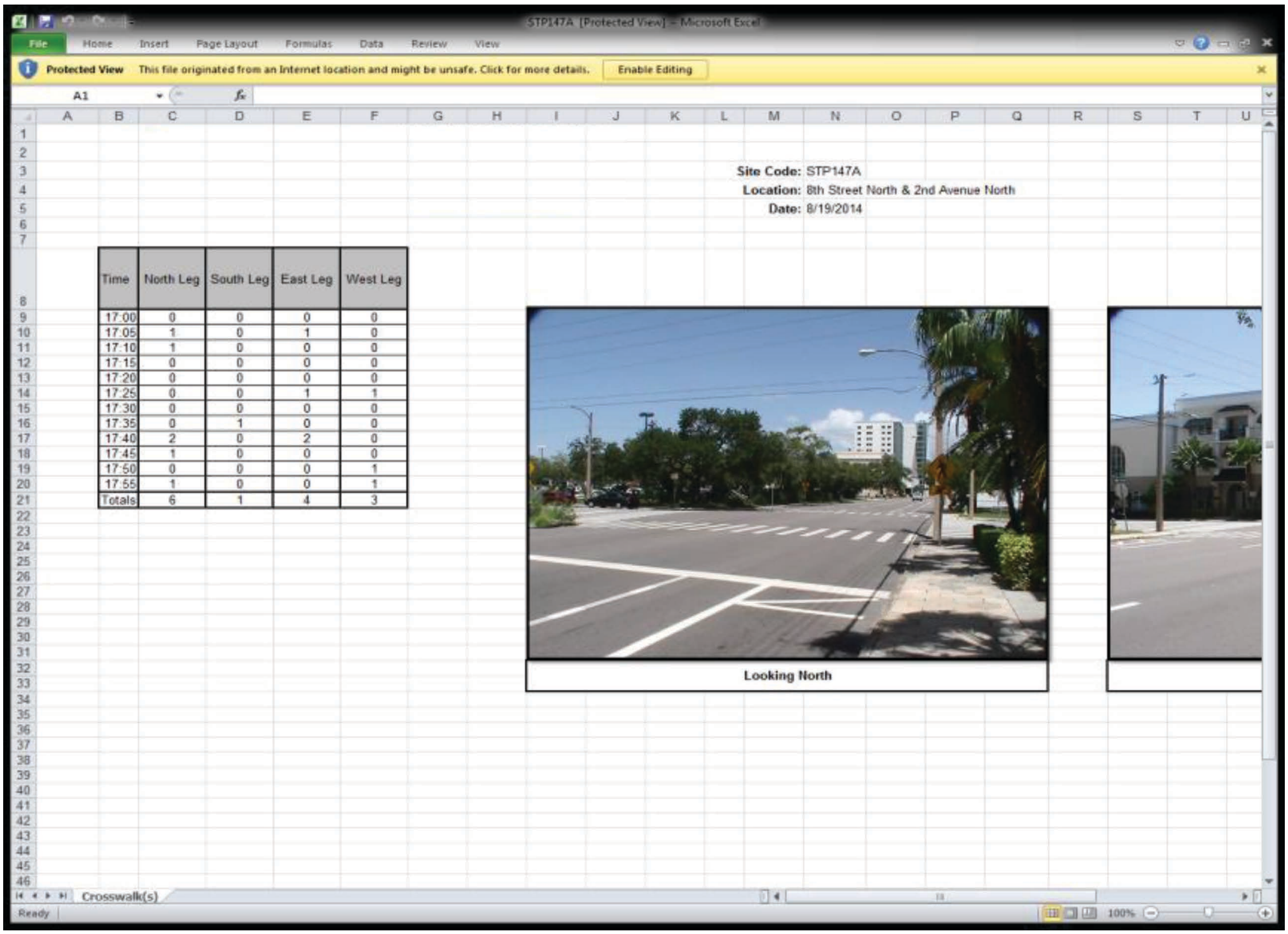
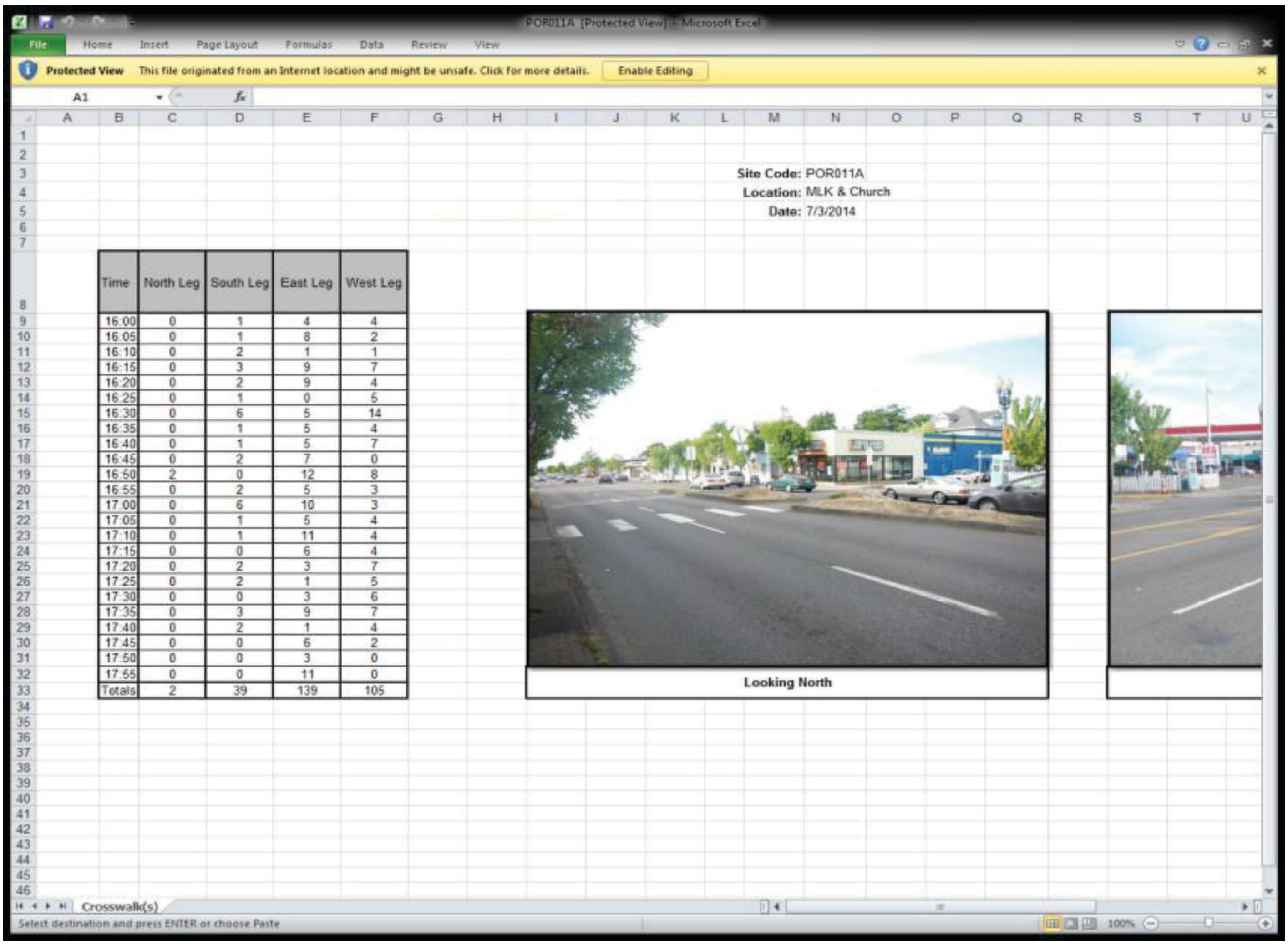


Figure B-3. Example of a St. Petersburg RRFB with AS.



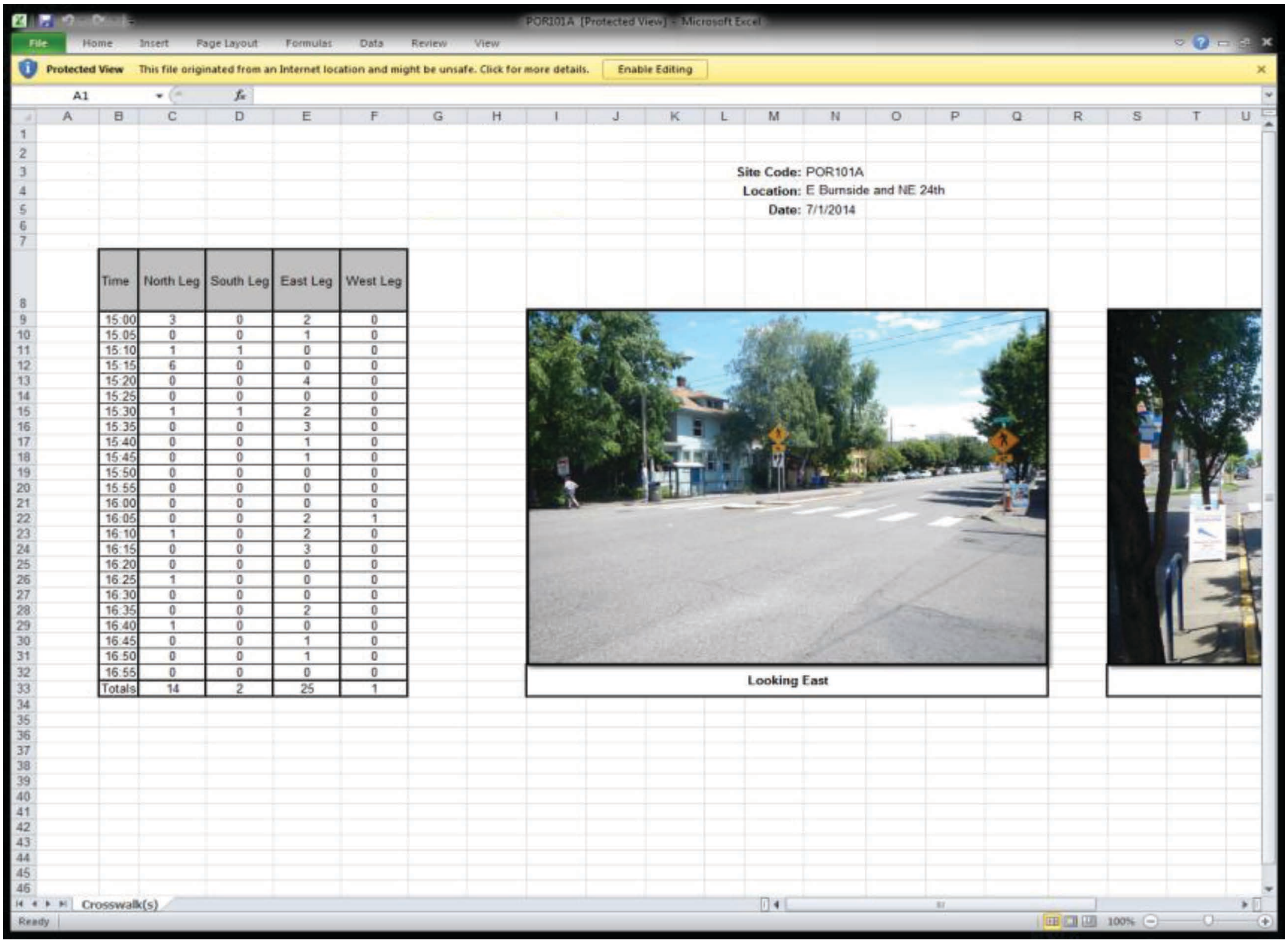
Time	North Leg	South Leg	East Leg	West Leg
17:00	0	0	0	0
17:05	1	0	1	0
17:10	1	0	0	0
17:15	0	0	0	0
17:20	0	0	0	0
17:25	0	0	1	1
17:30	0	0	0	0
17:35	0	1	0	0
17:40	2	0	2	0
17:45	1	0	0	0
17:50	0	0	0	1
17:55	1	0	0	1
Totals	6	1	4	3

Figure B-4. Example of a St. Petersburg AS.



Time	North Leg	South Leg	East Leg	West Leg
16:00	0	1	4	4
16:05	0	1	8	2
16:10	0	2	1	1
16:15	0	3	9	7
16:20	0	2	9	4
16:25	0	1	0	5
16:30	0	6	5	14
16:35	0	1	5	4
16:40	0	1	5	7
16:45	0	2	7	0
16:50	2	0	12	8
16:55	0	2	5	3
17:00	0	6	10	3
17:05	0	1	5	4
17:10	0	1	11	4
17:15	0	0	6	4
17:20	0	2	3	7
17:25	0	2	1	5
17:30	0	0	3	6
17:35	0	3	9	7
17:40	0	2	1	4
17:45	0	0	6	2
17:50	0	0	3	0
17:55	0	0	11	0
Totals	2	39	139	105

Figure B-5. Example of a Portland RI.



Time	North Leg	South Leg	East Leg	West Leg
15:00	3	0	2	0
15:05	0	0	1	0
15:10	1	1	0	0
15:15	6	0	0	0
15:20	0	0	4	0
15:25	0	0	0	0
15:30	1	1	2	0
15:35	0	0	3	0
15:40	0	0	1	0
15:45	0	0	1	0
15:50	0	0	0	0
15:55	0	0	0	0
16:00	0	0	0	0
16:05	0	0	2	1
16:10	1	0	2	0
16:15	0	0	3	0
16:20	0	0	0	0
16:25	1	0	0	0
16:30	0	0	0	0
16:35	0	0	2	0
16:40	1	0	0	0
16:45	0	0	1	0
16:50	0	0	1	0
16:55	0	0	0	0
Totals	14	2	25	1

Figure B-6. Example of a Portland RI.

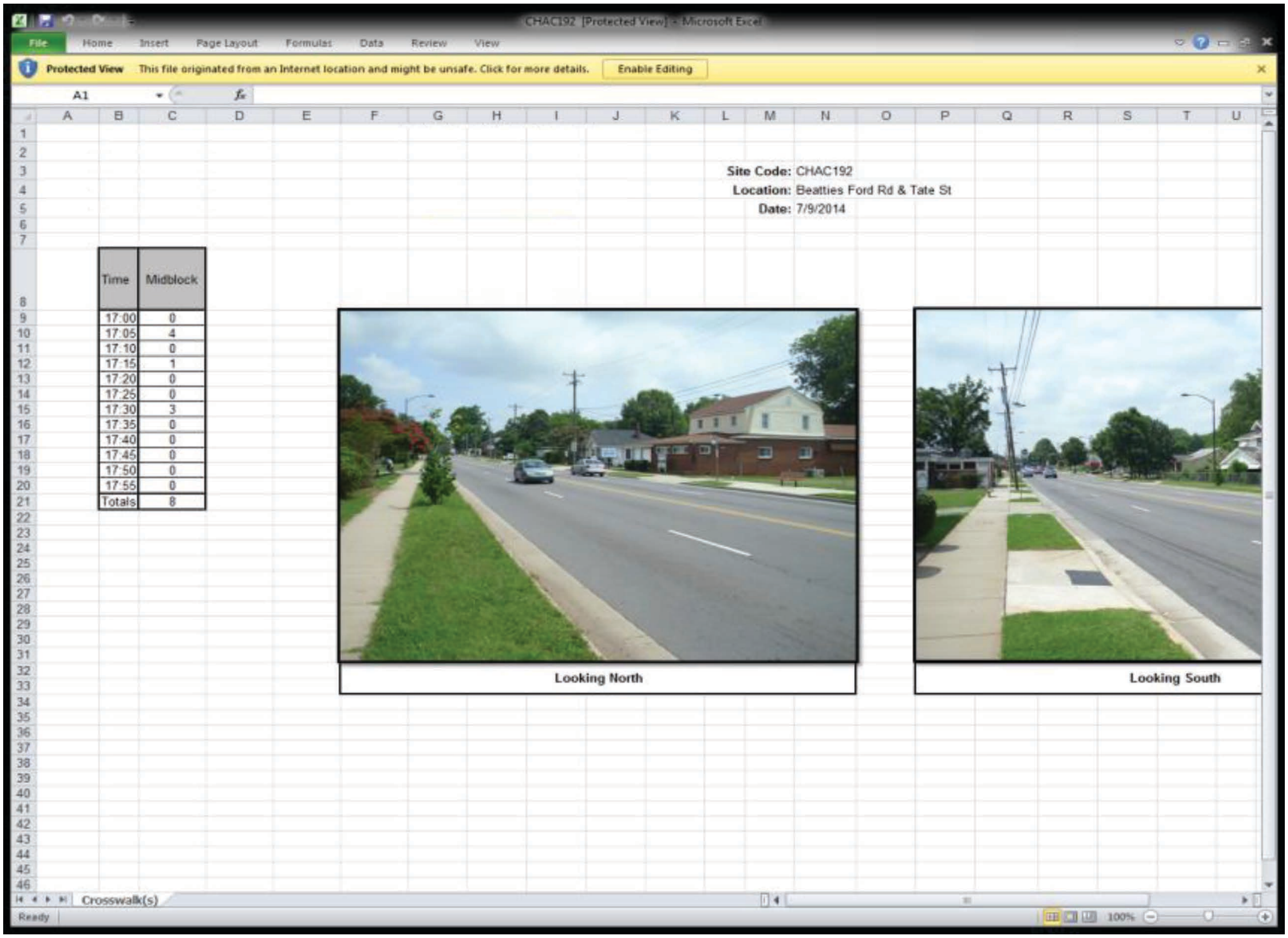
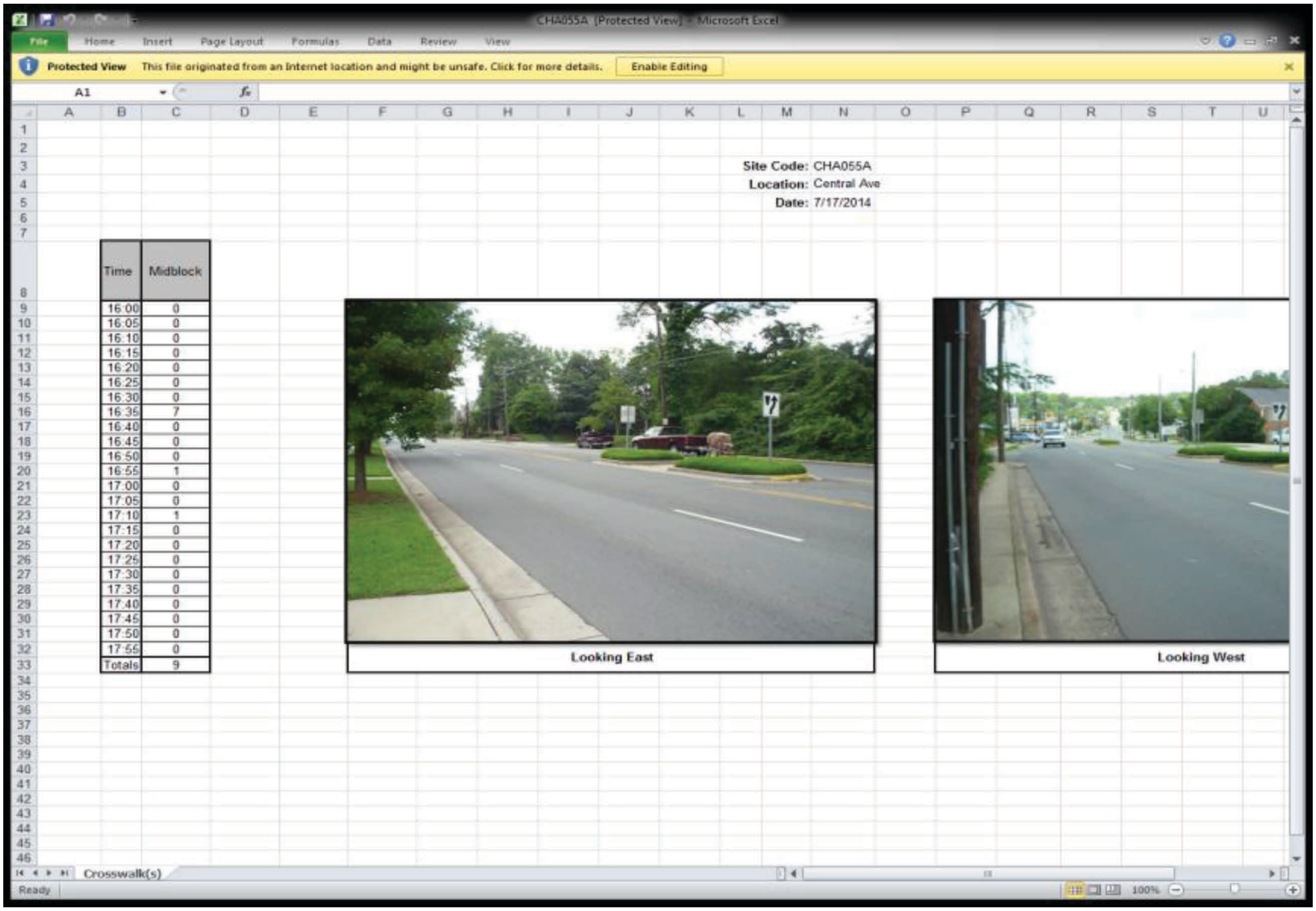


Figure B-7. Example of a Charlotte Comparison Site (four lanes next to bus stop and no marked crosswalk).



Time	Midblock
16:00	0
16:05	0
16:10	0
16:15	0
16:20	0
16:25	0
16:30	0
16:35	7
16:40	0
16:45	0
16:50	0
16:55	1
17:00	0
17:05	0
17:10	1
17:15	0
17:20	0
17:25	0
17:30	0
17:35	0
17:40	0
17:45	0
17:50	0
17:55	0
Totals	9

Figure B-8. Example of a Charlotte RI without a marked crosswalk.

APPENDIX C

Analysis of Charlotte Pedestrian Volumes to Determine Pedestrian Counting Procedure for NCHRP Project 17-56

The analysis approach for NCHRP Project 17-56 required the collection of pedestrian volumes at all study sites. Before beginning the counting effort, the team recognized that there were certain questions which needed to be answered:

1. What is the optimum time of day for conducting a short pedestrian count from which the entire daily pedestrian volume can be estimated?
2. How long should pedestrian counting be conducted at each site?

The team was able to use existing pedestrian volume data from Charlotte, NC, to answer these questions. The analysis was based on a group of 204 unsignalized intersections in Charlotte. Charlotte DOT provided historical pedestrian crossing volumes for these intersections, collected during their regular turning movement counts. These counts ranged in length from 12 to 17 hours, but were typically 12-hour counts between the hours of 7:00 a.m. and 7:00 p.m. The data used in this analysis were only from the period of 7:00 a.m. to 7:00 p.m., even though more hours were available at some sites. None of these intersections were in the Central Business District (uptown Charlotte).

Many of these intersections were fairly low in pedestrian volume. See Table C-1 for a frequency distribution of the intersection pedestrian volumes.

Optimum Time of Day

In order to answer the question regarding the optimum time of day for counting, the team analyzed the distribution of pedestrian volume throughout the day (Figure C-1). Even though some intersections had a range of 12- to 17-hour counts, only the data from 7:00 a.m. to 7:00 p.m. were used in Figure C-1. The data are presented in terms of the percentage of the daily volume represented for each 1-hour window. The percentages were calculated as a sliding 1-hour count divided by the total pedestrian volume for that day. For example, the point at 4:00 p.m. represents the number of pedestrians counted in the 4:00 p.m. to 5:00 p.m. time period. Also, the data were calculated on a "per-intersection" basis rather than by individual approach leg.

Based on the trend in Figure C-1, either midday (11:30 a.m. to 1:30 p.m.) or late afternoon (4:00 p.m. to 6:00 p.m.) were the most fruitful times for pedestrian counting in Charlotte. Given that both time periods appeared fairly equivalent, the team made the decision to conduct the NCHRP Project 17-56 data collection counts during the late afternoon.

Table C-1. Distribution of pedestrian volumes at Charlotte sites.

12-hour volume	Number of intersections
0-10	51
11-20	31
21-30	19
31-40	15
41-50	10
51-60	16
61-70	13
71-80	8
81-90	5
91-100	3
101+	33

1-Hour vs. 2-Hour Counts

The second question pertained to the duration of pedestrian counting that would be needed. With a limited research budget, the team needed to obtain an estimate of pedestrian volume at an intersection using only the minimum necessary counting time. It was estimated that the budget would likely support counts only in the range of 1 to 2 hours per intersection. The team needed to determine whether 1 hour would be sufficient or whether a second hour of counting would provide proportionally more data for the time spent.

The Charlotte pedestrian counts were provided for a full day (typically 12 hours) in 15-minute increments. This provided the ability to know the "ground truth" (the actual full 12-hour count)

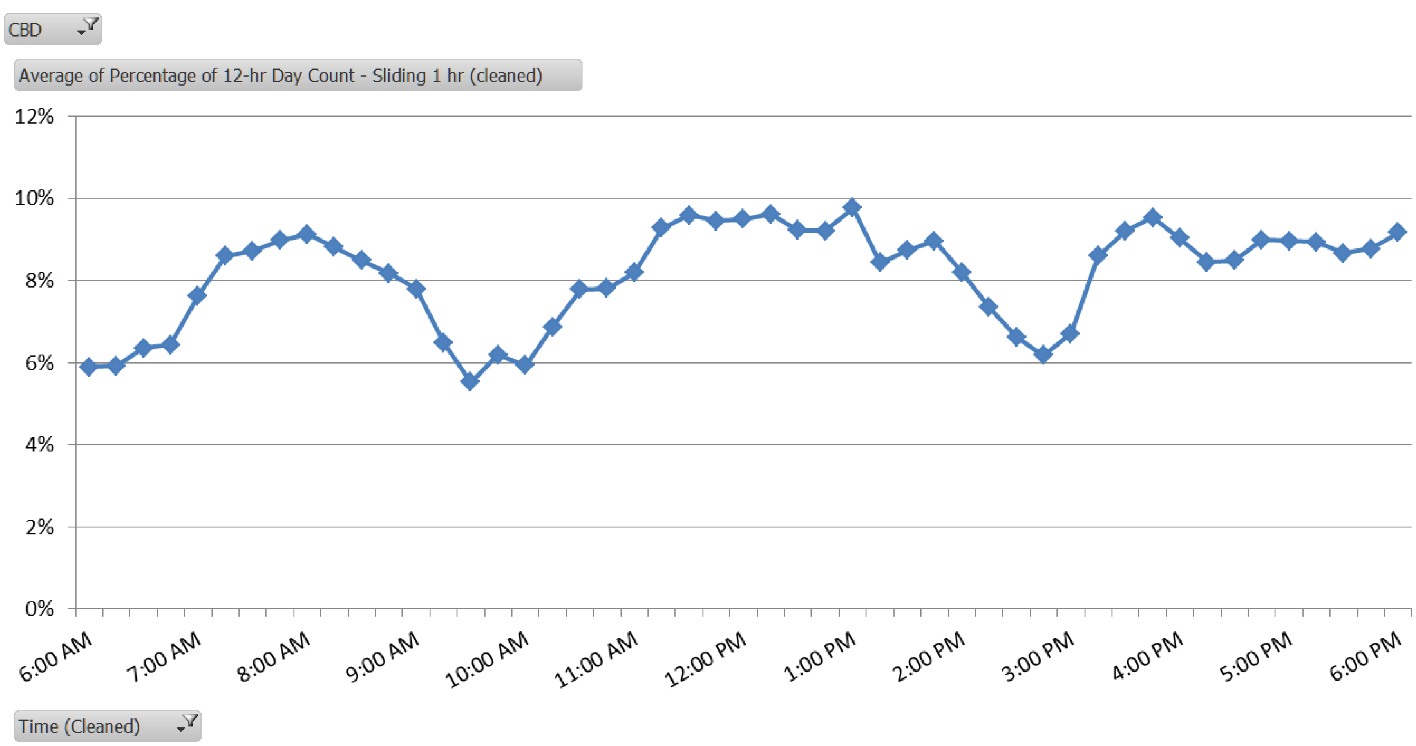


Figure C-1. Hourly pedestrian volume distribution at 204 unsignalized intersections in Charlotte.

for any intersection as well as the counts by specific times of the day (e.g., 4:00 to 5:00). The team used this information to simulate how much of the total day count was captured in a 1-hour block and a 2-hour block. Given that the time of day analysis resulted in a decision to collect pedestrian counts during the late afternoon, this counting duration analysis focused on the late afternoon time period (4:00 to 6:00 p.m.).

If the 2-hour count (i.e., 4:00 to 6:00 p.m.) captured only twice as much of the daily percentage as the 1-hour block (i.e., 5:00 to 6:00 p.m.), then there would be no proportional gain, and the 1-hour block would have sufficed. If the 2-hour count captured significantly more than double what was observed in the 1-hour block, this would represent a disproportional gain in data gathered and would provide a reason to conduct 2-hour counts at all study intersections. Table C-2 shows an example of the results of this analysis approach for six of the intersections. Even in this small example sample, it is obvious that results varied greatly by site. For example, Site 1 shows a significant gain from 2% to 10% when a second hour of counting is included and Site 2 shows that no pedestrians were observed during the first hour, but five were observed during the second hour. However, sometimes a second hour of counting was less than double the percentage seen in the first hour, such as with Site 4, representing an instance when the time invested in a second hour would not yield proportionally more data. Also, sometimes a second hour of counting did not yield any additional information, such as for Sites 5 and 6.

The analysis began with data from all 204 intersections for which pedestrian volumes were available. However, the final analysis did not include intersections with a total daily count of zero pedestrians or intersections with an abnormally high number of pedestrians (elimination of outliers). The results showed that on average, a 1-hour count (5:00 to 6:00 p.m.) captured 8% of the total 12-hour pedestrian volume whereas a 2-hour count (4:00 to 6:00 p.m.) captured 18% of the total volume. This result showed that the 2-hour count did yield slightly more than double the percentage compared to a 1-hour count. However, the team did not deem this a large enough gain to justify the substantial increase in costs to collect a second hour of counting at all study sites.

A follow-up question to this result was, "Are there situations in which a second hour of counting would be more necessary?" The assumption was that intersections with low pedestrian volumes would benefit more from a second hour of counting. This assumption was based on Figure C-2 and Figure C-3, where it can be seen that the percentage of the daily count captured during a 1- or 2-hour count increased as the overall daily volume increased. That is to say, sites with higher overall pedestrian volumes provided a better estimate of the daily volume from a short count.

However, the analysis of sites with low daily pedestrian volumes showed similar results to the results from all sites. As shown in Table C-3, the percentage increases when adding a second hour

Table C-2. Example analysis results for six sites.

Intersection ID	12-Hr Total Pedestrians ("Ground Truth")	1-Hr Total (5:00-6:00)	2-Hr Total (4:00-6:00)	Percent Captured by 1-Hr Count	Percent Captured by 2-Hr Count
1	135	3	14	2%	10%
2	88	0	5	0%	6%
3	157	16	38	10%	24%
4	53	13	22	25%	42%
5	20	0	0	0%	0%
6	24	3	3	13%	13%

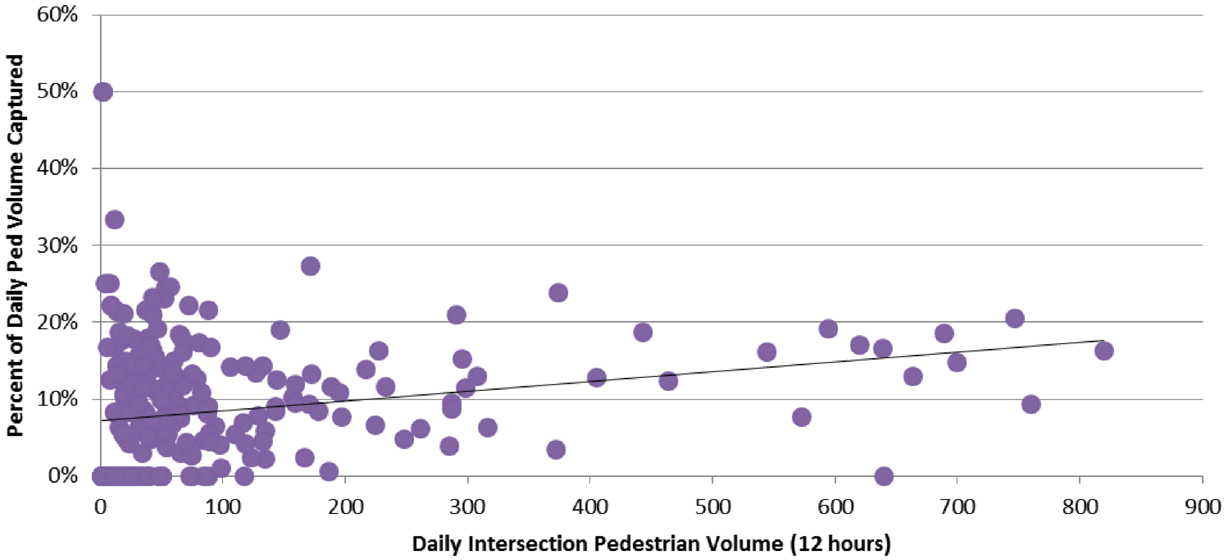


Figure C-2. Percent of daily pedestrian volume captured in a 1-hr count from 5:00 to 6:00 p.m.

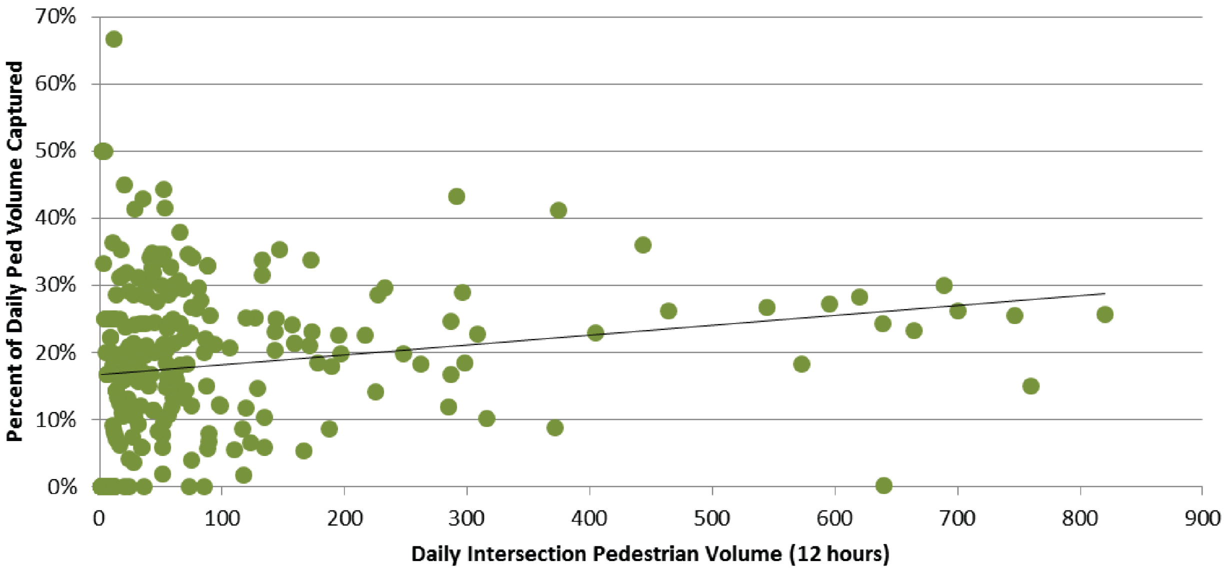


Figure C-3. Percent of daily pedestrian volume captured in a 2-hr count from 4:00 to 6:00 p.m.

Table C-3. Analysis of low volume sites.

	Percentage of Daily Count Observed from 1-Hr Count	Percentage of Daily Count Observed from 2-Hr Count
All sites	8%	18%
Low volume sites (1-20 peds/day)	6%	13%
Med volume sites (21-50 peds/day)	9%	21%

of counting for low volume and medium volume sites were still only slightly more than double the 1-hour yield (e.g., 6% vs. 13%, 9% vs. 21%). Again, this was deemed to be an insufficient gain of data for the added cost of collecting a second hour.

Given the results shown in Table C-3, the protocol used for the NCHRP Project 17-56 data collection was to count 1 hour of pedestrians at each treatment and comparison site. Although all data were collected in the late afternoon "rush hour" period, the actual time of collection varied throughout the study depending on factors specific to the location and time of year. For example, pedestrian counting at the Arizona sites was done at an earlier time period (4:00 to 5:00) since those counts were taken in the fall and the daylight hours were shorter.

APPENDIX D

Analysis of Charlotte Pedestrian Volumes to Determine Method for Adjusting Pedestrian Volume Counts

Given that the NCHRP Project 17-56 data collection consisted of short (1-hour or 2-hour) pedestrian counts, it was necessary during the analysis phase to convert these short counts into day-long pedestrian volumes. To address this need, the pedestrian volume data for the Charlotte intersections were used to calculate expansion factors to use during analysis. These data were also previously used to determine the optimum time of day for pedestrian counting and the most efficient length of count.

Expanding Short Counts to Daily Volumes

The calculations below are based on pedestrian volume from 204 unsignalized intersections in Charlotte. The Charlotte DOT provided historical pedestrian crossing volumes for these intersections, collected during its regular turning movement counts. These counts ranged in length from 12 to 17 hours, but were typically 12-hour counts between the hours of 7:00 a.m. and 7:00 p.m. The data used in this analysis were only from the period of 7:00 a.m. to 7:00 p.m., even though more hours were available at some sites. None of these intersections were in the Central Business District (uptown Charlotte).

Charlotte pedestrian counts were provided for a full day (typically 12 hours) in 15-minute increments. This provided the ability to know the "ground truth" (the actual full 12-hour count) for any intersection as well as the counts by specific times of the day (e.g., 4:00 to 5:00). Based on previous analysis, the afternoon and early evening hours were the target time periods counted during the NCHRP Project 17-56 data collection effort.

The expansion factors were calculated as the total pedestrian count ("ground truth") divided by the number of pedestrians counted in time period x. Table D-1 provides an example of how the expansion factor calculation for particular time periods would work for a single intersection with 135 pedestrians counted for the full day.

However, to calculate general expansion factors based on the entire group of 204 intersections, the count data were aggregated first and then used to determine expansion factors for each time period.

The expansion factors in Table D-2 were calculated using a citywide group of unsignalized intersections in Charlotte. Since this amount of detailed pedestrian volume information was not available in the other cities used in NCHRP Project 17-56, these factors were used to expand the 1- and 2-hour counts in those cities. For example, for a particular site in another city, if the field data collection of pedestrian volume was done from 5:00 to 6:00 p.m. and resulted in a count of 10 pedestrians, the estimated daily total for that intersection would be $10 \times 9.22 = 92$ pedestrians.

Table D-1. Example of expansion factor calculation for a single site.

Ground Truth (whole day pedestrian count)	Time Period	Pedestrian Count	Expansion Factor (ground truth/short count)
135	4:00-5:00	11	12.27
	5:00-6:00	3	45
	6:00-7:00	13	10.38
	4:00-6:00	14	9.64
	5:00-7:00	16	8.44

Table D-2. Expansion factors calculated from entire group of intersections.

Ground Truth (whole day pedestrian count, total of all intersections)	Time Period	Pedestrian Count	Expansion Factor (ground truth/short count)
34,824	4:00-5:00	3,248	10.72
	5:00-6:00	3,776	9.22
	6:00-7:00	3,223	10.8
	4:00-6:00	7,024	4.96
	5:00-7:00	6,999	4.98

Table D-3. Expansion factors by season.

Season	4:00-5:00	5:00-6:00	6:00-7:00	4:00-6:00	5:00-7:00
Winter (Dec-Feb)	10.72	8.92	12.92	4.87	5.28
Spring (Mar-May)	10.27	9.36	10.03	4.90	4.84
Summer (Jun-Aug)	9.62	8.59	12.78	4.54	5.14
Fall (Sep-Nov)	9.77	8.31	8.26	4.49	4.14

The factors presented in Table D-2 are general factors for any count taken, regardless of time of year. They are however weekday-only factors, since all pedestrian counts done by the City of Charlotte were performed on weekdays only. This synchronizes well with the NCHRP Project 17-56 counts, which were also taken only on weekdays.

It is reasonable to expect that weather variation throughout the seasons of the year will affect pedestrian activity. Table D-3 presents expansion factors by season. These factors were calculated in the same manner as for the entire group of intersections but using only intersections with counts in the specific season. To be as accurate as possible, the process for expanding short-term counts in NCHRP Project 17-56 used the seasonal expansion factors shown in Table D-3.

Comparison to Other Studies and Cities

Table D-4 compares the expansion factors calculated from the Charlotte data to factors based on Seattle data used in a previous FHWA study, *Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations: Final Report and Recommended Guidelines*, *FHWA-HRT-04-100* (Zegeer et al., 2005) and factors calculated using data obtained in NCHRP Project 7-19 research. The Seattle data are based on a group of sites in Seattle; the NCHRP Project 7-19 data were from a limited number of sites (five) that were geographically far apart. The Charlotte expansion factors match fairly closely to those calculated from Seattle data. The expansion factors from the five sites included in NCHRP Project 7-19 are mostly higher than the Charlotte and Seattle factors, but generally not by a large amount. This comparison validates the use of the expansion factors calculated from Charlotte data for the NCHRP Project 17-56 analysis.

Table D-4. Comparison of expansion factors from other cities.

Time Period	Expansion Factor from Charlotte Data	Expansion Factor from Seattle Data[a] (range is from fringe to residential)	Expansion Factors Calculated from NCHRP Project 7-19				
			Washington D.C. – Key Bridge	Davis, CA – Sycamore Park	Minneapolis, MN – 15th and Como	Portland, OR – 5th Ave	San Francisco, CA – Fell St
4:00-5:00	10.72	7.9 - 9.3	18.45	15.58	12.89	12.27	15.82
5:00-6:00	9.22	8.1 - 11.4	10.46	15.11	13.33	12.80	12.79
6:00-7:00	10.8	n/a	8.74	19.25	16.92	33.00	11.27
4:00-6:00	4.96	n/a	n/a	n/a	n/a	n/a	n/a
5:00-7:00	4.98	n/a	n/a	n/a	n/a	n/a	n/a

[a] Zegeer, C. et al. *Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations: Final Report and Recommended Guidelines*, Federal Highway Administration, FHWA-HRT-04-100, 2005.

Adjusting Pedestrian Volume through the Years

Another question for the analysis is if and how pedestrian volumes in past years should be estimated based on present day counts. Essentially, most treatment and comparison sites included in NCHRP Project 17-56 only have pedestrian volume from 1 year—typically 2014 when the field data collection was done. A before-after analysis would need to have annual pedestrian volumes for the past years at the intersection. Again, Charlotte pedestrian volumes were used to examine this issue.

Using the same group of intersections as listed above, certain intersections were identified as having two or more pedestrian volume counts in different years. For example, an intersection may have been counted in 2004 and again in 2009. This provides the basis to examine annual trends in pedestrian volumes. From the above group of intersections, there were 56 intersections which had two or more counts and thus could be used in this analysis. For each of these, the growth rate was calculated as

$$r = \sqrt[n]{\left(\frac{F}{P}\right)} - 1$$

where

r = growth rate
F = future year (i.e., the later year of the pair)
P = present year (i.e., the earlier year of the pair)
n = time between the two years (in years)

For example, if an intersection had a pedestrian count of 40 peds/day in 2004 and 60 peds/day in 2009, the growth rate would be calculated as:

$$r = \sqrt[(2009-2004)]{\left(\frac{60}{40}\right)} - 1$$

$$r = 0.084 \text{ or } 8.4\%$$

Table D-5. Growth rates by year.

	To										
From	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
2002	62%	18%	68%	7%	9%	-1%		38%		27%	-4%
2003		250%	53%	32%	6%		7%	11%	13%	4%	1%
2004				-73%	-12%	3%	-29%	19%	1%		9%
2005									27%		10%
2006					129%		11%	35%		12%	-3%
2007						26%		-14%	-18%	-26%	-3%
2008								17%		71%	-3%
2009											-14%
2010											34%
2011										-9%	
2012											28%

Table D-6. Number of intersections used to calculate each growth rate.

	To										
From	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
2002	1	1	1	1	1	1		1		2	1
2003		1	3	1	4		1	3	5	2	6
2004				1	3	1	1	2	2		1
2005									1		1
2006					1		2	2		1	2
2007						2		7	1	1	5
2008								2		2	1
2009											1
2010											3
2011										1	1
2012											3

Using this formula, growth rates were calculated for each intersection, specific to the combination of the original year and the later year (i.e., 2004 to 2009). Intersections that were counted in the same two years were grouped, and the average of their growth rates was taken. Table D-5 presents the growth rates in terms of the "from" year and "to" year.

Unfortunately, the group of 56 intersections that had at least two counts through the years was a small group to begin with. Thus, the numbers of intersections used to calculate the growth rates in each cell of Table D-5 were very small. Table D-6 provides the number of intersections used for each cell in Table D-5.

Based on the small amount of data available and the wide range of growth rates shown above, there is no basis on which to make a recommendation for adjusting present day pedestrian volumes to estimate past year volumes.

APPENDIX E

Safety Performance Functions for the Before-After Evaluation

This appendix documents the safety performance functions (SPFs) that were estimated as part of the Empirical Bayes (EB) before-after evaluation using the data from a reference group of 474 sites that included information for 3,842 site-years. The SPFs were estimated using negative binomial regression. The functional form of the SPFs was the following:

$$Y = \exp\left(\beta_0 + \sum_{i=1}^{n} \beta_i X_i\right)$$

where

Y = the number of crashes per year,
β_0 = the intercept,
X_i = the independent variables,
β_i = the coefficients for these independent variables, and
n = the number of independent variables.

The estimation was done using PROC GENMOD in SAS.

Tables E-1 through E-4 provide the SPFs that were estimated for total, rear-end, sideswipe, and pedestrian crashes. The tables show the coefficients, standard errors of the coefficients, the over-dispersion parameter (k), and the scaled deviance divided by the degrees of freedom. As is the norm, for the categorical variables, one of the levels or categories was included as a reference level. It is important to note that unlike the regression models that are documented in the main body of this report and used for estimating the CMFs, these SPFs are meant for prediction and not for making inferences regarding the safety effects of certain roadway features.

Table E-1. SPF for total crashes.

Variable	Level or Category	Coefficient	S.E.
Intercept		-8.5602	0.4051
ln(major AADT)		0.8243	0.039
ln(pedestrian volume)		0.1098	0.013
City	Alexandria	-0.4509	0.3144
	Arlington	-0.7981	0.1656
	Cambridge	0.0887	0.1035
	Charlotte	1.2773	0.0595
	Chicago	0.4627	0.0976
	Eugene	-0.6029	0.1448
	Miami	0.3052	0.0888
	Milwaukee	0.1719	0.1157
	New York	-0.2646	0.1656
	Phoenix	0.5687	0.0933
	Portland	0.2588	0.097
	Scottsdale	0.6593	0.1304
	St. Petersburg	0.2119	0.0938
	Tucson	----	----
Year	2004	----	----
	2005	-0.0449	0.0876
	2006	-0.0861	0.0838
	2007	-0.0738	0.0815
	2008	-0.1504	0.0805
	2009	-0.3778	0.082
	2010	-0.4724	0.0829
	2011	-0.4784	0.0831
	2012	-0.444	0.0832
	2013	-0.4887	0.0919
Intersection or Midblock	Intersection	0.5626	0.0508
	Midblock	----	----
Crosswalk Type	No crosswalk	----	----
	Other	0.2975	0.064
	PLC	0.229	0.0859
Area Type	Urban	0.21	0.0807
	Suburban	----	----
One-way or Two-way	One-way	0.464	0.1138
	Two-way	----	----
School Crosswalk	Yes	-0.3267	0.0731
	No	----	----
k		0.5843	0.0281
Scaled Deviance/df		1.0775	

Note: SPF was estimated based on information from 9,352 total crashes.

Table E-2. SPF for rear-end crashes.

Variable	Level or Category	Coefficient	S.E.
Intercept		-14.3684	0.6908
ln(major AADT)		1.3678	0.0708
ln(pedestrian volume)		0.0816	0.0192
Crosswalk length		-0.012	0.0024
City	Alexandria	-0.7634	0.4725
	Arlington	-0.9307	0.2662
	Cambridge	-0.3598	0.166
	Charlotte	1.1519	0.0895
	Chicago	0.1151	0.1475
	Eugene	-0.6767	0.2467
	Miami	-0.1524	0.149
	Milwaukee	-0.1074	0.1807
	New York	-0.3886	0.3018
	Phoenix	0.508	0.1298
	Portland	0.3115	0.1443
	Scottsdale	1.0372	0.2135
	St. Petersburg	0.0264	0.1544
	Tucson	----	----
Year	2004	----	----
	2005	-0.0646	0.1219
	2006	-0.1001	0.1179
	2007	-0.1885	0.1156
	2008	-0.1801	0.1138
	2009	-0.3712	0.1166
	2010	-0.5288	0.1194
	2011	-0.461	0.1185
	2012	-0.5994	0.1218
	2013	-0.5577	0.1305
Intersection or Midblock	Intersection	0.5718	0.0765
	Midblock	----	----
Lighting	Yes	0.2261	0.0707
	No	----	----
Crosswalk Type	No crosswalk	----	----
	Other	0.5612	0.0946
	PLC	0.5152	0.1268
k		0.7882	0.0588
Scaled Deviance/df		0.8196	

Note: SPF was estimated based on information from 2,989 rear-end crashes.

Table E-3. SPF for sideswipe crashes.

Variable	Level or Category	Coefficient	S.E.
Intercept		-13.2532	0.9558
ln(major AADT)		1.0215	0.0909
ln(pedestrian volume)		0.1094	0.0263
City	Alexandria	-0.7589	1.0282
	Arlington	-0.3505	0.4407
	Cambridge	1.3105	0.2043
	Charlotte	1.9124	0.1483
	Chicago	0.8885	0.2201
	Eugene	-0.4492	0.4449
	Miami	0.1643	0.2518
	Milwaukee	1.347	0.2322
	New York	-21.4792	22962.31
	Phoenix	1.5857	0.1822
	Portland	0.3786	0.2448
	Scottsdale	2.0354	0.2612
	St. Petersburg	-0.1471	0.3281
	Tucson	----	----
Year	2004	----	----
	2005	0.0796	0.1632
	2006	-0.0946	0.1652
	2007	0.3011	0.1522
	2008	0.0205	0.156
	2009	-0.1311	0.1607
	2010	-0.2377	0.1635
	2011	-0.3732	0.1677
	2012	-0.3416	0.1664
	2013	-0.2531	0.1758
Intersection or Midblock	Intersection	0.2571	0.1002
	Midblock	----	----
One-way or Two-way	One-way	1.0262	0.1987
	Two-way	----	----
Crosswalk Type	No crosswalk	----	----
	Other	0.5137	0.1451
	PLC	0.4959	0.1738
School Crossing	Yes	-0.7122	0.1732
	No	----	----
k		0.5721	0.1015
Scaled Deviance/df		0.5757	

Note: SPF was estimated based on information from 1,015 sideswipe crashes.

Table E-4. SPF for pedestrian crashes.

Variable	Level or Category	Coefficient	S.E.
Intercept		-12.4454	1.5093
ln(major AADT)		0.8448	0.1432
ln(pedestrian volume)		0.3158	0.0513
City	Alexandria	0.3544	1.0511
	Arlington	-1.2284	0.7367
	Cambridge	0.1865	0.2864
	Charlotte	0.1855	0.1943
	Chicago	-0.1748	0.326
	Eugene	-2.124	1.0173
	Miami	0.3153	0.2571
	Milwaukee	-2.4065	0.7494
	New York	0.1166	0.3808
	Phoenix	-0.3435	0.3473
	Portland	-0.4141	0.3079
	Scottsdale	-0.8352	0.7541
	St. Petersburg	-0.3729	0.4011
	Tucson	----	----
Area Type	Urban	0.8911	0.2393
	Suburban	----	----
k		1.2039	0.4162
Scaled Deviance/df		0.2858	

Note: SPF was estimated based on information from 272 pedestrian crashes.

APPENDIX F

Selection and Assessment of Model Form for Cross-Sectional Models

The functional form of the regression model sets the relationship between the explanatory and dependent variable. An incorrect functional form results in biased and inconsistent parameter estimates from which a CMF is derived, so it stands to reason that the selection of a functional form is critical to developing a reliable CMF.

The selection of model form followed logical considerations based on forms found to be appropriate for similar research and utilized two tools to aid in the investigation of the appropriate functional form. These were introduced in *Two Tools for Finding what Function Links the Dependent Variable to the Explanatory Variables* in the Proceedings for ICTCT (International Cooperation on Theories and Concepts in Traffic Safety) (Hauer and Bamfo 1997) and are called the Integrate-Differentiate (ID) and Cumulative Residual Plot (CURE) methods. Below is an overview of the methods.

ID Method Overview

In the ID method, the integrate function is a cumulative function, F(x). The primary assumption of the ID method is that if the empirical integral function, $F_E(X)$, is close to the integral function, $F_1(x)$, then the linear transformation of $F_E(x)$ should be close to one of $F_1(x)$. One can list all possible integral functions and choose the one closest to $F_E(X)$. For a better understanding of this method, refer to Hauer and Bamfo (1997). In their dataset, there is no visible relationship between crash frequency and the explanatory variable, so Hauer and Bamfo (1997) draw a bin graph to sum up the bin area, resulting in the empirical integral function. The width of the bin area is the difference between the nearest higher average annual daily traffic (AADT) and nearest lower AADT, divided by two, for each group. Then, all possible functions (*e.g.,* power function, polynomial function, and Hoerl's function) are listed and their linear transform graphs are compared with one of the empirical integral functions, $F_E(x)$. Figure F-1 provides an example. If the possible model,

$$F_1(x) = {}^{\alpha}\!/\!_{(\beta+1)} x^{\beta+1}$$

we should see a straight line with

$$\log {}^{\alpha}\!/\!_{(\beta+1)}$$

as the intercept and $\beta + 1$ as the slope when we plot $\log[F_E(X)]$ against log(X) one. Obviously, this is true when the log (AADT) is larger than 6.5 (the dashed circle).

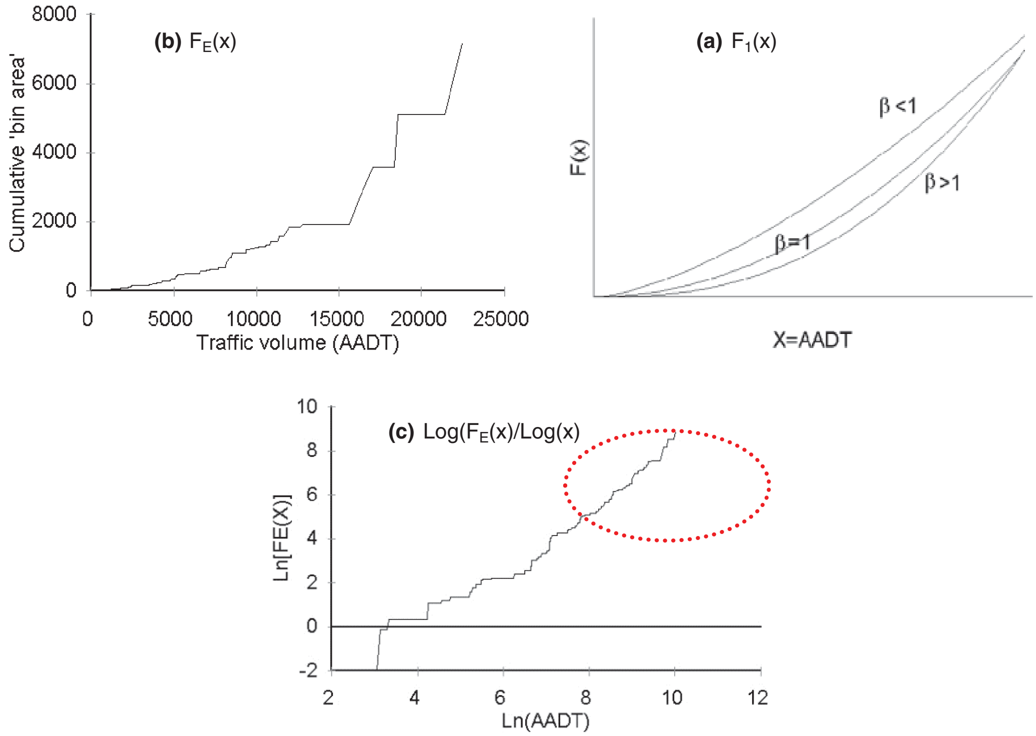


Figure F-1. Illustration of ID method.

For most of the variables available and for all those included in the final models, the structure of the variables was categorical, e.g., Area Type is either rural or urban, and not continuous. Thus, for these variables, the ID method is not relevant and was not applied. For the remaining variables, such as crossing width, the ID method indicated that either a power or exponential function seemed appropriate. With the exception of AADT and pedestrian AADT, however, none of these variables proved to be statistically significant and were not included in the final models.

CURE Plot Overview

A complementary method to the ID method is to build the model one variable at a time and examine the residuals to see if an alternate model form may improve the fit to the data. The tool for examining residuals is called the CURE plot. A CURE plot is a graph of the cumulative residuals (observed minus predicted crashes) against a variable of interest sorted in ascending order. A good CURE plot should not have vertical drops because these are indicative of inordinately large residuals—possible outliers. It should not have long increasing or decreasing runs because these correspond to regions of consistent over and under estimation. It should meander around the horizontal axis in a manner consistent with a "symmetric random walk." Even in the absence of any bias, symmetric random walks have "runs," i.e., stretches in which several consecutive residuals tend to be positive (an up-run) or negative (a down-run). For a CURE plot that is consistent with a symmetric random walk one can find the limits beyond which the plot should only rarely go.

The steps to constructing a CURE plot are the following:

- Step 1: Sort sites in ascending order of the variable of interest, such that N is the number of sites, n is an integer between 1 and N and S(n) is the cumulative sum of residuals from 1 to n.
- Step 2: For each site, calculate the residuals, res, by subtracting (observed – predicted).
- Step 3: For each site, calculate the cumulative residuals, S(n).
- Step 4: For each site, calculate the squared residuals, res^2.

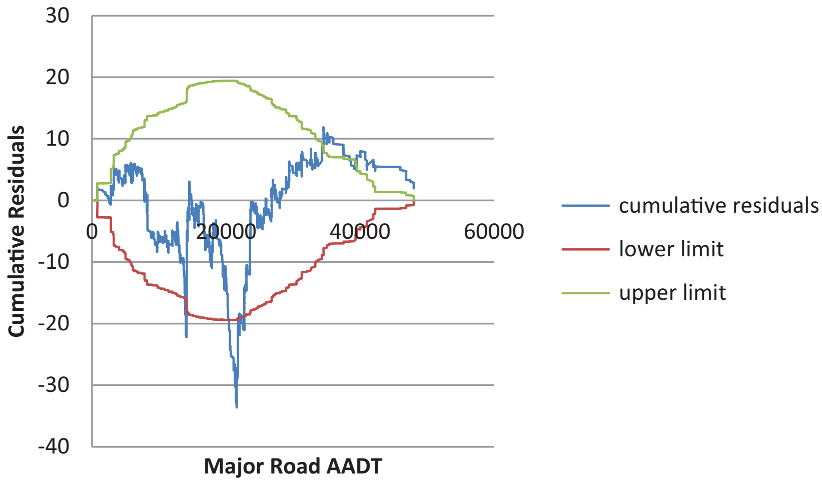


Figure F-2. Example of CURE plot.

- Step 5: For each site, calculate the cumulative squared residuals, $\sigma^2(n)$.
- Step 6: Sum the cumulative squared residuals over all sites, $\sigma^2(N)$.
- Step 7: For each site, estimate the variance of the random walk as:

$$\sigma^2 = \sigma^2(n)\left[1 - \frac{\sigma^2(n)}{\sigma^2(N)}\right]$$

- Step 8: For each site calculate the 95% confidence limits as:

$$Lower\ Limit = -1.96\sqrt{\sigma^2}$$

$$Upper\ Limit = +1.96\sqrt{\sigma^2}$$

- Step 9: Plot the cumulative residuals S(n) and the 95% confidence limits on the y-axis with the explanatory variable of interest on the x-axis.

An example CURE plot is shown in Figure F-2 for the variable major road AADT. This is for the model for pedestrian crashes for the refuge island treatment. In this example, the model is performing fairly well but does exhibit some bias by venturing outside the boundary limits around AADTs of 20,000 and above 35,000. The amount of bias is reasonably small in that the maximum deviation from zero of the cumulative residuals is approximately 32 while the number of pedestrian crashes in the data is 340.

While the CURE plot method works well for continuous variables, it is not applicable to variables with few categories, e.g., urban versus suburban area type or midblock versus intersection location. For such variables, a table can be produced showing the prediction bias for each level of the variable as shown in Table F-1. In this example, there are two categories of area type. As shown by the values of observed divided by predicted, the SPF is showing no bias between the two levels or area type. Where some bias appears evident, however, there is no statistical test to indicate if the biases are statistically significant.

Table F-1. Example of categorical variable results.

	Urban	Suburban
Observed/Predicted	1.00	1.00

APPENDIX G

NCHRP Project 17-56 Database Creation and Data Entry Methodology Notes

The following document was used as a guide for the completion of the database and to record/code observed site characteristic data on relevant treatment and comparison site features. The most recently available Google Earth Satellite overhead imagery and street-view photographs were used to the extent possible for selecting sites, where needed, and observing the relevant treatment or comparison site standards, characteristics, and measures. Additionally, QC/Kittelson photographs taken during the project's 2014 on-site pedestrian volume counts were used to verify, update, and augment site characteristic data captured from Google Earth imagery. As the data collection process continued, new columns were added for additional data and site characteristics required. Separate databases were created for treatment and comparison sites.

Site Characteristics/Feature Coding Instructions

Features List

1. Crosswalks
   a. no marked crosswalk
   b. white standard crosswalk
   c. yellow crosswalk
   d. staggered crosswalk
   e. ladder crosswalk
   f. zebra crosswalk
   g. piano crosswalk
   h. continental crosswalk
   i. double continental crosswalk
   j. diagonal crosswalk
   k. brick/block/stamped style crosswalk
   l. marked crosswalk unknown type
   m. raised crosswalk
2. Signs
   a. crosswalk warning sign
   b. children playing sign
   c. bicycle crossing sign
   d. other supplemental warning signs (including overhead signs)
   e. flashing beacon
   f. in-street sign
   g. school zone indication (sign or pavement marking)
   h. advisory speed signs
   i. driver speed feedback sign
   j. flashing LED border sign

3. Other Features
    a. school crossing guard
    b. markings for crosswalk ahead warning
    c. curb extension
    d. in-pavement warning lights
    e. post mounted delineator
    f. painted/flush median
    g. nearby traffic calming (e.g., speed humps)

Table G-1. Treatment sites methodology by column.

Column	Item	Description
A	Study ID	Study ID designation assigned by the project team. • Coding for treatment sites: the first three letters of the city/agency name followed by a three-digit ID number for the location (e.g., intersection) followed by a letter to denote the particular crossing. o Example: Phoenix site - PHO001A Crash data were collected and recorded in a different database and according to the applicable StudyID.
B	City	Location city for the site.
C	Status (definite, verify)	As the data collection process continued, some sites were excluded and some were added based on study requirements (e.g., installation dates 2010 or later, invalid intersection geometry, treatments no longer exist, unreliable or no crash or AADT data, could not collect ped-volume counts due to construction or other issues, unusual characteristics). The letter "D" denotes a confirmed site that has been fully verified as applicable for the study and has all required data available. Filter this column for "D" to observe all valid study sites.
D	County	The county jurisdiction in which the site is located (necessary for contacting agencies for AADT, crash. and other data at the site).
E	Place, town, or other possible jurisdiction	The place, township, or other jurisdictional level in which the site is located (necessary for contacting agencies for AADT, crash, and other data at the site).
F	Intersection Name	The current street names at the intersection or the main road only at a midblock location.
G	Midblock or intersection	M-Midblock I- Intersection
H	Site has ped-volume count	Y- Yes N- No
I	Site has AADT	Y- Yes N- No
J	Years of crash data available	The range of years for which crash data are available by city.
K	Transit/bus stop	Y- Yes N- No When selecting comparison sites or recording treatment and comparison site characteristics with Google Earth imagery, if the crossing was in close proximity to a transit or bus stop, the column was marked "Y."
L	Bus stop/route name	The number or name of the bus stop or route, as provided by Google Earth.
M	Street lighting	Y- Yes N- No
N	Unusual characteristics (geometry etc…)	Y- Yes N- No Treatment sites were screened for intersections that had unusual geometries or more than four legs, and if so they were marked with a "Y," which eliminated them from the study.
O	Road 1 Name 1	Name(s) or route(s) of road being crossed.
P	Road 1 Name 2	Secondary name(s) or route(s) of road being crossed (if applicable).
Q	Road 2 Name 1	Name(s) or route(s) of intersecting road, if treatment is installed at an intersection.
R	Road 2 Name 2	Secondary name(s) or route(s) of intersecting road, if treatment is installed at an intersection (if applicable).

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Table G-1. (Continued).

Column	Item	Description
S	Coordinates	Latitude/longitude coordinates of the crossing location, in decimal degrees.
T	Google map link	Hyperlink to the location of the crossing in Google Maps.
U	Baseline condition (NOTES)	A text description of the baseline condition of the crossing location before it received the safety treatment (or at time of treatment installation). Often includes a description of the type of crosswalk. No notes if the crosswalk was present prior to the year 2000.
V	Baseline condition	The feature code designation of the baseline condition of the crossing location before it received the safety treatment (or at time of treatment installation). Often includes the feature code for the type of crosswalk. If no pavement marking or crosswalk was present before the treatment was installed, then the coding "1A" for "no marked crosswalk" was used.
W	Earliest known year of baseline condition	The year that the crosswalk was visible on Google Earth imagery. If the crosswalk was visible prior to the year 2000, the year was noted as "pre-2000."
X	Condition before according to city	If any features were present before the earliest treatment installation according to the city (not Google Earth imagery), a description and feature code was noted here.
Y	Refuge island	Y- Yes N- No
Z	Continuous median	Y- Yes N- No
AA	Refuge island installation year	If refuge island is present, year when refuge island was installed. If no refuge island was installed at this location, enter n/a. Code as the year of installation (e.g., "2006") or a range of years ("2006-2008") if the exact year is unknown. When not sure when treatment originally installed, put in earliest known year according to Google Earth aerial imagery.
AB	Refuge island treatment leg of intersection	The leg of the intersection where the RI treated crosswalk is located, denoted by cardinal direction. If RIs are located at two legs of the crossing, these are noted as cardinal directions. If site is a midblock treatment, or no RI is at site, entered "n/a."
AC	RI width (ft)	The RI width in feet using the Google Earth aerial ruler tool.
AD	RI length (ft)	If the RI is located on a non-continuous median, the length of the island in feet is recorded using the Google Earth aerial ruler tool.
AE	Refuge island installation notes	Any special notes about the installation of the island. This only applies to characteristics of the island, not other countermeasures that were installed with it. That is handled in another variable. Variables noted were • Raised island • Cut-out • Diagonal cut-out • Flushed median • Staggered cut-out • Etc….
AF	Advanced stop/yield line presence	Y- Yes N- No
AG	Advanced stop installation year	If advance stop or yield line is present, year when advance line was installed according to city or Google aerial imagery. If no advance line was installed at this location, enter "n/a."
AH	Advanced stop/yield line type	Indication whether drivers are instructed to stop or yield, based on local statute or supplementary sign indication. Coding: S = Stop Y = Yield
AI	Advanced stop/yield sign type	Determined using Google Earth street-view or QC/Kittelson ped-volume photographs • No sign • Stop sign • Yield sign • "n/a" if no AS line is present
AJ	AS treatment leg of intersection	The leg of the intersection where the AS line treated crosswalk is located, denoted by cardinal direction. If AS lines are associated with crosswalks at two legs of the intersection, these are noted as cardinal directions. If site is a midblock treatment or no AS line is at site, entered "n/a."

Table G-1. (Continued).

Column	Item	Description
AK	Advanced stop/yield line notes	Any special notes about the installation of the advance line. This only applies to characteristics of the advance line, not other countermeasures that were installed with it. That is handled in another variable. Variables noted were • Shark tooth • Solid line • "n/a" if no AS line is present
AL	PHB presence	Y- Yes N- No
AM	PHB installation year	If PHB is present, year when PHB was installed. If no PHB was installed at this location, enter "n/a."
AN	PHB treatment leg of intersection	The leg of the intersection where the PHB treated crosswalk is located, denoted by cardinal direction. If PHBs are associated with crosswalks at two legs of the intersection, these are noted as cardinal directions. If site is a midblock treatment, or no PHB is at site, entered "n/a."
AO	PHB installation notes	Any special notes about the installation of the PHB. This only applies to characteristics of the PHB, not other countermeasures that were installed with it. That is handled in another variable. Example 1: "Supplemental sign to clarify what driver should do on flashing red."
AP	Other measures installed with HAWK or other pedestrian improvement (according to city)	Any other items installed with or as part of the PHB according to the city.
AQ	RRFB presence	Y- Yes N- No
AR	RRFB installation Year	If RRFB is present, year when RRFB was installed. If no RRFB was installed at this location, enter "n/a."
AS	RRFB treatment leg of intersection	The leg of the intersection where the RRFB treated crosswalk is located, denoted by cardinal direction. If RRFBs are associated with crosswalks at two legs of the intersection, these are noted as cardinal directions. If site is a midblock treatment, or no RRFB is at site, entered "n/a."
AT	RRFB installation notes	Any special notes about the installation of the RRFB. This only applies to characteristics of the RRFB, not other countermeasures that were installed with it. That is handled in another variable.
AU	Other countermeasures installed with primary project	Any other countermeasures or modifications installed at this location with the primary treatment, as reported by city (not observed by Google Earth).
AV	Other countermeasures installation year	Year of installation of the other countermeasures installed along with primary treatment.
AW	Other pedestrian safety devices found at location	Features without designated feature codes.
AX	Crossing guard	Y- Yes N- No If a crossing guard at site crosswalk was reported by city or seen on Google street-view photos.
AY	School crossing	Y- Yes N- No If indications of a school zone were seen on Google aerial imagery, street-view photos, QC/Kittelson ped-vol count site photos, or as reported by the city.
AZ	Reason for safety installations	If known, reason why the site was selected for safety installations as reported by city. If not, marked "unknown."
BA	Other pedestrian safety devices found at location (current)	Pedestrian safety devices with designated feature codes that were noted as currently being present at the site by Google street-view photos or QC/Kittelson ped-volume count site photos. Uses feature list codes.

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Table G-1. (Continued).

Column	Item	Description
BB	Other pedestrian safety device year & source	The year that the safety device was observed on streetview (SV) and QC/Kittelson photos (e.g., SV-2012 & QC-2014).
BC-BJ	Subsequent change/year of change	The oldest to newest observed change and year of change of site characteristics and features coded in the features list or noted as otherwise.
BK	Speed limit of road being crossed	The marked or indicated speed limit of the road being crossed by the treatment. As reported by city or observed on Google street-view. If no speed limit is observed or reported, marked “unknown.”
BL	Number of lanes on road being crossed	This is the total number of lanes (including turn lanes) that the crosswalk or crossing goes through. Determined from Google Earth aerial imagery. (If there was a center or right/left turn lane, it was noted in the notes column.)
BM	Crosswalk length in feet	As measured with the Google Earth ruler tool, this is the total distance in feet of the crossing.
BN	Presence of median on road being crossed	Y- Yes N- No Indicates if a median is or is not present at the crossing.
BO	Crosswalk type	Using the feature list coding, indicates what type of crosswalk is currently present at the crossing. If no crosswalk or crosswalk markings are present, the code “1A” is used.
BP	Urban vs suburban	Indicated if site is located in urban or suburban area type. (Urban was marked if the site is within the city CBD; or by use of Google Earth aerial imagery is located in a dense and urban zone.)
BQ	One-way vs two-way	Indicates if the road being crossed is one- or two-way traffic.
BR	Notes	Includes any notes (center turn lane, bike lanes, or interesting and unique features at the site in regard to geometry, crossing, characteristics, history, and other features).
BS	Two-stage crossing installation year	If a two-stage crossing is present, indicates the year of installation as determined by Google Earth aerial imagery or reported by city. Two-stage crossing has an RRFB, PHB, or flashing LED border sign and the RI is staggered. Each stage has a pedestrian push-button activation for the flashing LED border sign.
BT	AADT major rd site ID	If a site ID associated with the study site location is provided with the source city’s AADT data, it is noted here. If not, then it is marked “not provided.”
BU	AADT data source	This is the jurisdiction that provided the AADT data or from which they were found.
BV	Possible anomalous AADT data	If the only data available for the site were estimates from the data source contacts or from the source data, or if there were unusual characteristics about the data, it is noted here. If not, it is marked “no.”
BW	AADT count timeframe	This indicates the type of count as indicated by the data source city (e.g., AADT, 24-hour count, average daily count, 24-hour weekday, etc.)
BX-CK	Major rd AADT/major rd AADT year	This is the AADT count on the road being crossed and the date of the count (if specific day and month are provided, they are noted). Data are recorded from most recent to oldest.
CJ	Minor rd site ID	If the site was at an intersection and the minor road(s) (road not being crossed) has AADT available, the site ID is noted here. If no data at the minor road are available, it is marked “none available.”
CK-CR	Minor rd AADT/minor rd AADT year	This is the AADT count on the road not being crossed and the date of the count (if specific day and month are provided, they are noted). Data are recorded from most recent to oldest.
CS	QC ped count total	The pedestrian volume count from the QC/Kittelson on-site video counts.
CT	QC number of hours counted	The number of hours that QC/Kittelson counted pedestrians on site (1-2).
CU	QC count start time	The time of day the QC/Kittelson on-site video count started.
CV	QC count date	The date that QC/Kittelson conducted the on-site video count.
CW	QC count notes	Any notes from QC/Kittelson about the count (usually to explain why a count could not be conducted, i.e., construction, no access, site now signalized, treatment removed or changed, etc.)
CX-CY	Ped volume (not QC)/ped volume year (not QC)	If there was a previous pedestrian volume count available, then QC/Kittelson did not conduct an on-site video count and the previous count data were recorded here, along with the year of the count (if day and month were available they were also noted).

Table G-1. (Continued).

Column	Item	Description
CZ	Number of hours counted	The duration in number of hours of the previous count.
DA	Count times	The time of day of the previous count.
DB	Projected expanded pedestrian count ADT 12hr*	Expanded total pedestrian count ADT for all 1-2 hr counts attained by QC/Kittelson on-site counts. Used calculated seasonal expansion factors from analysis of Charlotte data and other studies. (Note: previous 12 hour counts from City of St. Petersburg were not expanded.)
DC	Projected expanded pedestrian count ADT 24hr**	Expanded total pedestrian count for column DB total to projected expanded 24-hr pedestrian volume count ADT.
DD-DH	Install in 2010-2014	FALSE TRUE Filter cells to indicate if any of the four treatments were installed in 2010-2014. If so, these sites were eliminated from the study.

Table G-2. Comparison sites methodology by column.

Column	Item	Description
A	Study ID	Study ID designation assigned by the project team. • Coding for comparison sites: the first three letters of the city/agency name, followed by "C" (to indicate that it is a comparison site), followed by a three-digit ID number for the location (e.g., intersection). Example: Phoenix comparison site - PHOC001. Crash data were collected and recorded in a different database and according to the applicable StudyID.
B	City	Location city for the site.
C	Status (definite, verify)	As the data collection process continued, some sites were excluded and some were added based on study requirements (e.g., invalid intersection geometry, newly installed treatment at site, site has raised median island, unreliable or no crash or AADT data, could not collect ped-volume counts due to construction or other issues, unusual characteristics). The letter "D" denotes a confirmed site that has been fully verified as applicable for the study and has all required data available. Filter this column for "D" to observe all valid study sites.
D	County	The county jurisdiction in which the site is located (necessary for contacting agencies for AADT, crash and other data at the site).
E	Place, town or other possible jurisdiction	The place, township, or other jurisdictional level in which the site is located (necessary for contacting agencies for AADT, crash and other data at the site).
F	Midblock or intersection	M-Midblock I- Intersection
G	Untreated raised median	Y- Yes N- No If the site had a untreated raised median island and the crossing, it was invalidated as a comparison site and eliminated from the study.
H	Site has ped-volume count	Y- Yes N- No
I	Site has AADT	Y- Yes N- No
J	Years of crash data available	The range of years for which crash data is available by city.
K	Transit/bus stop	Y- Yes N- No When selecting comparison sites or recording treatment and comparison site characteristics with Google Earth imagery, if the crossing was in close proximity to a transit or bus stop, the column was marked "Y."
L	Bus stop/route name	The number or name of the bus stop or route, as provided by Google Earth.
M	Street lighting	Y- Yes N- No

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Table G-2. (Continued).

Column	Item	Description
N	Unusual characteristics (geometry, etc.)	Y- Yes N- No Comparison sites were screened for intersections that had unusual geometries or more than four legs, and if so they were marked with a "Y," which eliminated them from the study.
O	Road 1 Name 1	Name(s) or route(s) of road being crossed.
P	Road 1 Name 2	Secondary name(s) or route(s) of road being crossed (if applicable).
Q	Road 2 Name 1	Name(s) or route(s) of intersecting road, if treatment is installed at an intersection.
R	Road 2 Name 2	Secondary name(s) or route(s) of intersecting road, if treatment is installed at an intersection (if applicable).
S	Coordinates	Latitude/longitude coordinates of the crossing location, in decimal degrees.
T	Google map link	Hyperlink to the location of the crossing in Google maps.
U	Other pedestrian safety devices found at location (current)	Pedestrian safety devices with designated feature codes that were noted as currently being present at the site by Google street-view photos or QC/Kittelson ped-volume count site photos. Uses feature list codes.
V	Other pedestrian safety device year & source	The year that the safety device was observed on streetview (SV) and QC/Kittelson photos (e.g., SV-2012 & QC-2014).
W-AD	Subsequent change/year of change	The oldest to newest observed change and year of change of site characteristics and features coded in the features list or noted as otherwise.
AE	Speed limit of road being crossed	The marked or indicated speed limit of the road being crossed by the treatment. As reported by city, or observed on google street-view. If no speed limit is observed or reported, marked "unknown."
AF	Number of lanes on road being crossed	This is the total number of lanes (including turn lanes) that the crosswalk or crossing goes through. Determined from Google Earth aerial imagery. (If there was a center or right/left turn lane, it was noted in the notes column.)
AG	Crosswalk length in feet	As measured with the Google Earth ruler tool, this is the total distance in feet of the crossing.
AH	Crosswalk type	Using the feature list coding, indicates what type of crosswalk is currently present at the crossing. If no crosswalk or crosswalk markings are present, the code "1A" is used.
AI	Urban vs suburban	Indicated if site is located in urban or suburban area type. (Urban was marked if the site is within the city CBD; or by use of Google Earth aerial imagery is located in a dense and urban zone.)
AJ	One-way vs two-way	Indicates if the road being crossed is one- or two-way traffic.
AK	School crossing	Y- Yes N- No If indications of a school zone were seen on Google aerial imagery, street-view photos, QC/Kittelson ped-vol count site photos, or as reported by the city.
AL	Name of school near site	If the name of the school could be determined from Google imagery or reported by city, it was noted here. If not, "n/a" is marked.
AM	Notes	Includes any notes (bike lanes or interesting and unique features at the site in regards to geometry, crossing, characteristics, history, and other features).
AN	AADT major rd site ID	If a site ID associated with the study site location is provided with the source city's AADT data, it is noted here. If not, then it is marked "not provided."
AO	AADT data source	This is the jurisdiction that provided the AADT data or from which the data were found.
AP	Possible anomalous AADT data	If the only data available for the site were estimates from the data source contacts or from the source data itself, or if there were unusual characteristics about the data, it is noted here. If not, it is marked "no."
AQ	AADT count timeframe	This indicates the type of count as indicated by the data source city. (e.g., AADT, 24-hour count, average daily count, 24-hour weekday, etc.).
AR-BE	Major rd AADT/major rd AADT year	This is the AADT count on the road being crossed and the date of the count (if specific day and month are provided, they are noted). Data are recorded from most recent to oldest.
BF	Minor rd site ID	If the site was at an intersection and the minor road(s) (road not being crossed) has AADT available, the site ID is noted here. If no data at the minor road are available, it is marked "none available."

Table G-2. (Continued).

Column	Item	Description
BG-BN	Minor rd AADT/minor rd AADT year	This is the AADT count on the road not being crossed and the date of the count (if specific day and month are provided, they are noted). Data are recorded from most recent to oldest.
BO	QC ped count Total	The pedestrian volume count from the QC/Kittelson on-site video counts.
BP	QC number of hours counted	The number of hours that QC/Kittelson counted pedestrians on site (1-2).
BQ	QC count start time	The time of day the QC/Kittelson on-site video count started.
BR	QC count date	The date that QC/Kittelson conducted the on-site video count.
BS	QC count notes	Any notes from QC/Kittelson about the count (usually to explain why a count could not be conducted, i.e., construction, no access, site now signalized, treatment removed or changed, etc.).
BT-CB	Ped volume (not QC)/number of hours Counted/ped volume year (not QC)	If there was a previous pedestrian volume count available, then QC/Kittelson did not conduct an on-site video count, and the previous count data were recorded here, along with the number of hours counted and the year of the count (if day and month were available they were also noted).
CC	Count times	The time of day of all previous counts.
CD	Projected expanded pedestrian count ADT 12hr	Expanded total pedestrian count ADT for all 1-2 hr counts attained by QC/Kittelson on-site counts. Used calculated seasonal expansion factors from analysis of Charlotte data and other studies. (Note: previous 12 hour counts from City of Charlotte were not expanded.)
CE	Projected expanded pedestrian count ADT 24hr	Expanded total pedestrian count for column DB total to projected expanded 24-hr pedestrian volume count ADT.

Pedestrian 24-Hour ADT Expansion Method

Step 1: Expansion to Projected 12-Hour Counts

1—All sites without previous count data provided by the city had in-person pedestrian volume counts conducted by Kittelson during 2014. These were all 1- or 2-hour counts, with start times at 1500–1700, and during June–November 2014. The seasonal expansion factors (Table E-3 in Appendix E) were used to expand these counts to projected 12-hour counts. Two-hour counts were first halved to get the 1-hour volume and then multiplied by the appropriate expansion factor to get the estimated 12-hour volume.

2—There were 28 treatment sites from St. Petersburg, FL, and 83 comparison sites from Charlotte, NC, that had previous 12-hour counts. The most recent year's count was used, and these were not adjusted.

Step 2: Expansion to Projected 24-Hour Pedestrian ADT

1—Adjustment factors by time of day and area type used to obtain estimated pedestrian ADT from Table 12 (p. 67) of Zegeer, C. V., Stewart, J. R., Huang, H. H., Lagerwey, P. A., Feaganes, J., & Campbell, B. J. (2005). *Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations: Final Report and Recommended Guidelines* (No. FHWA-HRT-04-100) were used to expand all 12-hour adjusted and non-adjusted counts to estimated 24-hour pedestrian ADTs. The 12-hour count columns were divided by the 0.86 factor used in the Zegeer et al. (2005) report to arrive at the adjusted 24-hour pedestrian ADT numbers.

APPENDIX H

Effects of Pedestrian Treatments at Unsignalized Crossings: A Summary of Available Research

Introduction

This appendix reviews and summarizes research studies that have evaluated the safety effects of selected types of pedestrian crossing treatments at unsignalized crossing locations. Specifically, this appendix is the result of Task 2 of NCHRP Project 17-56, "Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments." The following types of pedestrian treatments are included:

- Unsignalized pedestrian crosswalk signs and pavement markings, including advanced yield or stop markings and signs;
- High-visibility crosswalk marking patterns;
- High-intensity activated crosswalk (HAWK) signals;
- Rectangular rapid flashing beacons (RRFBs);
- In-pavement warning lights;
- Pedestrian refuge areas;
- Curb extensions, and
- Raised pedestrian crosswalks.

Although NCHRP Project 17-56 focused on the crash modification factors (CMFs) of those pedestrian treatments, this literature review includes not only crash-based studies, but also studies which investigated behavioral and operational measures of effectiveness (e.g., pedestrian/vehicle conflicts, vehicle speeds, driver yielding behavior). This is because there are very few research studies that have been able to use pedestrian crashes in their evaluation. Specifically, sample size issues may arise since pedestrian crashes usually do not cluster in large numbers at a single site; thus, a larger number of treatment and comparison sites may be needed to get statistical significance compared to evaluation of countermeasures for vehicle/vehicle crashes. Also, studies that use behavioral measures may at least be useful in gaining insights into potential safety behaviors by motorists and pedestrians that result from the treatments. However, the analysis performed in NCHRP Project 17-56 is strictly based on crash effects (CMFs) of the selected treatments.

The following is a summary of available research for each of the eight pedestrian treatments. At the end of this appendix, a set of summary tables provides an overview of the studies and results of the research for each of the eight treatments of interest, which are listed above. The primary source used to compile this literature review was a UNC HSRC produced draft report of the *Evaluation of Pedestrian-Related Roadway Measures: A Summary of Available Research* by Mead, Zegeer, and Bushell[1]. Selected sections from this resource were extracted or adopted for use in this literature review.

[1]Mead, J., C. Zegeer, and M. Bushell (2013). *Evaluation of Pedestrian-Related Roadway Measures: A Summary of Available Research*. Chapel Hill, North Carolina: Federal Highway Administration.

Treatment 1. Unsignalized Pedestrian Crosswalk Signs and Pavement Markings, including Advanced Yield or Stop Markings and Signs

Signing

In-Street Pedestrian Signs

An early version of in-street pedestrian signs was studied as part of a 2000 report by Huang, Zegeer, Nassi, and Fairfax published by the Federal Highway Administration. The treatment consisted of pedestrian safety cones with the message "State Law—Yield to Pedestrians in Crosswalks in Your Half of the Road," which were installed in New York State and Portland, Oregon. The cone was developed in 1996 and designed to be placed in the middle of a crosswalk. The use of the cones was evaluated at six sites in New York State and one site in Portland, Oregon. Pre- and post-treatment data were collected for seven sites, and the following measures of effectiveness (MOEs) were used: (1) percentages of pedestrians for whom motorists yielded, (2) percentage of motorists who yielded to pedestrians, (3) percentage of pedestrians who hesitated, rushed, or aborted in crossing, and (4) percentage of pedestrians crossing in the crosswalk. Of the three treatments that were evaluated in the report, pedestrian safety cones were the most successful in increasing the percentage of yielding drivers. When all study sites were combined, motorist yielding increased from 69.8 percent pre-treatment to 81.2 percent post-treatment, which is significant at the 0.001 level. Pedestrians who ran, aborted, or hesitated decreased, but the decrease was not statistically significant. The authors concluded that pedestrian safety cones were generally effective in increasing the percentages of pedestrians for whom motorists yielded (*1*).

A 1999 article sponsored by the Federal Highway Administration described the 2-year evaluation of then-experimental in-street yield-to-pedestrian signs installed at various locations throughout the city of Madison, Wisconsin, in 1997. Three test sites were used in the first year of

Source: pedbikeimages.org

Figure H-1. Prototype in-street yield to pedestrians sign used in the 1990s.

Source: Kannel et al., 2000. (*3*)

Figure H-2. Two types of impactable yield signs.

the experiment, while five sites were used in the second year. The researchers were able to conduct before-after analysis at two of the sites and after-only analysis at two of the sites. The researchers used motorist yielding to pedestrians in the crosswalk as the measure of effectiveness (MOE). The proportion of drivers yielding was analyzed using a Z-test for proportions in the before-after study, and results indicated a statistically significant increase in yielding behavior at sign locations. Because of differences between test site geometry and results, the authors called for further research on the effectiveness of the signs. The City of Madison Traffic Engineering staff reported positive feedback from pedestrians regarding the signs, as well as citizen involvement in reporting damaged or missing signs at study locations (*2*).

The following year, a 2000 report sponsored by the Iowa Department of Transportation summarized the results of placing in-street yield-to-pedestrian signs at three sites throughout Cedar Rapids, Iowa. The researchers measured vehicle speed, percentage of vehicles yielding to pedestrians, and percentage of failed or rushed crossings before and after the signs were installed. Results indicated that the presence of the signs had a positive effect on driver behavior, leading to speed reductions at one site and increased driver yielding at another. Similar to the Madison study, results were not uniform, with overall roadway configuration affecting driver behavior (*3*).

A 2003 paper by Kamyab, Andrle, Kroeger, and Heyer discussed the effects of installing a removable pedestrian island and pedestrian crossing signs on a two-lane highway in rural Mahnomen County, Minnesota. Researchers collected pre- and post-treatment speed data to assess short and long-term effects of the treatments. Results showed a statistically significant reduction in mean speeds and increase in speed-limit compliance at the treatment site for both the long- and short term (*4*).

With the goal of improving pedestrian safety in Pennsylvania, the Pennsylvania Department of Transportation organized a program to distribute Yield-to-Pedestrian Channelizing Devices (YTPCD) to interested municipalities. A 2006 report summarized a safety evaluation of the in-roadway yield-to-pedestrian signs installed at 21 midblock and intersection sites in four Pennsylvania cities. The researchers collected pre- and post-treatment driver and pedestrian behavior data at treatment and potential spillover sites. Driver yielding to pedestrians increased by 30 to 40 percent at intersections and by 17 to 24 percent at treated crosswalk sites. Pedestrian yielding to motorists decreased by 11 to 16 percent at intersections and by 8 to 13 percent at treated crosswalk sites. A statistically significant increase in pedestrians using the crosswalks

Source: Kamyab et al., 2003. (*4*)

Figure H-3. An in-street pedestrian sign used with a removable crossing island in Minnesota.

Table H-1. Mean driver speeds before and after the installation of an in-street pedestrian sign and removable pedestrian island.

	Observed Traffic	Mean Speed (mi/h)	t-statistic	Significant (95%)	Speed Compliance %	t-statistic	Significant (95%)
				Passenger Cars			
Before	1152	34.8	--	--	31	--	--
After-1	1067	29.5	13.49	Yes	58	-12.80	Yes
After-2	1331	30.7	11.05	Yes	51	-10.01	Yes
				Nonpassenger Cars			
Before	71	37.4	--	--	24	--	--
After-1	46	28.8	4.11	Yes	65	-4.42	Yes
After-2	60	29.5	4.01	Yes	57	-3.84	Yes
				All Vehicles			
Before	1237	35	--	--	30	--	--
After-1	1113	29.5	14.20	Yes	58	-13.68	Yes
After-2	1392	30.6	11.02	Yes	51	-10.85	Yes

Source: Kamyab et al., 2003. (*4*)

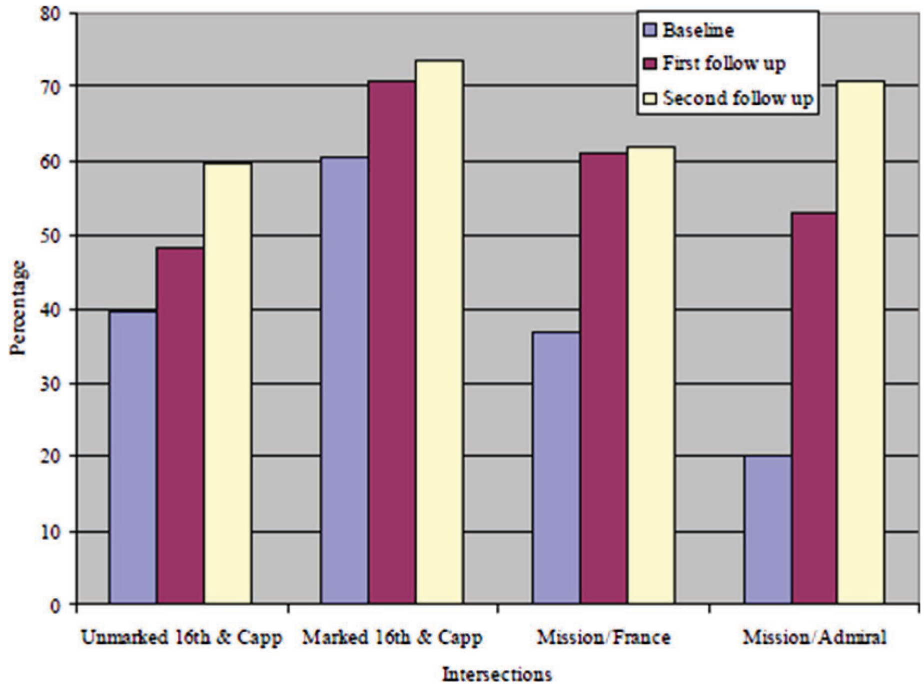
was also observed. The researchers concluded that the signs were more effective at intersections than at midblock crossings, but that the in-roadway yield-to-pedestrian signs had an overall positive effect on increasing pedestrian safety. They also found that follow-up data collection was complicated by damaged, moved, or missing signs (*5*).

A 2007 study by Banerjee and Ragland used video recordings to examine the changes in driver yielding rates as a result of impactable yield signs installed at three intersections in San Francisco. The researchers concluded that a large increase in yielding did occur following the installation of the signs. Figure H-5 shows increases in percentages of vehicles that yielded at each of the four sites (*6*).

A 2007 report by Ellis, Van Houten, and Kim studied the effect of placing an in-roadway "Yield to Pedestrians" at different distances in advance of a crosswalk. Three marked crosswalks were chosen in Miami Beach, Florida, and baseline data about pedestrian and driver behavior were collected. To test optimal sign placement, signs were placed at one or all three of the crosswalks

Source: pedbikeimages.org

Figure H-4. In-roadway pedestrian sign installed mid-crosswalk.



Source: Banerjee and Ragland, 2007. (*6*)

Figure H-5. Graph showing the percentage of yielding motorists before and after the installation of impactable yield signs in San Francisco, California.

on a rotating, random order either at the crosswalk itself, 20 feet in advance of the crosswalk, or 40 feet in advance of the crosswalk. A z-test for comparing proportions was utilized to analyze pedestrian and driver behavior as a result of the sign placement. While researchers determined that the presence of the signs alone was highly effective at increasing the percentage of drivers who yielded to pedestrians, the location and number of in-roadway signs placed in a crosswalk approach was not a critical factor in determining the magnitude of this outcome (*7*).

Figure H-6. Two placements of in-roadway pedestrian signs as tested in a Miami, Florida, evaluation study by Ellis et al., 2007. (7)

Source: Federal Highway Administration.

Figure H-7. Two pedestrians use a high-visibility yellow crosswalk that has been enhanced with an in-street pedestrian sign in San Francisco, California.

A 2009 evaluation of the Pedsafe II project in San Francisco used video observation and intercept surveys to collect pre- and post-treatment data to evaluate the effectiveness of 13 countermeasures deployed at 29 sites throughout San Francisco, California. As part of the project, in-street "Yield-to-Pedestrian" signs were installed in the medians of uncontrolled crosswalks. At the four crosswalks where in-street pedestrian signs were installed, there was a significant increase in the percentage of yielding drivers, from 53 percent pre-treatment to 68 percent post-treatment. Of the 13 countermeasures that were tested, in-street "Yield-to-Pedestrian" signs were one of the six countermeasures considered the most effective in increasing pedestrian safety (*8*).

A 2014 presentation by Bennett, Manal, and Van Houten at the Transportation Research Board conference evaluated the use of in-street pedestrian crossing signs in gateway configurations at locations in East Lansing, Michigan. The gateway configuration consists of one sign in the middle of the roadway, and two signs installed in the gutter pans on each side of the roadway. Three conditions were alternated and evaluated at the two study sites: no in-street sign (baseline), one in-street sign in the median (typical configuration), and three in-street signs in the gateway configuration. For each data collection session, staged pedestrian crossings were conducted while research assistants measured motorist yielding behavior. At both sites, motorist yielding averaged 25 percent when no signs were present. The presence of one in-street sign was associated with motorist yielding of 57 percent at both locations. The gateway (three signs) configuration was associated with 79 percent and 82 percent at the two locations. Thus, the gateway configuration using three signs was associated with the highest motorist yielding rates (*9*).

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Other Signs

Evaluation of pedestrian signs has shown them to be of moderate efficacy in increasing pedestrian safety, with some variation across treatments and site characteristics. A 2006 report by Fitzpatrick et al. suggested that some of the factors that influenced driver yielding at sign locations included the speed and volume of the roadway and whether the motorists perceived yielding as a courtesy or the law (*1*). Signs that are enhanced with flashing beacons or lights have been shown to be more effective when activated manually or automatically by pedestrians than those that blink continuously (*1*). The following paragraphs give an overview of some of the sign-related research and evaluation from the past 20 years. More information about in-street pedestrian signs can be found in the section of the same name.

In the 1990s, a new manufacturing process allowed for the development of high-visibility, "fluorescent strong yellow-green" (SYG) sign material. In 1996, Clark, Hummer, and Dutt evaluated the performance of pedestrian warning signs that used the new design at sites in central North Carolina. The use of this new sign was associated with increased numbers of cars that slowed down or stopped for pedestrians, although there was no decrease in conflict events following sign installation (*2*).

In 1998, Van Houten, Healey, Malenfant, and Retting evaluated the effects of two types of experimental signs on motorist yielding behavior. The first was a pictograph of a walking pedestrian that was added to a pedestrian-activated amber flashing beacon suspended over the roadway at the crossing site. It was coupled with a "Yield When Flashing" sign placed 50 m ahead of the crosswalk. Results indicated that both measures were effective in increasing motorist yield percentage, with the most effective treatment being the combination of the two. Only the "Yield When Flashing" sign was effective in reducing vehicle-pedestrian conflicts; the researchers theorized it was a result of the sign's placement within adequate stopping distance of the crosswalk (*3*).

In 1999, Nitzburg and Knoblauch studied the effectiveness of internally illuminated overhead crosswalk signs that were installed in conjunction with high-visibility crosswalks at two midblock crossing locations in Clearwater, Florida. Using case-control research design, they compared motorist and pedestrian behavior at the treatment sites with two similar sites, one that featured standard pedestrian crossing signage and crosswalk design, and one that had no crosswalk. The researchers found that during the day, drivers at the experimental crossing locations were 30–40 percent more likely to yield than drivers at the control locations. At night, there was a smaller and statistically insignificant increase in driver yielding of 8 percent. There was a significant increase in pedestrians using the crosswalk at the treatment sites compared to control sites. Although the individual effects of having the signs in place could not be analyzed

Source: Huang et al., 2000.

Figure H-8. An overhead crosswalk sign used in conjunction with double bar pair crosswalk markings and pedestrian crossing signs in Seattle, Washington.

separately from the high-visibility crosswalk, the researchers concluded that the treatments had a positive effect on pedestrian safety at the two intersections that were studied (*4*).

In 2000, the Federal Highway Administration published a report that evaluated two types of innovative pedestrian signs that were tested in Seattle and Tucson. Pre- and post-treatment data were collected for all sites, and the following measures of effectiveness (MOEs) were used: (1) percentages of pedestrians for whom motorists yielded; (2) percentage of motorists who yielded to pedestrians; (3) percentage of pedestrians who hesitated, rushed, or aborted in crossing; and (4) percentage of pedestrians crossing in the crosswalk (*5*).

The first of the treatments was an overhead, yellow crosswalk sign installed in Seattle, Washington. Before-after data were collected at a single intersection, and analysis of results showed an increase in driver yielding from 45.5 percent before installation to 52.1 percent, which was significant at the 0.06 level. Following the installation of the sign, there was a statistically significant decrease in the percentage of pedestrians who ran, aborted, or hesitated in crossing. The researchers concluded that the overhead crosswalk sign was effective at encouraging driver yielding behavior (*5*).

The second of the treatments studied was a pedestrian-activated "Stop for Pedestrian in Crosswalk" overhead sign installed in Tucson, Arizona. The sign, activated by a pedestrian push button, can be seen to the right in Figure H-9. Two sites were studied. It was found that following the installation of the signs, motorist yielding to pedestrians decreased from 62.9 percent to 51.7 percent. The percentage of pedestrians who ran, aborted, or hesitated decreased from 16.7 percent to 10.4 percent. Both decreases were statistically significant. It was theorized that installing the devices on arterial roads with speed limits of 40 mi/h may have limited their effectiveness, and the authors concluded by giving several modifications to the design and test conditions that might improve treatment performance (*5*).

Neither of the two treatments led to a statistically significant increase in crosswalk use; however, the authors concluded that the overhead crosswalk sign and pedestrian regulatory sign were generally effective in increasing the percentages of pedestrians for whom motorists yielded. They cautioned that site characteristics would need to be taken into account when choosing or designing treatments to draw motorists' attention to pedestrians in crosswalks (*5*).

Source: Huang et al., 2000. (*5*)

Figure H-9. Pedestrian regulatory signs used in Tucson, Arizona, in the 1990s.

In 2002, a *Transportation Research Record* article by Van Houten, McCusker, Huybers, Malenfant, and Rice-Smith gave the results of experiments that studied the effects of advance yield markings and fluorescent yellow-green RA 4 signs at 24 rural and urban crosswalks throughout Nova Scotia, Canada. The signs featured the message "yield here to pedestrians," using the yield symbol and an arrow pointing in the direction of the crosswalk on a rectangular, fluorescent yellow-green sign. Once baseline data were collected for all 24 crosswalks, they were put into treatment groups of 4, with one of the groups serving as a control throughout the experiment. The other three treatments consisted of (1) advance yield line markings with white-background "yield here to pedestrian" signs, (2) fluorescent yellow-green "yield here to pedestrian" signs, and (3) advance yield line markings with fluorescent yellow-green "yield here to pedestrian" signs. Follow-up data were collected at 6 months following treatment installation. Results showed that there was no reduction of vehicle-pedestrian conflicts when the more conspicuous fluorescent yellow-green sign was used instead of the white sign. However, the average number of vehicle-pedestrian conflicts decreased from 11.1 percent and 12.8 percent to 2.7 percent and 2.3 percent, respectively, at sites with the advance yield bar and either a white or fluorescent sign. Advanced stop lines were associated with a statistically significant increase in motorist yielding from 69 percent to 85 percent. The authors conclude by recommending the installation of advanced yield markings 7 m to 18 m in advance of the crosswalk, in order to better increase pedestrian visibility of oncoming vehicles when crossing (*6*).

A 2009 evaluation of the Pedsafe II project in San Francisco used video observation and intercept surveys to collect pre- and post-treatment data to evaluate the effectiveness of 13 countermeasures deployed at 29 sites throughout San Francisco, California. Two types of signs were installed: portable changeable message speed-limit signs used at midblock locations and "Turning Traffic Must Yield to Pedestrians" signs installed at the corners of intersections. At the midblock locations where portable changeable message speed-limit signs were placed, researchers found a significant reduction in vehicle speeds, by between 1-6 mi/h. At the four intersections where "Turning Traffic Must Yield to Pedestrians" signs were installed, there was a small, but significant increase in the percentage of drivers yielding at all four corners. Of the 13 countermeasures that were tested, these two types of signs were among the six countermeasures considered the most effective in increasing pedestrian safety (*7*).

Source: Lalani, 2001. (*8*)

Figure H-10. A flashing beacon used in conjunction with a pedestrian crossing sign in Austin, Texas.

A 2011 Vermont Agency of Transportation (VTRANS) report described the agency's experience with installing, evaluating, and maintaining the SmartStud in-pavement crosswalk lighting system and BlinkerSign, a sign equipped with LED lights. In 2006, VTRANS installed and evaluated SmartStud at a crosswalk in Hartford, Vermont. While the results of a pre- and post-treatment analysis revealed that the SmartStud system was effective in increasing pedestrian safety, several of the markers failed as a result of damage from snowplows and vehicles. As a result, in 2008, VTRANS decided to install BlinkerSigns, a type of experimental flashing LED traffic sign that used the existing SmartStud wiring system. The system is activated by pushing a SmartButton or by applying weight to a SmartPed sensor located underfoot. The 2005 pre-SmartStud baseline

Source: Kipp and Fitch, 2011. (*9*)

Figure H-11. A pedestrian sign with blinking lights installed at a crosswalk.

data were used and new data were collected to evaluate the BlinkerSign. The researchers found that yielding compliance increased by 23 percent on average following the installation of the BlinkerSign, compared to 13 percent following the installation of SmartStud. Both systems had a comparable effect on approach speeds, leading to a decrease in average driver speed in five of the eight studied scenarios. At 2 years following its installation, BlinkerSign has not required any additional maintenance (*9*).

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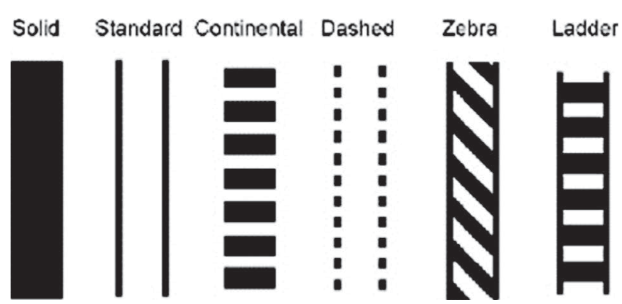
Marked Crosswalks and Enhancements

The marking of crosswalks at uncontrolled locations, locations where no traffic signals or stop signs exist on the approach at either intersection or midblock locations, has been the subject of debate in the United States. Recent safety research on crosswalks, as discussed below, has helped to resolve some of the controversy on this issue.

Marked crosswalks are typically installed at signalized intersections, in school zones, and at unsignalized intersections. The MUTCD defines three types of crosswalk markings: standard



Source: Zegeer et al., 2004. (*3*)

Figure H-12. Examples of crosswalk marking patterns.

parallel lines, ladder or continental stripes, and diagonal stripes (*1*). A 2002 study by Zegeer et al. found no statistically significant difference in pedestrian crash risk for various types of crosswalk markings (standard parallel lines, ladder, zebra, or continental style). Crosswalks may be raised ("speed tables") or used in conjunction with supplemental signing, in-pavement flashing lights, overhead flashers, nighttime lighting, pedestrian refuge islands, signalization, and/or other devices.

Several studies prior to comprehensive studies by Zegeer et al. in 2002 and Knoblauch et al. in 2000 produced a wide range of results concerning the safety effects of marked vs. unmarked crosswalks. However, none of these earlier studies attempted to analyze the effects of marked vs. unmarked crosswalks specifically for different numbers of lanes, traffic volume, or other roadway features.

A number of studies conducted between 1972 and 2000 concluded that pedestrian crashes were higher in marked crosswalks compared to unmarked crosswalks. For example, an often-cited 1972 San Diego study by Herms concluded that crashes on marked crosswalks were twice as frequent per unit of pedestrian volume compared to unmarked crosswalks (Herms, 1972 as cited in [*4*]). Herms looked at 400 intersections in the city, each of which had one marked and one unmarked crosswalk leg on the same street. In an earlier version of the same study (Herms, 1970), the author mentioned San Diego's 1962 warrants for determining where to paint crosswalks. The city's warrants required marking crosswalks when traffic gaps were inadequate, pedestrian volume was high, speed was moderate, and/or there were other relevant factors such as previous crashes. These criteria suggest that crosswalks in San Diego were painted where the conditions were already most conducive to pedestrian crashes or which already had a history of pedestrian crashes.

In 1974, Gurnett described a project in which painted crosswalk stripes were removed from three locations because of a recent bad crash history (Gurnett, 1974 as cited in [*4*]). There were fewer crashes after removal of the stripes, but these findings might simply be due to regression-to-mean, since the only sites that were "treated" (i.e., crosswalks were removed) were those that had a recent history of pedestrian crashes.

In 1983, Tobey et al. examined crashes at both marked and unmarked crosswalks as a function of pedestrian volume (P) multiplied by vehicle volume (V) and, unlike some of the previous studies cited, reported fewer accidents at marked crosswalks than at unmarked ones (Tobey et al., 1983 as cited in [*4*]). However, this may be due to the fact that Tobey's study included signalized as well as uncontrolled crossings, and it is likely that more marked crosswalks were at controlled locations than unmarked crosswalks were. It should be mentioned that the study methodology was designed to determine the pedestrian crash rate for a variety of human and location conditions, but was not specifically intended to quantify the isolated safety effects of marked vs. unmarked crosswalks.

In 1994, Gibby et al. analyzed crashes at 380 unsignalized highway intersections in California from among 10,000 candidate intersections throughout the state (Gibby et al., 1994 as cited in [*4*]). Crash rates per pedestrian–vehicle volume were two or three times higher in marked than in unmarked crosswalks at these sites. Like other older studies, this study combined all sites with marked crosswalks and unmarked crosswalks, and did not conduct a separate analysis for different cross sections, traffic volumes, and other roadway features.

In 2000, Jones and Tomcheck evaluated pedestrian crashes at crosswalks at unsignalized arterial intersections in Los Angeles to test the validity of the city's crosswalk policies. The study attempted to determine whether removing a crosswalk marking reduced pedestrian crashes at such locations, and/or increased pedestrian crashes at adjacent unprotected sites. Jones and Tomcheck analyzed pedestrian crashes at 104 unsignalized intersections on arterials where parallel-line crosswalks had been removed due to resurfacing, rather than at sites with pedestrian accident histories. At many intersections, some legs had both marked and unmarked crosswalks before and after the study. An average of approximately 7 years of pedestrian crash data was collected for each of the before and after periods for the 104 sites. Traffic and pedestrian exposure data were not collected, but untreated comparison sites were identified and used in the analysis (*9*).

When only the legs of the intersections that previously had marked crosswalks were considered, Jones and Tomcheck found that there was a 73 percent reduction (from 116 to 31) in pedestrian crashes after crosswalk markings were removed at the 104 sites combined. Considering both legs (previously marked and unmarked crosswalks) of the intersections, there was a statistically significant decline of 61 percent (from 129 to 50) in pedestrian crashes. There was no statistically significant increase in pedestrian crashes at intersections adjacent to intersections where crosswalk markings were removed. At the 15 intersections where crosswalk markings were retained, pedestrian crashes did not decrease. The authors recommended supporting "a policy of selectively installing or reinstalling marked, unprotected crosswalks only after careful consideration" (*9*). It should be noted that the study did not report the effects of removing crosswalk markings by road type (i.e., two-lane vs. multi-lane) or volumes at the study sites.

In the most comprehensive study of marked crosswalks at uncontrolled intersection and midblock locations to date, Zegeer, Stewart, Huang, and Lagerwey (2002) analyzed data from 1,000 marked and 1,000 matching unmarked crosswalk sites in 30 U.S. cities. Zegeer et al. determined that some site factors such as area type, speed limit, and crosswalk marking pattern were not associated with pedestrian crashes. Site factors that were related to pedestrian crashes, which were used as control variables in the analysis, included pedestrian ADT, vehicle ADT, number of lanes, median type, and region of the United States. Poisson and negative binomial regression models were used to analyze the crash effects of marked vs. unmarked crosswalks (*2*).

At uncontrolled locations on two-lane roads and multi-lane roads with low traffic volumes (ADT below 12,000 vehicles per day), it was found that a marked crosswalk alone, compared with an unmarked crosswalk, made no statistically significant difference in pedestrian crash rate. On multi-lane roads with an ADT of more than 12,000 vehicles per day, a marked crosswalk in the absence of other substantial improvements was associated with a statistically significant higher pedestrian crash rate compared to sites with an unmarked crosswalk. On multi-lane roads, the presence of raised medians in marked or unmarked crosswalks provided statistically significant lower crash rates than did no raised median.

There were two potential explanations for some of the higher crash rates seen at higher volume crosswalks. First, the crash rates for older pedestrians were higher than for other pedestrian age groups, considering pedestrian crashes and exposure by age. It was found that older pedestrians were more likely than younger pedestrians to cross at a marked crosswalk, which may partially explain the higher pedestrian crash rate at marked crosswalks. Second, it was theorized that marked crosswalks led to higher crash rates due to multiple-threat crashes on multi-lane roads. Multiple-threat crashes occur when a vehicle in the curb lane stops for a pedestrian in the crosswalk, simultaneously screening the pedestrian's view of an oncoming vehicle and the oncoming vehicle's view of the pedestrian, leading to a failure of the vehicle to yield.

Zegeer et al. suggested a number of potential improvements at unsignalized crossing locations on multi-lane, higher volume roads to enhance pedestrian safety. These recommendations include providing raised medians on multi-lane roads, installing traffic and pedestrian signals where warranted, adding curb extensions or raised islands to reduce street-crossing distance, installing adequate nighttime lighting at pedestrian crossings, constructing raised street crossings, and designing safer intersection and driveways (e.g., with tighter turn radii).

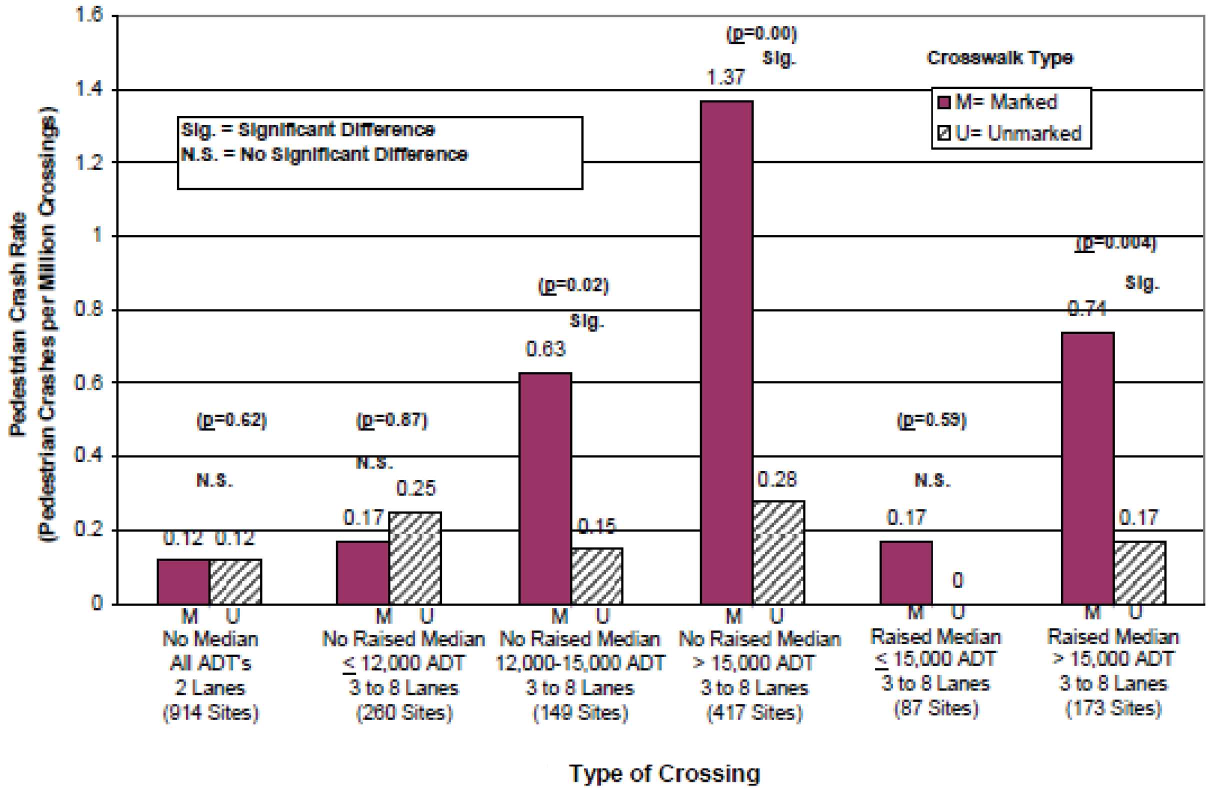
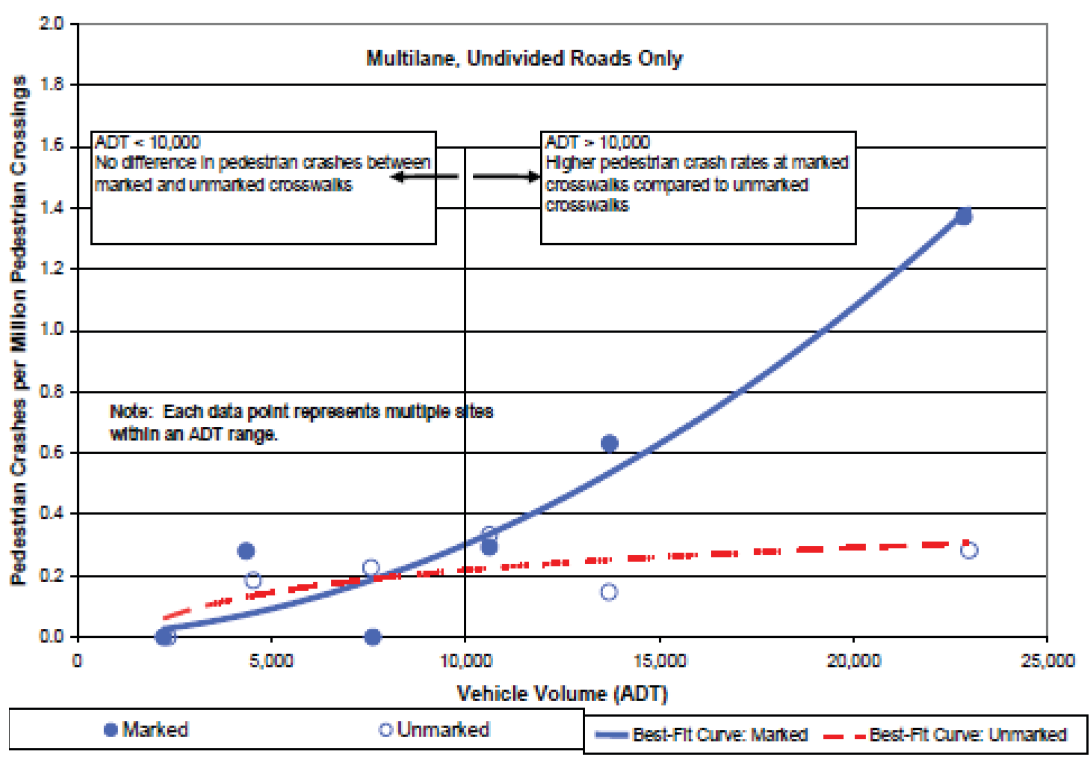


Figure 18. Pedestrian crash rate versus type of crossing.

Source: Zegeer et al., 2002. (*2*)



Source: Zegeer et al., 2002. (*2*)

Figure H-13. Pedestrian crash rates by traffic volume and presence/absence of crosswalk markings.

Table H-2. Recommended guidelines for installing marked crosswalks and other pedestrian improvements at uncontrolled locations.

Roadway Type (Number of Travel Lanes and Median Type)	Vehicle ADT ≤9,000			Vehicle ADT >9,000 to 12,000			Vehicle ADT >12,000-15,000			Vehicle ADT >15,000		
	Speed Limit											
	≤48.3 km/h (30 mi/h)	56.4 km/h (35 mi/h)	64.4 km/h (40 mi/h)	≤48.3 km/h (30 mi/h)	56.4 km/h (35 mi/h)	64.4 km/h (40 mi/h)	≤48.3 km/h (30 mi/h)	56.4 km/h (35 mi/h)	64.4 km/h (40 mi/h)	≤48.3 km/h (30 mi/h)	56.4 km/h (35 mi/h)	64.4 km/h (40 mi/h)
Two lanes	C	C	P	C	C	P	C	C	N	C	P	N
Three lanes	C	C	P	C	P	P	P	P	N	P	N	N
Multilane (four or more lanes) with raised median	C	C	P	C	P	N	P	P	N	N	N	N
Multilane (four or more lanes) without raised median	C	P	N	P	P	N	N	N	N	N	N	N

Table 11 from Zegeer et al. (2002) giving recommended guidelines for installing marked crosswalks and other pedestrian improvements at uncontrolled locations. C = Candidate sites for marked crosswalks, P = Possible increase in pedestrian crash risk if other enhancements are not used, N = Marked crosswalks alone are insufficient due to increased crash risk. (*2*)

Revisiting Older Studies

As documented by Campbell et al. (*4*), authors of the Zegeer et al. study (2002) attempted to compare their results with those of the 1972 Herms San Diego study. Taking all of the 2,000 sites together as one group and simply dividing the crashes by pedestrian crossing volume (as Herms did), the Zegeer group also found that marked crosswalks had a pedestrian crash rate that was slightly more than twice the rate of unmarked crosswalk sites. Only when a more sophisticated statistical analysis was applied did the researchers in the Zegeer et al. study find that marked crosswalks are associated with higher pedestrian crash risk only on high-volume, multi-lane roads (i.e., ADT above 12,000 veh/day). Similarly, in 1967, the Los Angeles County Road Department found that accident frequency increased from 4 to 15 after marked crosswalks were installed at 89 non-signalized intersections (as cited in [*10*]). All the locations that showed an increase in crashes after crosswalk installation had an ADT greater than 10,900 vehicles; sites with fewer vehicles experienced no change in pedestrian crashes, which was consistent with the findings of the Zegeer et al. study.

At the same time as Zegeer et al.'s research, Knoblauch performed two studies published in 2000 and 2001 on pedestrian and motorist behavior. The first of these studies was an effort to assess the effect of crosswalk markings on driver and pedestrian behavior at 11 unsignalized locations in four U.S. cities (*5*). All of the sites were two- or three-lane roads with relatively low speed limits (35 to 40 mi/h) and low volumes (fewer than 12,000 vehicles per day). Given these characteristics, the authors concluded that marking pedestrian crosswalks had no measurable negative effect on either pedestrian or motorist behavior. Crosswalk usage increased after markings were installed, but no evidence was found that pedestrians were less vigilant or more assertive in the marked crosswalk. Drivers were found to approach a pedestrian in the crosswalk rather slowly, but no changes in driver yielding were noted. Details on the duration of the study periods were not reported (*5*).

Knoblauch's second study was performed at six sites in Maryland, Virginia, and Arizona in 2000. All of the locations were uncontrolled intersection approaches without traffic signals or stop control and with a 35 mi/h speed limit that had been recently resurfaced. Using a staged pedestrian at sample crossing locations, speed data were taken under three conditions: no pedestrian present, pedestrian looking, pedestrian not looking. Results indicated a slight reduction in vehicle approach speeds at most, but not all, of the locations after the crosswalk markings had been installed. There was a significant reduction in overall speed under conditions of no pedestrians and where pedestrians were not looking (*6*).

A 2002 *JAMA* article by Koepsell, McCloskey, Wolf, Moudon, Buchner, Kraus, and Patterson studied the effect of crosswalk markings at urban intersections on the risk of injury to older pedestrians. The researchers looked at 282 sites where a pedestrian 65 years old or older had been struck by a motor vehicle while crossing the street. They matched these case sites to 564 control sites chosen for proximity to case sites and street classification characteristics. On the same day of the week and at the same time of day when the accident occurred, trained observers collected data on environmental characteristics, vehicle flow and speed, and pedestrian use for each site. Once the data were adjusted based on pedestrian and vehicle flow, crossing length, and signalization, it was found that the risk of a pedestrian–motor vehicle accident was 2.1 times as great at sites with a marked crosswalk. This excess risk was due almost entirely to the higher risk associated with using marked crosswalks at uncontrolled, unsignalized locations. The researchers concluded that marked crosswalks, when used alone, put older pedestrians at elevated risk of being struck by vehicles (*7*).

In 2007, Mitman, Ragland, and Zegeer conducted another study summarizing pedestrian and driver behavior at uncontrolled intersections using observations at marked and unmarked crosswalks. The data were collected on low speed, two-lane, and multi-lane arterials. Using statistical analysis, the study found that drivers are more likely to yield to pedestrians in marked crosswalks as opposed to unmarked crosswalks. The results led the research team to recommend the creation of a crosswalk inventory to prioritize improvements, using HAWK beacons, undertaking education initiatives, and using enforcement measures both for pedestrians and drivers (*8*).

Despite contradictory findings of various studies, it is clear that marked crosswalks are generally not associated with any statistically significant difference in pedestrian crash risk (compared to unmarked crosswalk sites) on two-lane roads or on multi-lane roads with fewer than 12,000 vehicles per day. On multi-lane roads with ADT higher than 12,000 vehicles per day, marked crosswalks installed alone, without other substantial safety devices, carry significantly increased crash risk for pedestrians, unless more substantial pedestrian safety treatments are provided. On many roads (particularly for multi-lane roads with ADT higher than about 12,000 veh/day), the safety professional may consider such crossing treatments (e.g., raised medians on multi-lane roads, traffic and pedestrian signals, where warranted, adequate nighttime lighting at pedestrian crossings, etc.) to help pedestrians to cross streets more safely.

The following is a summary of some of these studies that involved evaluating pedestrian behavior on marked vs. unmarked crosswalks. Studies of pedestrian and motorist behavior suggest that pedestrian behavior is generally improved by marking crosswalks, and no indication of reckless behavior has been found associated with marked crosswalks. However, most of these behavioral studies were on two- or three-lane roads, where no differences were found in pedestrian crash risk between marked and unmarked crosswalks.

Pedestrian Behavior

Knoblauch et al. (2001) launched a study intended to observe the type of reckless pedestrian behavior to which Herms and others attributed the negative crash results reported in some of the marked crosswalk studies (as cited in [*4*]). The researchers gathered data at 11 sites before and after marked crosswalks were installed, evaluating the information in terms of three hypotheses regarding pedestrian behavior. The first hypothesis was that pedestrians, feeling more protected in a marked crosswalk, would act more aggressively toward motorists. An analysis of data by the research team found no statistically significant difference in blatantly aggressive behavior by pedestrians following the crosswalk installation. The second hypothesis involved whether the pedestrians crossed within the marked lines of the crosswalk, and the data showed that pedestrians walking alone tended to use the marked crosswalk, especially at intersections, while pedestrian groups did not. Additionally, there was a statistically significant increase in overall crosswalk usage following crosswalk installation. The third hypothesis dealt with pedestrian vigilance. It was thought that pedestrians might become less vigilant in monitoring oncoming traffic when using a marked crosswalk, but results showed that pedestrian vigilance increased following crosswalk installation (*4*). These findings were consistent with an earlier study of pedestrian behavior done by Knoblauch et al. (1987) that considered the effect of marked crosswalks on pedestrian looking behavior and staying within the area defined by the markings (*4*).

A 1979 study by Hauck evaluated 17 crosswalks at traffic signals that were re-painted in Peoria, IL (as cited in [*4*]). A before-after analysis found a decrease in both pedestrian and motorist violations at the sites after installation of marked crosswalks. Jaywalking was unchanged, but the number of people who stepped out in front of traffic decreased at 12 of the locations, and those crossing against the DON'T WALK signal phase decreased at 13 sites.

Motorist Behavior

In 2000, Knoblauch and Raymond took speed measurements at six locations before and after marked crosswalks were installed (as cited in [*4*]). Speeds were measured (1) with no pedestrians present, (2) with a member of the research team posing as a pedestrian who was looking at traffic, and (3) when the team member approached and stood at the curb looking straight across the road rather than at oncoming traffic. Motorist behavior was not consistent, so the results were not clear-cut. At one site, drivers slowed down considerably even when no pedestrians were present. When a pedestrian was present and looking at traffic, there was a small but not statistically significant decrease in speed at all six locations. Knoblauch reasoned that drivers might assume a pedestrian looking toward oncoming traffic would not try to cross the street, so vehicles did not need to slow down. However, when the pedestrian was present and not looking for oncoming cars, drivers approaching the marked crosswalk did slow down enough to register a statistically significant change. Knoblauch's conclusion was that drivers usually respond to crosswalk markings, especially when a pedestrian is present but not watching traffic (*4*).

In 2001, Knoblauch et al. studied motorist behavior on two- and three-lane roads with 35 to 40 mi/h speed limits, studying the effects of the crosswalk markings on motorist behavior. The researchers found that drivers slowed slightly more when approaching pedestrians in marked rather than unmarked crosswalks, as well as no effect on yielding behavior when comparing pedestrians in marked versus unmarked crosswalks.

In 1975, Katz et al. studied driver-pedestrian interaction when members of the research team crossed the street under a variety of conditions in 960 trials. Drivers were more likely to stop for pedestrians when the vehicle approach speed was low, when the pedestrian was in a marked crosswalk, when the distance between the car and pedestrian was greater rather than lesser, when there was a group of pedestrians, and when the pedestrians did not make eye contact with the driver (as cited in [*4*]).

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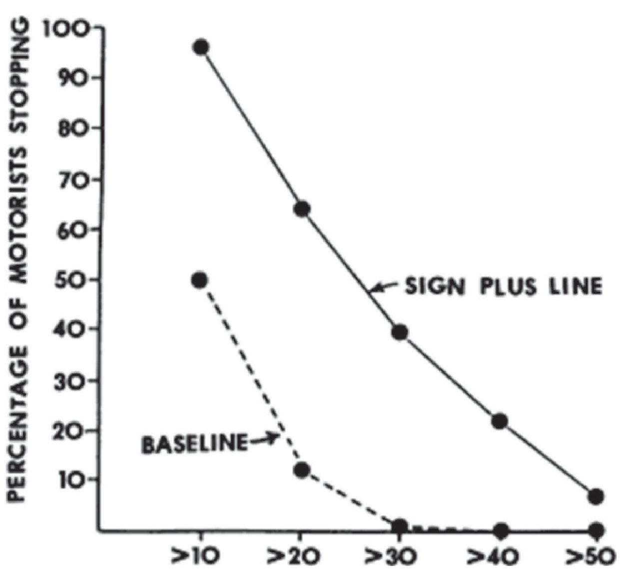
Advanced Yield or Stop Markings and Signs

Advance yield or stop markings are a type of pavement marking placed before a crosswalk to increase the distance at which drivers stop or yield to allow pedestrians to cross. Increasing the distance between yielding vehicles and pedestrians increases the ability of motorists in other lanes to see the pedestrian as he or she crosses and to yield accordingly. Pedestrian visibility of oncoming traffic is likewise improved.

In 1988, Van Houten used a combination of advanced stop markings and "Stop Here for Pedestrians" signs at three Dartmouth, Nova Scotia, crosswalks to analyze the effect of the

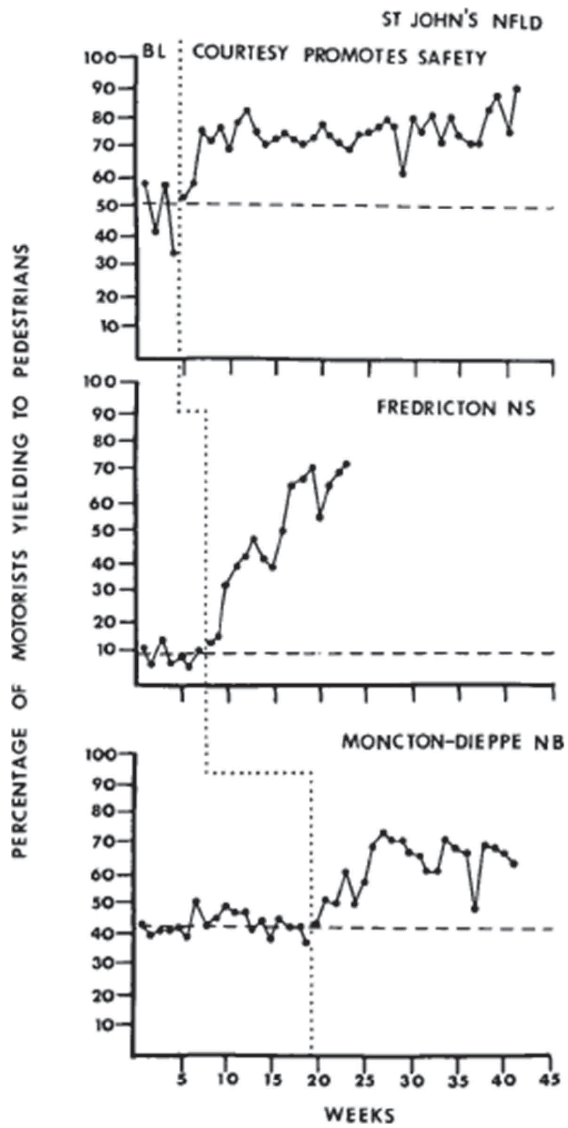


Source: Van Houten, 1988. (*1*)

Figure H-14. Graph showing the percentage of motorists stopping under two sets of study conditions.

treatments on vehicle-pedestrian conflicts and yielding behavior at the sites. An analysis of pre- and post-treatment data indicated that the markings and signs produced an 80 percent decrease in vehicle-pedestrian conflicts as well as an increase in percentage of yielding motorists at treatment sites. Based on the results of this study, the Nova Scotia Department of Transportation began using advance yield markings throughout the province in order to mark crosswalks (*1*).

One year later, Malenfant and Van Houten (1989) studied advance stop lines used with signs as a means of increasing motorist yielding at 34 crosswalks in three Canadian cities in Newfoundland



Source: Malenfant and Van Houten, 1989. (*2*)

Figure H-15. Motorist yielding following the implementation of countermeasures in Canada. The vertical stepped line shows the introduction of the treatments, pedestrian signs, and advance stop lines, deployed with education and enforcement programs. The horizontal lines represent the mean yielding percentage during baseline.

and New Brunswick. Baseline data were collected in each of the cities prior to treatment, which consisted of education and enforcement in addition to the engineering countermeasures. Motorist yielding at follow up increased from 54 percent to 81 percent in St. John's (Newfoundland), from 9 percent to 68 percent in Fredericton (New Brunswick), and from 44 percent to 71 percent in Moncton-Dieppe (New Brunswick). Given the scope of the treatment program, it was unclear to what extent the advance stop lines and signs contributed to the increase in motorist yielding behavior (*2*).

A 1992 article in *Accident Analysis and Prevention* by Van Houten and Malenfant continued to evaluate advance stop markings as used with a pedestrian warning sign. The researchers applied a sequential series of enhancements at two marked crosswalks in Dartmouth, Nova Scotia. Pre-treatment data were collected at baseline and then following the addition of "Stop Here for Pedestrian" signs, following the placement of a stop line 50 ft in advance of the crosswalk, and at 1 year following treatment installation. Following the installation of the signs, pedestrian–vehicle conflicts decreased from 53 percent to 25 percent on Portland Street and from 25 percent to 10 percent on Prince Albert Road. The introduction of the stop lines was associated with an additional reduction of pedestrian–vehicle conflicts from 25 percent to 10 percent at Portland Street and from 10 percent from 6 percent on Prince Albert Road. The reduction in pedestrian–vehicle conflicts was maintained at follow-up one year following their installation. While the sign and advance stop line had little effect on the percentage of motorists who yielded to pedestrians, they did produce an increase in motorist yielding distance and a decrease in vehicle-pedestrian conflicts (*3*).

Advance stop lines and signs, as well as education and enforcement were evaluated at 34 crosswalks in three Canadian cities in Newfoundland and New Brunswick provinces. Motorist yielding increased before to after in all three cities. Yielding increased from 54 to 81 percent in St. Johns (NL), from 9 to 68 percent in Fredericton (NB), and from 44 to 71 percent in Moncton-Dieppe (NB) in response to the treatments. Given the treatment combination, it is unclear to what extent the advance stop lines and signs and the education and enforcement measures contributed to the increase in motorist yielding behavior. Average pedestrian crashes and injuries also trended lower in St. John's and Fredericton and in the after period, but there were no controls for other potential causes (*4*).

In 1993, Cynecki, Sparks, and Grote studied the effects of a different type of advance stop indicator: transverse rumble strips installed in advance of marked crosswalks at 19 uncontrolled locations. There was little change in vehicle speed; 85th percentile speeds showed no real change (*5*).

FIGURE 1 Midblock crosswalk on Wyse Road.

FIGURE 2 Crosswalk on South Park at the intersection of Brenton Street.

FIGURE 3 Crosswalk on Young Street at the intersection of Monaghan Drive.

Source: Van Houten et al., 2001. (*6*)

Figure H-16. Photos of crosswalk sign and markings at three sites.

In 2001, Van Houten, Malenfant and McCusker studied the effectiveness of advance yield markings used with symbol signs at three crosswalks in Nova Scotia, Canada, where yellow flashing beacons were already in place. The researchers experimented with yield marking placement, finding that marking and sign placement was effective at distances between 10 and 25 meters in advance of the crosswalk. The addition of the sign and yield markings led to decreases in vehicle-pedestrian conflicts of 74 percent, 87 percent, and 67.1 percent at the three sites. Like previous studies, there was a small increase in motorist yielding behavior (*6*).

A 2002 *Transportation Research Record* article by Van Houten, McCusker, Huybers, Malenfant, and Rice-Smith gave the results of experiments that studied the effects of advance yield markings and fluorescent yellow-green RA 4 signs at 24 rural and urban crosswalks throughout Nova Scotia, Canada. The signs featured the message “Yield Here to Pedestrians,” using the yield symbol and an arrow pointing in the direction of the crosswalk on a rectangular, fluorescent yellow-green sign. Once baseline data were collected for all 24 crosswalks, they were put into treatment groups of four, with one of the groups serving as a control throughout the experiment. The other three treatments consisted of (1) advance yield line markings with white-background “yield here to pedestrian” signs, (2) fluorescent yellow-green “yield here to pedestrian” signs, and (3) advance yield line markings with fluorescent yellow-green “yield here to pedestrian” signs. Follow-up data were collected at 6 months following treatment installation. Results showed that there was no reduction of vehicle-pedestrian conflicts when the more conspicuous fluorescent yellow-green sign was used instead of the white sign. However, the average number of vehicle-pedestrian conflicts decreased from 11.1 percent and 12.8 percent to 2.7 percent and 2.3 percent, respectively, at sites with the advance yield bar and either a white or fluorescent sign. Advanced stop lines were associated with a statistically significant increase in motorist yielding from 69 percent to 85 percent. The authors conclude by recommending the installation of advanced yield markings 7 m to 18 m in advance of the crosswalk, in order to better increase pedestrian visibility of oncoming vehicles when crossing (*7*).

Another study by Nambisan, Vasudevan, Dangeti, and Virupaksha in 2007 examined driver and pedestrian behavior at unsignalized intersections with respect to combinations of Danish offset, advance yield markings, and high-visibility crosswalk markings. This analysis was based on data from Las Vegas, Nevada, and used an observational study approach. Results indicated

Source: Van Houten et al., 2001. (*6*)

Figure H-17. A pedestrian crosses while a vehicle waits at the advance yield markings.

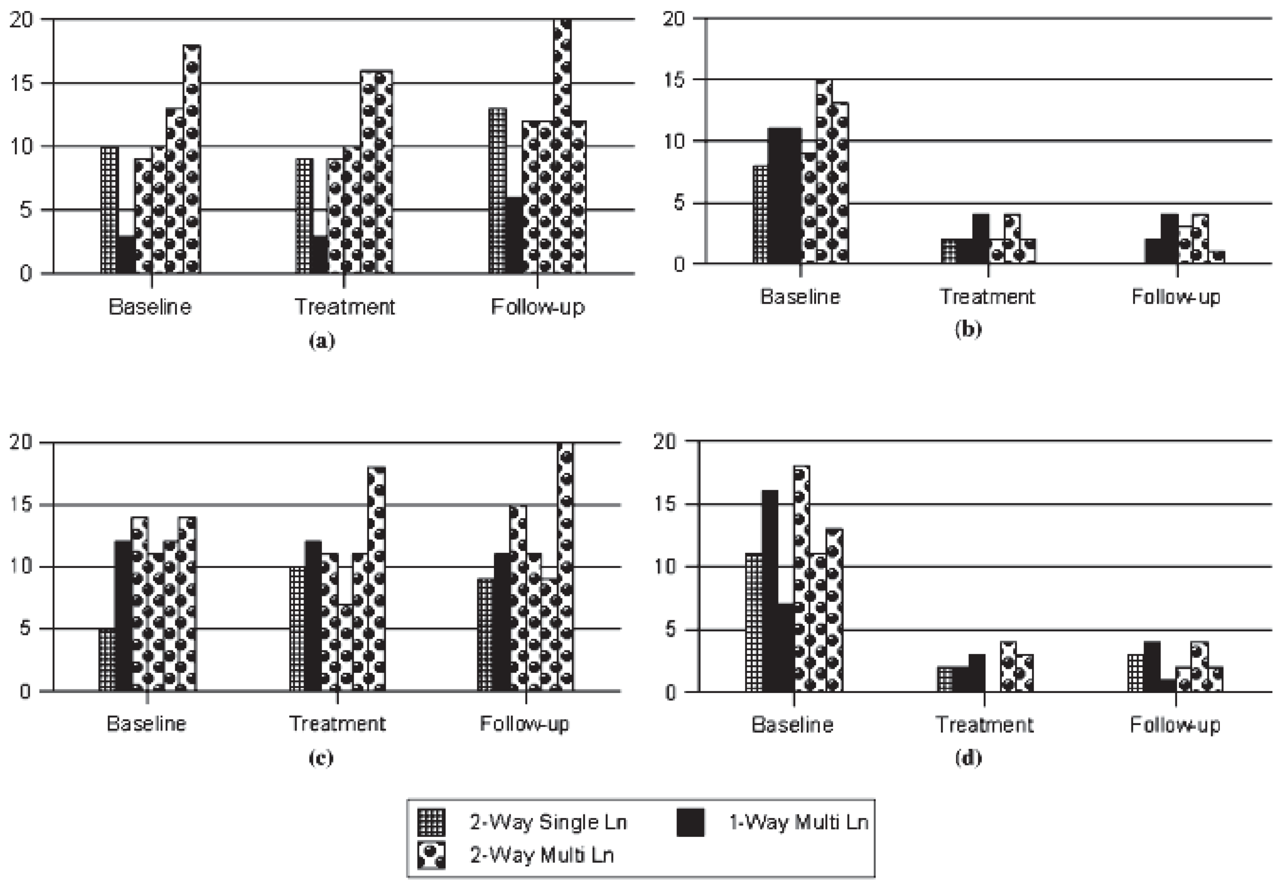
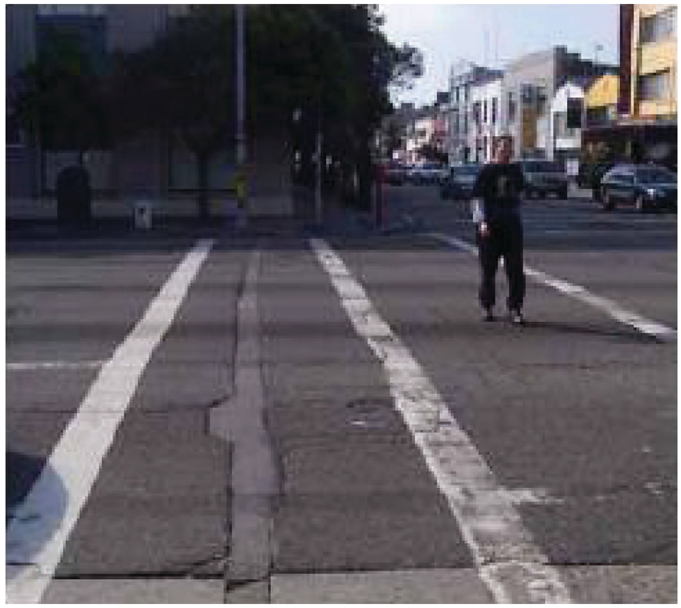


Figure H-18. Graph from Van Houten et al. (2002) showing the number of pedestrian-motor vehicle conflicts per 100 crossings at each site during each phase of the evaluation: (a) control sites, (b) advance yield marking sites, (c) yellow-green pedestrian sign sites, and (d) advanced yield marking and yellow-green pedestrian sign sites. (7)

that Danish offset and high-visibility crosswalk treatments lead to a yielding rate of just below 50 percent at two sites, while the use of advanced yield markings caused the yielding rate to increase. Following statistical tests, the study concluded that Danish offsets, median refuge islands, and high-visibility crosswalks do enhance pedestrian safety with advance yield markings being more successful when coupled with Danish offsets as opposed to a combination with pedestrian refuge islands (*8*).

A 2009 report by Pecheux, Bauer, and McLeod gave the results of an evaluation of advance stop lines installed at one signalized and one unsignalized intersection in San Francisco. Based on pre- and post-treatment measurements taken of driver yielding, vehicle stop position, and pedestrian–vehicle conflicts, the researchers concluded that the advance stop lines had no impact on driver behavior or pedestrian safety at the sites (*9*).

A 2013 TRB paper by Samuel et al. summarized the results of two experiments conducted in Massachusetts to evaluate the effectiveness of advanced yield lines on drivers' ability to scan for pedestrians and driver yielding behavior. The researchers conducted an observational study using a staged pedestrian attempting to use the crosswalk and a second experiment on an open-road course in Greenfield, MA. Results show that advanced yield markings (coupled with warning signs) improved drivers' compliance in scanning for pedestrians. Additionally, advanced yield markings (coupled with vacant on-street parking adjacent to the crosswalk) were found to improve driver yielding compliance (*10*).



Source: Pecheux et al., 2009. (*9*)

Figure H-19. A pedestrian crosses in a crosswalk at an intersection where advance stop lines have been installed. These lines increase the distance between stopped cars and pedestrians, increasing visibility for both.

A 2013 TRB paper by Hengel presented the results of a study of a single site in Santa Barbara, CA, where a curb extension, pedestrian refuge island, and stop bars were installed. MOEs were crossing delay, number of motorists failing to yield, and distance drivers yield from the crosswalk. Results show that the combination of treatments is effective at reducing wait times to cross, decreasing percentage of vehicles that pass before yielding, and increasing the distance that vehicles yield in advance of the crosswalk (*11*).

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Treatment 2. High-Visibility Crosswalk Marking Patterns

Evaluation Studies of High-Visibility Crosswalks

A 2001 Federal Highway Administration report by Nitzburg and Knoblauch evaluated the effectiveness of high-visibility crosswalk markings used in conjunction with an illuminated overhead crosswalk sign at two sites in Clearwater, Florida. The researchers used case-control research design to compare motorist and pedestrian behavior at the treatment sites with two similar sites, one that featured standard pedestrian crossing signage and crosswalk design, and one that had no crosswalk. The researchers found that during the day, drivers at the experimental crossing locations were 30–40 percent more likely to yield than drivers at the control locations. At night, there was a smaller and statistically insignificant increase in driver yielding of 8 percent. There was a significant increase in pedestrians using the crosswalk at the treatment sites compared to control sites. Although the individual effects of having the signs in place could not be analyzed separately from the high-visibility crosswalk, the researchers concluded that the treatments had a positive effect on pedestrian safety at the two intersections that were studied (*1*).

A 2005 report for the Chicago Department of Transportation gave the results of an evaluation of the experimental use of strong yellow/green (SYG) crosswalk markings at over 100 Chicago elementary school zone crosswalks. City officials measured traffic speeds before and after the installation of the SYG crosswalks to determine whether the color of the pavement markings led to an improved pedestrian safety environment at the crossings. An analysis of traffic speeds suggested that the use of SYG crosswalk markings failed to have a significant effect on the percentage of drivers exceeding the speed limit or median 85th percentile speeds at study locations. Based on the results of the Chicago Department of Transportation's analysis, the FHWA concluded that the use of yellow-green pavement markings did not improve crosswalk safety compared to standard white markings (*2*).

A 2010 article by Feldman, Manzi, and Mitman provided an Empirical Bayesian evaluation of the safety outcomes of installing high-visibility crosswalks at 54 school sites in San Francisco, California. The researchers used an equal number of control intersections and pre-treatment data to predict the number of collisions that would have been expected in absence of treatment. The results of their analysis demonstrated a statistically significantly reduction in collisions of 37 percent (*3*).

A 2011 Federal Highway Administration report by Fitzpatrick, Chrysler, Iragavarapu, and Park evaluated the relative visibility of three types of crosswalk markings, transverse lines, continental markings, and bar pair markings, under daytime and nighttime conditions. Seventy-eight participants were recruited, evenly divided by gender and age (over/under 55), and drove an instrumented vehicle on a route in College Station, Texas. The participants were given instructions to identify crosswalks and other roadway features as they came into view, at which point researchers used the instrumentation to mark the location at which the crosswalk was visible. Results were adjusted to account for response delay. Detection distances were analyzed with regards to marking type, light conditions, site characteristics, traffic characteristics, vehicle type,

Source: Fitzpatrick et al., 2011. (*4*)

Figure H-20. Bar pair markings.

and driver characteristics. Analysis of results showed that detection distances for continental and bar pairs were statistically similar and are also statistically significantly longer than for transverse line markings at day and at night. Participants also preferred the continental and bar pair markings to the transverse markings. The presence of traffic also had the effect of reducing detection distance. Age, gender, driver eye height, and vehicle type were found to have minimal significance by the research team. The researchers concluded by suggesting the addition of bar pairs to the MUTCD and to also make bar pairs or continental markings the default crosswalk marking across uncontrolled approaches (*4*).

A 2012 article by Chen, Chen, Ewing, McKnight, Srinivasan, and Roe considered the effectiveness of high-visibility crosswalks in increasing pedestrian safety at intersections. The researchers used a two-group pre-test/post-test research design to compare collision statistics following the implementation of high-visibility crosswalks at 72 sites throughout New York City. Pedestrian collision statistics were collected for the 5 years preceding treatment installation, as well as the two years following it, and the authors used ANCOVA analysis in order to control for potential regression-to-the-mean effects. Analysis of their results indicated that the average pedestrian

Source: safety.transportation.org

Figure H-21. High-visibility crosswalks and raised crossing islands help pedestrians cross safely.

crash rate decreased by 44.9 percent at treatment sites and by 11.5 percent at comparison sites. This resulted in an ANCOVA-adjusted reduction in pedestrian collisions of 48 percent at treatment sites, results which were significant at the 0.05 level (*5*).

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Treatment 3. High-Intensity Activated Crosswalk (HAWK) Signals

Pedestrian Hybrid Beacon (HAWK Signal)

Pedestrian hybrid beacons, also known as HAWK beacons (short for High-Intensity Activated crossWalK beacon), were developed by Tucson traffic engineer Dr. Richard Nassi in the late 1990s as a means of providing safe pedestrian crossings where minor streets intersected with

Source: pedbikeimages.org

Figure H-22. Pedestrians cross at a crosswalk enhanced with a pedestrian hybrid beacon in Phoenix, Arizona.

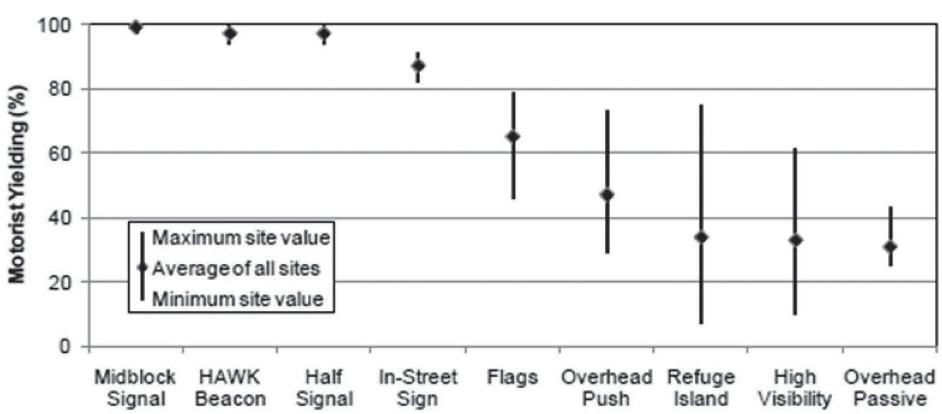
major arterials (*1*, *2*). The first pedestrian hybrid beacon was installed in Tucson in 2000. The pedestrian hybrid beacon (PHB) was considered an experimental treatment until 2009, when it was included for the first time in the *Manual on Uniform Traffic Control Devices* (MUTCD). Today, PHBs are widely used in Tucson, and, as of 2012, have been installed in Georgia, Minnesota, Virginia, Arizona, Alaska, and Delaware (*3*).

Evaluation of Pedestrian Hybrid Beacons

A 2006 report authored by Fitzpatrick et al. and published by TRB, *TCRP Report 112/NCHRP Report 562: Improving Pedestrian Safety at Unsignalized Crossings*, evaluated various midblock crossing treatments, including the PHB. The researchers used trained data collectors and video recordings to collect motorist and pedestrian behavior data at five PHB sites in Tucson, Arizona. Post-treatment data were collected for staged and non-staged pedestrians, and measures of effectiveness such as pedestrian crosswalk compliance, pedestrian–vehicle compliance, and motorist yielding were used to evaluate the safety performance of the treatments. Results from the five PHB sites showed an average of 97 percent motorist yielding across all sites, comparable to the other treatments in the red signal or beacon category (see Figure H-23). Nearly all of the red signals or beacons studied were used on high-volume, high-speed arterial streets. Based on the results of this study, the researchers recommended the addition of a red signal or beacon to the MUTCD, given that no such treatment had yet been included (*4*).

A 2010 report by Fitzpatrick and Park published by the Federal Highway Administration evaluated the safety effectiveness of the PHB at 21 sites in Tucson, Arizona. The researchers used collision data for the 3 years pre-treatment and for the 3 years following treatment, as well as nearby untreated reference sites, in order to calculate reduction in expected collisions using the Empirical Bayes method. Results of the analysis showed a statistically significant reduction in total crashes of 29 percent as well as a statistically significant 69 percent reduction in pedestrian crashes. There was a 15 percent reduction in severe crashes; however, this result was not statistically significant. The authors concluded that the PHB was effective at leading to a reduction in total collisions at treatment sites. However, there are two main shortcomings of the Fitzpatrick and Park study: (1) the crash sample size was quite small, particularly for the after period and (2) all of the sites were from one single city (Tucson, AZ), and results may vary in other cities (*1*).

A 2013 TRB paper by Deng, Ni, and Li investigated the safety and effectiveness of four midblock crossing signal controls (pedestrian actuated (PA), pedestrian light controlled (PELICAN),



Source: Federal Highway Administration, 2010 (*1*).

Figure H-23. Motorist yielding percentages by countermeasure type. The PHB, or HAWK, beacon is shown second from the left.

Source: Hunter-Zaworski and Miller, 2012. (*8*)

Figure H-24. A pedestrian hybrid beacon installed in Portland, Oregon.

high intensity activated crosswalk (HAWK), and pedestrian user-friendly intelligent (PUFFIN)) during the clearance interval phase of the signal operation. The researchers hypothesized that the safety benefit of these treatments may be minimized because pedestrians are not always crossing during the green phase of the signal but in fact are often crossing during the clearance interval phase. Results for the HAWK and PUFFIN signals show that they are better at balancing efficiency and safety for all road users. The HAWK signal was observed to have a "satisfactory performance" with "low" pedestrian flow; however, as pedestrian flow increased, so did the conflicts (*6*).

Pulugurtha and Self (2013) evaluated the safety effects of PHBs at three sites in Charlotte, North Carolina. The researchers collected data from pedestrian crossings during weekday morning and evening peak times at five time points: before the installation, and at 1, 3, 6, and 12 months following installation. The chosen measures of effectiveness were average traffic speed, the percentage of yielding motorists, the proportion of pedestrians trapped mid-crossing, and pedestrian–vehicle conflicts. An analysis of the results showed an increase in the percentage of yielding motorists, a decrease in the percentage of trapped pedestrians, and a decrease in pedestrian–vehicle conflicts at all three sites; however, these changes were significant at only one of the three sites. At the same time, a statistically significant increase in average vehicle speed was also observed at one of three sites. An analysis of pre- and post-installation crash data showed no significant change in pedestrian–vehicle crashes, although the sample size was small in both cases. The results also indicated that changes in pedestrian and motor vehicle actions were more consistent after the PHBs had been in place for 3 months or more. Overall, the PHBs were effective at increasing motorist yielding and reducing trapped pedestrians and pedestrian–vehicle conflicts (*7*).

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Treatment 4. Rectangular Rapid Flashing Beacons (RRFBs)

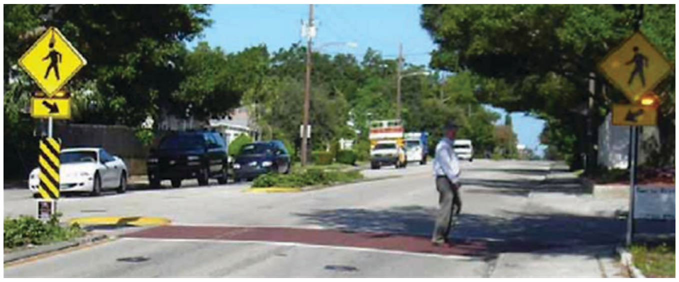
The rectangular rapid flash beacon (RRFB) is a type of amber LED installed to enhance pedestrian crossing signs at midblock crossings or unsignalized intersections. RRFBs can be automated or pedestrian actuated and feature an irregular, eye-catching flash pattern to call attention to the presence of pedestrians. Research has demonstrated that installing RRFBs on roadside pedestrian crossing signs significantly increases motorist yielding behavior. The RRFB was given interim approval as a crossing sign enhancement by the FHWA in 2008 (*1*).

A 2008 *Transportation Research Record* article by Van Houten, Ellis, and Marmolejo studied the effectiveness of RRFBs (referred to as stutter-flash LED beacons in the article) in increasing motorist yielding behavior. RRFBs were installed at two Miami-Dade County, Florida, multilane crosswalks. Baseline data were collected pre-treatment, and, during the post-treatment phase, the researchers alternated the activation of the beacons at the sites in order to take further control measurements. Observers measured the numbers of yielding motorists, vehicle-pedestrian conflicts, trapped pedestrians, and motorist yielding distance. At the two crosswalks, motorist yielding to resident pedestrians increased from 0 percent and 1 percent to 65 percent and 92 percent, respectively. There was also a reduction in the number of vehicle-pedestrian conflicts and

Table H-3. Measures of effectiveness measured by researchers in an evaluation of RRFBs, Miami, Florida.

Measure of Effectiveness	Site	Before	After	percent Change	p-value
Percent Drivers Yielding (Staged Crossings, Daytime)	NW 67th & Main St.	4.2 (n=2330)	55.2 (n=2131)	+51	0.01 (daytime and nighttime combined at this site)
	S. Bayshore & Darwin	4.1 (n=2075)	60.1 (n=1361)	+56	0.01 (daytime and nighttime combined at this site)
Percent Drivers Yielding (Staged Crossings, Nighttime)	NW 67th & Main St.	4.4 (n=703)	69.8 (n=223)	+65.4	See above.
	S. Bayshore & Darwin	2.5 (n=139)	66 (n=225)	+63.5	See above.
Percent Drivers Yielding (Resident Crossings)	NW 67th & Main St.	12.5 (n=137)	73.7 (n=259)	+61.2	0.001
	S. Bayshore & Darwin	5.4 (n=200)	83.4 (n=111)	+78	0.001
Percent of Pedestrians Trapped in Roadway	NW 67th & Main St.	44	0.5	-43.5	<0.01
Percent Of Vehicle-Pedestrian Conflicts	NW 67th & Main St.	11	2.5	-8.5	<0.05
	S. Bayshore & Darwin	5.5	0	-5.5	<0.01

Source: Pecheux et al., 2009. (*3*)



Source: Pecheux et al., 2009. (*3*)

Figure H-25. A pedestrian crosses in a crosswalk where pedestrian crossing signs have been enhanced with RRFBs, Miami, Florida.

trapped pedestrians, leading the authors to conclude that the stutter-flash beacon was effective in increasing pedestrian safety at multilane crosswalks (*2*).

A 2009 report by Pecheux, Bauer, and McLeod gave the results of an evaluation of RRFBs at two sites in Miami, Florida. The study team used the following measures of effectiveness (MOEs) to assess the effect of the RRFB on pedestrian and driver behavior: the percentage of pedestrians trapped in the roadway, the percentage of drivers yielding to pedestrians, and the percentage of pedestrian–vehicle conflicts. The researchers found statistically significant improvements in all of the studied MOEs. Table H-3 gives a summary of the results (*3*).

The researchers concluded that the RRFB offered clear safety benefits, and it was placed into the category of highly effective countermeasures (*3*).

A 2009 evaluation of the Pedsafe II project in San Francisco used video observation and intercept surveys to collect pre- and post-treatment data to evaluate the effectiveness of 13 countermeasures deployed at 29 sites throughout San Francisco, California. As part of the project, two types of flashing beacons were evaluated: one that was activated by pedestrians and a second that automatically detected pedestrians using infrared technology. The flashing beacons were installed at one uncontrolled crosswalk each in order to assess their effectiveness. Based on pre- and post-treatment video recordings of pedestrian and driver behavior at the site, the push-button activated beacon led to a significant reduction in vehicle/pedestrian conflicts, from 6.7 percent pre-treatment to 1.9 percent post-treatment, as well as a significant increase in vehicle yielding, from 70 percent pre-treatment to 80 percent post-treatment. It was also noted that only 17 percent of pedestrians activated the beacon, although an additional 27 percent of pedestrians crossed

Table H-4. Motorist responses during interactions with bicyclists and pedestrians before and after RRFB installation.

Motorist response	Before	After	Total
Full stop	21 (1.9)[1]	217 (27.3)	238 (12.4)
Major direction change	0 (0.0)	5 (0.6)	5 (0.3)
Slows	5 (0.5)	65 (8.2)	70 (3.7)
No change	1096 (97.7)	508 (63.9)	1604 (83.7)
Total	1122 (58.5)[2]	795 (41.5)	1917 (100.0)

[1]Column percent [2]Row percent
Source: Hunter et al., 2009. (*5*)

Source: Hunter et al., 2009. (*5*)

Figure H-26. RRFB used at a crosswalk in a St. Petersburg, Florida, evaluation.

when the beacon was activated. The automated flashing beacon led to a significant reduction in vehicle/pedestrian conflicts (from 6.1 percent pre-treatment to 2.9 percent post-treatment), a significant reduction in the number of trapped pedestrians (from 4.1 percent pre-treatment to 0 percent post-treatment), and a significant increase in vehicle yielding (from 82 percent pre-treatment to 94 percent post-treatment). Of the 13 countermeasures tested, both the push-button and automated flashing beacons were among the 6 countermeasures from this study that were considered the most effective in increasing pedestrian safety (*4*).

A 2009 report summarized the effects of installing a pedestrian-activated rectangular rapid flash beacon (RRFB) at the location of one uncontrolled trail crossing at a busy (15,000 ADT), four-lane urban street in St. Petersburg, Florida. The researchers used a mounted video camera to collect pre- and post-treatment data about pedestrian and driver interactions at the trail crossing. An analysis of the data showed a statistically significant reduction in trail user crossing delay and pedestrian yielding, as well as a statistically significant increase in motorist yielding (from 2 percent pre-treatment to 35 percent post-treatment and 54 percent when the beacon was activated) and ability of pedestrians to cross the entire intersection (from 82 percent pre-treatment to 94 percent post-treatment). The researchers concluded that there was an increase in safety at the intersection as a result of installing the RRFB (*5*).

A 2011 report by the Federal Highway Administration by Shurbutt and Van Houten reported on the effects of installing a yellow rectangular rapid-flashing beacon (RRFB) at 22 multilane, uncontrolled crosswalks in St. Petersburg, Florida; Washington, D.C.; and Mundelein, Illinois. The study compared the performance of RRFBs to traditional overhead yellow flashing beacons and a side-mounted traditional yellow beacon at two of the sites. They also compared the performance of two beacons (one facing each direction of traffic) to four beacons (two per approach on both sides of the road). The researchers measured driver yielding behavior and pedestrian/vehicle conflicts at baseline (pre-treatment) and compared it to post-treatment data collected eight times over the following 2 years to assess long-term effects. On average across all sites, 4 percent of drivers yielded to pedestrians pre-treatment, while at 2-year follow-up, an average of 84 percent of drivers yielded to pedestrians at all sites, demonstrating the measure's maintenance of effect over time (*6*).

Source: Shurbutt and Van Houten, 2011. (*6*)

Figure H-27. Pedestrian sign enhanced with RRFBs.

The RRFB also produced increases in driver yielding behavior at the two sites where its performance was compared to overhead and side-mounted beacons. At the site of the overhead beacon, motorist yielding increased from 15.5 percent with the overhead beacon to 78.3 percent when two RRFBs were installed and to 88 percent when four RRFBs were installed. At the site of the side-mounted beacon, motorist yielding increased from 12 percent with the side-mounted beacon to 72 percent with the installation of two RRFBs. Data collected at night showed an increase in driver yielding behavior from 4.8 percent pre-treatment to 84.6 percent (two-beacon RRFB) and 99.5 percent (four-beacon) post-treatment. The authors also compared the performance of beacons aimed parallel to the roadway to beacons aimed toward the eyes of drivers upon approach, a measure that increased yielding behavior. The authors concluded that the RRFB appeared to be an effective tool for greatly increasing the number of drivers yielding to pedestrians at uncontrolled crosswalks (*6*).

A 2011 Oregon Department of Transportation report by Ross, Serpico, and Lewis evaluated RRFB installation at two Bend, Oregon, crosswalks. Previous to the installation of the RRFBs, motorist yield rates were 23 percent and 25 percent at the intersections; these rates increased to 83 percent at both sites following treatment. Based on their experience, the authors gave 11 suggestions for the installation of RRFBs and their evaluation (*7*).

Six locations in Calgary, Canada, with RRFBs and traffic volumes ranging from 4,800 to 14,600 on streets with one to five lanes were observed for driver yielding rates with staged crossings. The RRFBs were observed to increase driver yielding by an average of 15 percent, to nearly 100 percent motorist yielding at the majority of the study sites. Overall the average motorist yielding increased from 83 to 98 percent following RRFB installation (*8*).

Fitzpatrick et al. in 2014 reported on driver yielding rates at multilane crossings in Texas with PHBs, RRFBs, and traffic control signals (TCSs) installed. In this study, the researchers also used

Source: Ross, Serpico, and Lewis, 2011. (*7*)

Figure H-28. RRFB installation in Bend, Oregon.

staged pedestrians and employed the same protocol for crossing and observing driver yielding across all sites to ensure more comparable study conditions. Yielding rates for 22 RRFB sites varied more across different cities (34 to 92% yielding) compared to yielding rates for TCS sites (7 sites, 95 to 100% yielding) or PHB sites (32 sites, 73 to 92% yielding). Yielding rates also varied by one- or two-way cross sections, with a decreasing yielding effect for two-way compared to one-way, even controlling for total crossing distance (and city effects). Total crossing distance also had an independent negative effect on driver yielding at RRFBs. Interestingly, there was a correlation of increased yielding with higher speed limits, even when two anomalous sites with low volumes and very low driver yielding rates were removed from the analysis. Closer analysis revealed that the results were related to very slight differences in yielding (1 percentage point between the two averages) on roads with posted speeds of 40 versus 35 mph, and were considered not practically significant. All of the RRFB sites in this study also had School Crossing signs, which the researchers thought could have contributed to an overall average yielding of 86 percent, which they indicated was higher than national averages (*9*).

Foster, Monsere, and Carlos (2014) reported on motorist yielding and pedestrians' use of RRFBs when they were activated by the pedestrians versus not activated for an urban and a suburban arterial in Portland, Oregon:

- Site 1 is a five-lane, 35 mi/h urban arterial, with 30,700 vpd, and a narrow median refuge. Three RRFBs are installed on each side of the crosswalk, one on the side, one in the median, and one overhead, facing each direction, for a total of six pedestrian-activated RRFBs at the crosswalk site. There is also one more RRFB in advance of the crosswalk facing each direction of traffic for a total of eight RRFBs surrounding the crosswalk. Motorist yielding was 92% when beacons were activated and 75% when beacons were not activated. There is high pedestrian crossing activity at this location, with transit stops on each side, and over 200 activations of the RRFB each weekday.
- Site 2 is a TWLTL lane, 40 mph, suburban arterial, with 26,400 vpd, a median island, and a Z crossing (Danish offset, a type of path in the median that directs pedestrians to face oncoming traffic before completing their crossing). Four RRFB assemblies were implemented at this location. Motorist yielding was 91% when the RRFBs were activated and 45% when not activated. Pedestrian activity is also high at this location. Pedestrians activated the beacon 94 percent of the time at Site 1 and 83 percent of the time at Site 2. Researchers also documented that motorists yielded more often to pedestrians in the second stage of their crossing at both locations. At Site 2 (the Danish offset), 82 percent of pedestrians who crossed the roadway chose to use the crosswalk, which compared favorably with a 71 percent compliance rate for marked midblock crosswalks in general (*10*).

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Treatment 5. In-Pavement Warning Lights

In-pavement lighting is sometimes used to alert motorists to the presence of a crosswalk at uncontrolled locations. Both sides of the crosswalk are lined with encased raised pavement markers, which sometimes contain LED strobe lighting. In-pavement lighting has shown positive results such as increasing driver compliance and motorist yielding to pedestrians in Washington State but not in Florida (*1*, *2*). At the same time, there are several drawbacks to this method. For example, the whole system must be replaced whenever road surfacing or utility repairs occur. Also, in-pavement lights are generally visible to only the first car in a platoon. Headlights from oncoming traffic may obscure a driver's view of the entire crossing. Furthermore, in-pavement lighting does not indicate the direction of a pedestrian's travel or whether people are crossing simultaneously from both sides of the road. Finally, the in-pavement flashers may be difficult to see during bright daylight hours.

A 2002 evaluation by Hakkert, Gitelman, and Ben-Shabat studied the effectiveness of in-pavement flashing light systems that automatically detect the presence of pedestrians using infrared sensors at four uncontrolled pedestrian crossings in two Israeli cities. One of the systems, called ARMS (Active Road Marking System for Road Safety), was developed by an Israeli startup company. The second system, called Hercules, was a modified version of an American system. Pedestrian and driver behavior were studied pre- and post-treatment by trained field observers. Analysis of results suggested that the use of the in-pavement flashing light systems could bring about a reduction in vehicle speeds near the crosswalk by 2–5 kph, increase yielding to pedestrians by 35 percent at the beginning and 70 percent at the middle of the crosswalk, significantly reduce pedestrian/driver conflict rates to less than 1 percent, and increase the percentage of diverted pedestrians from 50 percent to 90 percent. The authors concluded that, owing to the differences across sites and observed treatment effects, it would be advisable to further study the systems before considering them fully ready for field implementation (*3*).

A 2003 paper by Van Derlofske, Boyce, and Gilson gave the results of a field evaluation of in-pavement flashing lights that were installed at a two crosswalk sites at one uncontrolled intersection in Denville, New Jersey. The site was chosen for safety improvements by the Department of Transportation because it posed crossing difficulties for pedestrians. Successive improvements were made, and evaluations were carried out between treatment phases. The first evaluation was made pre-treatment, when there was only one, eroded, standard crosswalk marking. The second evaluation was made in 2000, when a second crosswalk was added and both crosswalks were striped. The final evaluation was made later in 2000, following the installation of an in-pavement flashing lights system with automatic, microwave pedestrian detectors. Follow-up evaluations were made at 9 and 12 months following the treatments. Analysis of the results of adding an in-pavement flashing light system indicated that it enhanced the noticeability of the crosswalk, reduced the mean speed at which vehicles approached the crosswalk, and reduced the mean number of vehicles failing to yield to a waiting pedestrian. The researchers also noted important safety benefits from using high-visibility crosswalk markings (*4*).

A 2006 article by Nambisan et al. summarized the effectiveness of an in-pavement flashing light system installed at one uncontrolled crosswalk in the Las Vegas metropolitan area in Nevada. The researchers collected data on driver behavior (yielding, vehicle speeds, yielding distance, and vehicle/pedestrian conflicts) before and after treatment installation and compared the data to see if mean values differed statistically at 95 percent confidence levels. Analysis showed that the system appeared to be effective at increasing driver yielding behavior. There was a statistically significant reduction in mean driver speed when pedestrians were crossing or waiting to cross. While yielding distance was increased by 9 ft in one direction, it decreased by 20 ft in the opposite direction, perhaps due to driver confusion. There was no statistically significant reduction in pedestrian/vehicle conflicts. The authors concluded that the in-pavement lighting solution did appear to have pedestrian safety benefits at a low-traffic-volume location (*5*).

A 2011 report from Vermont found that while the system installed increased yielding and decreased approach speeds, it was removed due to multiple malfunctions and damage during the winter (before an evaluation could be completed) and the DOT's preference for a treatment

Source: Van Derlofske et al., 2003. (*4*)

Figure H-29. In-pavement flashing lights used at a crosswalk in Vermont.

that would be visible during all seasons. Also, in-pavement lights are generally visible to only the first car in a platoon. Headlights from oncoming traffic may obscure a driver's view of the entire crossing. Furthermore, in-pavement lighting does not indicate the direction of a pedestrian's travel or whether people are crossing simultaneously from both sides of the road. Finally, the in-pavement flashers may be difficult to see during bright daylight hours (*6*).

In 2010, Thomas conducted a critical review of previous studies that had been conducted on the effects of in-pavement flashing lights. A total of nine studies were reviewed primarily with respect to safety effectiveness of these devices on driver and pedestrian behavior and resulting conflicts (*7*).

Thomas summarizes the findings of this critical review of In-Roadway Warning Lights (IRWL):

> In conclusion, while motorist yielding to pedestrians has improved to varying degrees at most locations examined, yielding may not be raised to a sufficiently high degree at locations with poor pedestrian conditions. The effects of IRWL on traffic speeds and pedestrian use of the crosswalks is not at all clear, as results have varied among the studies. Positive effects observed may also degrade over time as found in several studies. Unfortunately, it is not clear from the evaluation studies reviewed, under what conditions flashing crosswalk treatments may be most beneficial over the long term, while not recommended for others. Clearly, the location should be carefully evaluated prior to implementation, and the specifics should be assessed thoroughly to determine if this treatment, alone or in combination with other treatments, is the best solution for a particular situation. Some communities have removed IRWLs due to both safety and efficiency reasons. If installed, the treatment should be carefully evaluated and monitored long term for effects on pedestrian safety and mobility. Ideally, comparison locations with similar environmental and user characteristics would be used to help control for time trends and other unknown effects (*7*).

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Treatment 6. Pedestrian Refuge Areas

Median refuge islands, sometimes referred to as a center islands, refuge islands, or pedestrian islands, are raised areas that help protect pedestrians who are crossing the road at intersections and midblock locations. The presence of a median refuge island in the middle of a street or intersection allows pedestrians to focus on one direction of traffic at a time as they cross and gives them a place to wait for an adequate gap between vehicles. Islands are appropriate for use at both uncontrolled and signalized crosswalk locations. Where the road is wide enough and on-street parking exists, center islands can be combined with curb extensions to enhance pedestrian safety (*1*).

A 1994 study by Bowman and Vecellio was conducted to determine the effects of urban and suburban median types on the safety of vehicles and pedestrians. The study involved an analysis of

32,894 vehicular crashes and 1,012 pedestrian crashes that occurred in three U.S. cities (Atlanta, Georgia; Phoenix, Arizona; and Los Angeles/Pasadena, California). The authors compared sites that had no median, those that had a raised median, and those with a flush or two-way, left-turn lane. A variety of statistical tests were used, including t-tests, analysis of variance, and the Scheffe multiple comparison test. The authors did not have pedestrian volume data, but used area type (CBD and suburban areas) and land use as surrogate measures for pedestrian activity and developed pedestrian crash prediction models separately for the two area types (*2*).

The results of this analysis provide evidence that having some area of refuge (either a raised median or TWLTL) on an arterial CBD or suburban street provides a safer condition for pedestrians than having an undivided road with no refuge for pedestrians in the middle of the street. Furthermore, while this study found that suburban arterial streets with raised-curb medians had lower pedestrian crash rates compared to TWLTL medians, this difference was not statistically significant. This may be a clear indication that some refuge area in the middle of wide streets is more beneficial to pedestrian safety when crossing streets than having no refuge area. However, the safety benefits for a raised median vs. a TWLTL were not quantified in this study. Based on the study results, Bowman and Vecellio suggest that in CBD areas, whenever possible, divided cross sections should be used due to their lower crash rates for pedestrians and motor vehicles (*2*).

A 1994 study by Claessen and Jones (*4*) found that replacing a 6 ft (1.8 m) painted median with a wide raised median reduced pedestrian crashes by 23 percent. According to Cairney in *Pedestrian Safety in Australia* (1999), this conclusion was consistent with Scriven's finding that pedestrian crash rates for roads with 10 ft (3.05 m) medians were 33 percent lower than for roads with 4 ft (1.2 m) painted medians (*3*).

In 2001, a study by Huang and Cynecki evaluated a variety of traffic calming measures in several U.S. cities, using before-after analysis of pedestrian and motorist behavior as measures of effectiveness. The study included an evaluation of four refuge islands at two unsignalized four-leg intersections in Sacramento, California. The refuge islands constricted the width of the travel lanes and were expected to reduce vehicle speeds, increase the number of pedestrians for whom motorists yielded, and increase the percentage of pedestrians who crossed in the crosswalk. After installation of pedestrian refuge islands at the four crosswalk locations, the percentage of motorists who yielded to pedestrians increased from 32.6 percent to 42.1 percent, but this was not statistically significant at the 90 percent level, due to relatively small sample sizes of crossing pedestrians. However, there was a statistically significant increase in the percentage of pedestrians who crossed in the crosswalk, from 61.5 percent to 71.9 percent. There was no statistically significant difference in the pedestrian wait time after the refuge islands were installed. It would be expected that pedestrian wait time would more likely be improved in situations where refuge islands are installed on multi-lane roads (*5*).

Also in 2001, Bacquie, Egan, and Ing conducted a before-after study to evaluate the safety effectiveness of raised pedestrian refuge islands. Pedestrian accidents that could have been prevented by a pedestrian refuge island were reduced at 28 sites for which data were available, from 22 in

Location	Treatment	Before	After	Significant
Corvallis, Oregon	Refuge island and pavement markings	51.9% (n=79)	78.0% (n=113)	No
Sacramento, California	Refuge islands with zebra crosswalks 4 locations	61.5% (n=314)	71.9% (n=224)	Yes (p=0.012)

Table from Huang and Cynecki (2001) showing the percentage of pedestrians who crossed in the crosswalk before and after the installation of median islands. (*5*)

Source: Huang and Cynecki, 2001. (*5*)

Figure H-30. A pedestrian crosses in a zebra crosswalk that has been enhanced with a refuge island in Sacramento, California.

the 3 years before installation to 6 during the 3 years following installation of the refuge islands. However, there were 46 vehicle-island crashes during the after period, which were not possible during the 3 years prior to island installation. The study authors concluded that pedestrian safety had been enhanced by addition of the islands due to the 73 percent reduction in midblock pedestrian crashes, but overall safety, as reflected in crash frequency, had decreased due to a 136 percent increase in total crashes. It was noted that the decrease in safety related to vehicle-island crashes might be helped by better island design and lane alignment (*6*).

A 2002 study by Zegeer, Stewart, Huang, and Lagerwey that was primarily intended to determine the safety effects of marked vs. unmarked crosswalks on pedestrian crashes provided some insight into the effectiveness of raised medians (*7*). The 2,000 crossing sites used in the study were uncontrolled crossings at intersection (i.e., no traffic signals or STOP control on intersection approach of interest) or midblock locations. Zegeer et al. found that the presence of a raised median or crossing island was associated with a significantly lower rate of pedestrian crashes on multi-lane roads having either marked or unmarked crosswalks. This was true at marked as well as unmarked crosswalks. Comparing urban or suburban four- to eight-lane roads with a minimum ADT of 15,000 vehicles per day and marked crosswalks, the pedestrian crash rate (pedestrian crashes per million crossings) was 0.74 at crosswalks where there was a raised median and 1.37 for sites without a raised median. For similar sites (multi-lane with ADT above 15,000 veh/day) at unmarked crosswalk locations, the pedestrian crash rate was 0.17 with a raised median and 0.28 for sites without a raised median. Multi-lane road sites that had a center two-way-left-turn lane (TWLTL) or painted (but not raised) median did not correspond to safety benefits for pedestrians compared to multi-lane roads with no medians at all. Thus, this study found that raised medians clearly provide a significant safety benefit to pedestrians on multi-lane roads, particularly on such roads with ADT above 15,000 veh/day (*7*).

A 2003 paper by Kamyab, Andrle, Kroeger, and Heyer discussed the effects of installing a removable pedestrian island and pedestrian crossing signs on a two-lane highway in rural Mahnomen County, Minnesota. Researchers collected pre- and post-treatment speed data to assess short- and long-term effects of the treatments. Results showed a statistically significant reduction in

Source: Kamyab et al., 2003. (*8*)

Figure H-31. A removable pedestrian island installed in conjunction with an in-roadway yield to pedestrians sign at a crosswalk in Minnesota.

mean speeds and increase in speed-limit compliance at the treatment site for both the long and short term (*8*).

A 2003 paper by King, Carnegie, and Ewing evaluated the effect of traffic calming measures involving signal, curb, sidewalk, and raised median installation and intersection redesign along a 3,200-foot section of a four-lane suburban roadway in New Jersey. The researchers used pre- and post-treatment on speed and volume counts, pedestrian tracking, video, and photography to evaluate the effect of the treatments on pedestrian safety. Results showed a 2 mi/h decrease in 85th percentile vehicle speed and a 28 percent decrease in pedestrian exposure risk without affecting vehicle volumes. The researchers predicted that $1.7 million would be saved due to avoided collisions over 3 years as a result of the roadway improvements (*9*).

A 2009 report compiled by Pecheux, Bauer, and McLeod gave the results of an evaluation of median refuge islands installed at two signalized intersections in San Francisco, California. The

Table H-5. Mean vehicle speeds before and after the installation of a removable pedestrian island and pedestrian crossing sign.

	Observed Traffic	Mean Speed (mi/h)	t-statistic	Significant (95%)	Speed Compliance %	t-statistic	Significant (95%)
Passenger Cars							
Before	1152	34.8	--	--	31	--	--
After-1	1067	29.5	13.49	Yes	58	-12.80	Yes
After-2	1331	30.7	11.05	Yes	51	-10.01	Yes
Nonpassenger Cars							
Before	71	37.4	--	--	24	--	--
After-1	46	28.8	4.11	Yes	65	-4.42	Yes
After-2	60	29.5	4.01	Yes	57	-3.84	Yes
All Vehicles							
Before	1237	35	--	--	30	--	--
After-1	1113	29.5	14.20	Yes	58	-13.68	Yes
After-2	1392	30.6	11.02	Yes	51	-10.85	Yes

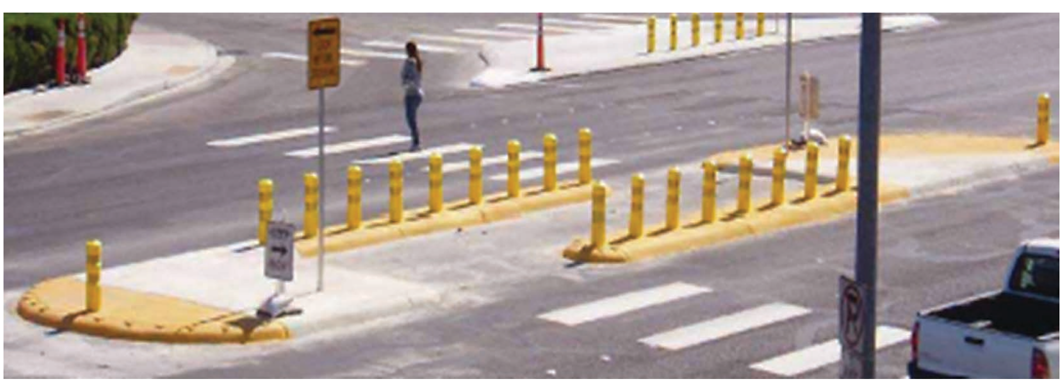
Source: Kamyab et al., 2003. (*8*)

Source: Pecheux et al., 2009. (*10*)

Figure H-32. Pedestrians making use of a median refuge island in San Francisco.

researchers measured the percentage of pedestrians trapped in the roadway, the percentage of pedestrian–vehicle conflicts, the percentage of drivers yielding to pedestrians, and the average pedestrian delay before and after the medians were installed. The researchers found no significant impact on driver yielding, trapped pedestrians, or pedestrian–vehicle conflicts at either of the sites, and a statically significant increase in pedestrian delay at one of the sites. Based on these results, the researchers concluded that the median refuge islands were not very effective at altering driver and pedestrian behaviors at the two San Francisco study sites (*10*).

More recently, a 2012 paper by Pulugurtha, Vasudevan, Nambisan, and Dangeti evaluated four different infrastructure-based countermeasures, including median refuge and Danish offset, combined with high-visibility crosswalks at eight different sites in Las Vegas, Nevada. Pre- and post-treatment observations were collected on weekdays to record data regarding the following measures of effectiveness (MOEs): pedestrians trapped in the street, pedestrians looking for vehicles before beginning to cross, pedestrians looking for vehicles before crossing the second half of the street, percent of captured or diverted pedestrians, driver yield behavior and distance, and drivers blocking the crosswalk. A two-proportion z-test was conducted to determine the statistical significance of post-treatment measurements. For median refuge, there was a statistically significant increase in the proportion of pedestrians who looked for vehicles before beginning to cross, the proportion of drivers yielding to pedestrians, and the distance at which drivers yielded to pedestrians. For



Source: Pulugurtha et al., 2012. (*11*)

Figure H-33. A Danish offset median refuge island as used in Las Vegas, Nevada. This type of offset design is configured so that pedestrians view oncoming traffic as they walk to the second half of the crosswalk.

Danish offset, there was a statistically significant increase in the proportion of diverted pedestrians, proportion of drivers who yielded to pedestrians, and driver yield distance (*11*).

A 2013 TRB paper by Hengel presented the results of a study of a single site in Santa Barbara, California, where a curb extension, pedestrian refuge island, and stop bars were installed. MOEs were crossing delay, number of motorists failing to yield, and distance drivers yield from the crosswalk. Results show that the combination of treatments is effective at reducing wait times to cross, decreasing percentage of vehicles that pass before yielding, and increasing the distance that vehicles yield in advance of the crosswalk (*12*).

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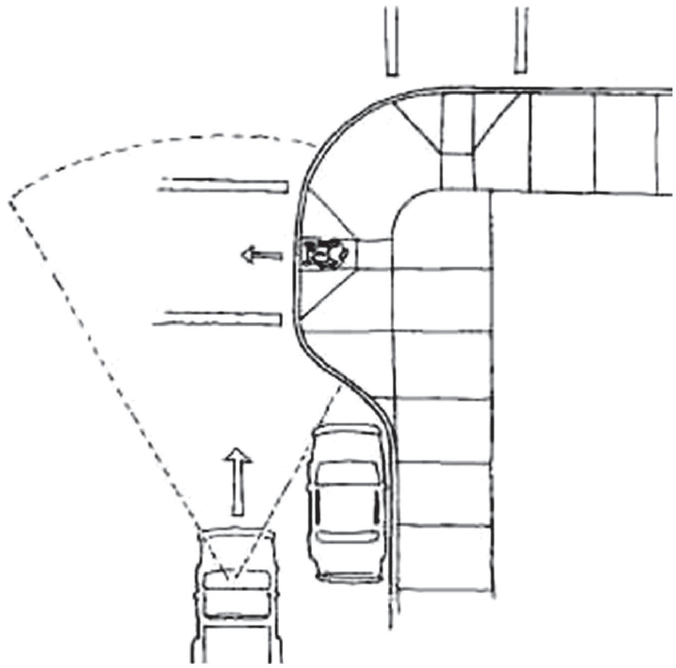
Treatment 7. Curb Extensions

Curb extensions are a way of narrowing the roadway width by extending the curb line or sidewalk into the parking line, which results in reduced vehicle speeds, improved visibility between pedestrians and oncoming motorists, and reduced crossing distance for pedestrians.

A 1999 presentation by King on the subject of traffic calming evaluated the effect of curb extensions on crashes at six locations in New York City. Between 5 and 10 years of collision data were collected for the six curb extension sites. Each crash was given a value based on severity. Overall, the curb extensions reduced overall severity rate at four of the six intersections, leading to increased pedestrian safety and the more widespread use of curb extensions in New York City (*2*).



Source: Axelson et al., 1999. (*1*)

Figure H-34. Sketch of a curb extension, demonstrating how it increases visibility for both drivers and pedestrians and reduces pedestrian crossing distances and vehicle turn speeds.

A 2001 study by Huang and Cynecki involved evaluating curb extensions at eight residential and arterial crosswalk locations in Massachusetts, Washington, North Carolina, and Virginia, based on pedestrian wait time, vehicle speed, and motorist yielding behavior. The researchers employed pre- and post-treatment research design for the sites in Massachusetts and Washington and treatment and control design in North Carolina and Virginia. No significant improvements were found at most of the sample sites after curb extensions were installed. Huang and Cynecki stated that some of the results may have been due to traffic conditions at the study sites. The authors also stated that such devices cannot guarantee that motorists will slow down or yield to pedestrians, or that pedestrians will choose to cross at the crosswalk (*3*).

A 2005 Federal Highway Administration case study analyzed the effect of curb extensions at one uncontrolled intersection in Albany, Oregon. Because there were no pre-treatment data available, nor an appropriate control site, the researchers chose to observe driver behavior at a pedestrian crosswalk that had a recently installed curb extension on only one side of the intersection, with the untreated curb acting as a control. Measures of effectiveness (MOEs) were the average number of vehicles that passed before a pedestrian could cross, the percent of pedestrians crossing with yield, and the percent of vehicles yielding at the advance stop bar. Difference in means was analyzed using a two-sample t-test. It was found that the curb extension contributed to a significant reduction in the mean number of vehicles passing a pedestrian before yielding, possibly due to the increased visibility offered by the curb extension. A 20 percent reduction was observed in vehicles stopping at the advance stop bar on the treatment side; however, this was not statistically significant. The researchers suggested that driver behavior, in addition to a lack of appropriate pedestrian facilities, also contributed to the observed failure to yield to pedestrians (*4*).

A 2013 TRB paper by Hengel presented the results of a study of a single site in Santa Barbara, California, where a curb extension, pedestrian refuge island, and stop bars were installed. MOEs were crossing delay, number of motorists failing to yield, and distance drivers yield from the crosswalk. Results show that the combination of treatments is effective at reducing wait times to cross, decreasing percentage of vehicles that pass before yielding, and increasing the distance that vehicles yield in advance of the crosswalk (*5*).

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Treatment 8. Raised Pedestrian Crossings

Raised pedestrian crossings tend to be applied most often on two-lane business streets in urban environments and are applied both at intersections and midblock. They are generally installed on lower speed roads because they are designed for speeds in ranges below 35 mph and therefore would not be appropriate on higher speed roads.

In 2001, Huang and Cynecki looked at how various pedestrian safety countermeasures, including raised pedestrian crossings, affected the behavior of pedestrians and drivers at three sites in North Carolina and Maryland. Each of the three treatment sites was matched with a control site. Overall, the use of raised crosswalks resulted in lower overall vehicle speeds. At the two North Carolina sites, 50th percentile vehicle speeds were 4.0 to 12.4 mph lower at treatment sites than at control sites. At the Maryland site, 50th percentile vehicle speeds were 2.5 miles per hour lower at treatment sites than at control sites; however, this difference was not statistically significant. At the North Carolina site where the raised crosswalk was installed, there was already an overhead flashing beacon and motorist yielding was significantly higher, while at the other

Source: Federal Highway Administration.

Figure H-35. A raised pedestrian crosswalk.

North Carolina crosswalk, there were insufficient pedestrian crossings for comparison. At the Maryland site, the difference in motorist yielding was not statistically significant. The authors concluded that raised crosswalks are effective at reducing motor vehicle speeds, especially when combined with an overhead beacon. However, in the case of the intersection with the overhead beacon, it was impossible to gauge how much each countermeasure contributed to motorist yielding behavior (*1*).

In the same study, Huang and Cynecki evaluated the installation of a raised intersection in Cambridge, Massachusetts. Before and after data were collected to assess the impact of the raised intersection on motorist yielding, percentage of pedestrians using the crosswalk, and average pedestrian wait time. There was a significant increase in the percentage of pedestrians who crossed in the crosswalk, from 11.5 percent to 38.3 percent. There was an increase in the percentage of motorists who yielded to pedestrians in the crosswalk, but this increase was not statistically significant due to small sample size (*1*).

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Other Treatments

A 2001 report entitled "Alternative Treatments for At-Grade Pedestrian Crossings" (*1*) contains a discussion of experimental measures used at uncontrolled crossings.

A 2012 presentation by Dougald, Dittberner, and Sripathi detailed an experimental zig-zag pavement marking treatment in Loudoun County, Virginia. The Virginia Department of Transportation installed the markings at two locations where pedestrians and bicyclists use the Washington and Old Dominion Trail to cross area highways in 2009. Researchers measured vehicle speeds and driver attitudes pre- and post-treatment and concluded that the use of the markings

Source: Dougald et al., 2016. (*2*)

Figure H-36. Zig-zag pavement markings used in Virginia to call attention to the presence of pedestrians.

increased motorist awareness of the crossings, as evidenced by lower mean vehicle speeds and self-reported yielding behavior. However, surveys revealed limited driver understanding of the markings' purpose (*2*).

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Comprehensive Countermeasure Evaluations

While researchers have been successful in studying various pedestrian safety countermeasures on an individual basis, there are many cases where researchers have studied the effects of comprehensive, often citywide, pedestrian safety programs. Such programs often involve simultaneous engineering, education, and enforcement efforts. While comprehensive programs are frequently successful at improving pedestrian safety, it can be impossible to measure the contribution of any individual countermeasures to the overall improvement in the pedestrian environment. Nonetheless, large-scale safety programs can publicly demonstrate how changes in the pedestrian environment can lead to significantly improved streets for all travelers.

In 1989, Malenfant and Van Houten studied the effects of a program that combined the installation of advance stop lines with signs, education, and enforcement, as a means of increasing motorist yielding at 34 crosswalks in three Canadian cities in Newfoundland and New Brunswick. Baseline data were collected in each of the cities prior to treatment. Post-treatment data analysis revealed that motorist yielding at follow up increased from 54 percent to 81 percent in St. John's (Newfoundland), from 9 percent to 68 percent in Fredericton (New Brunswick), and from 44 percent to 71 percent in Moncton-Dieppe (New Brunswick) (*1*).

In 1999–2000, the small town of Storuman in Sweden reconstructed an arterial road that passed through its center, adding a collection of various traffic calming measures: pedestrian walkways, traffic islands, chicanes ("Danish buns"), a roundabout, and a bicycle path. At the same time, driver conduct codes became stricter, requiring drivers to yield to pedestrians at marked crosswalks at all times. Based on analysis of pre- and post-treatment observations, including video recordings at treatment sites, it was determined that the treatments had significant effects on mode and route choice, increasing pedestrian and bicyclist flow and perception of safety, and reducing the speed of motor vehicles. While fall injury incidence increased slightly in the post-treatment study period (it was theorized to be an effect of greater pedestrian use), collision data analysis indicated that safety increased not only along the arterial road, but also on adjacent roads (*2*).

A 2011 study by Savolainen, Gates, and Datta evaluated the impact of a 2006 comprehensive education, enforcement, and engineering countermeasure program implemented in Detroit, Michigan, on improving pedestrian safety throughout the city. In addition to education and enforcement measures implemented in 2008 and 2009, the City of Detroit installed pedestrian countdown timers at 362 intersections, seven high-intensity activated crosswalk (HAWK) signals, traversable medians, and new pavement markings at crosswalks. Additional pedestrian countdown timers, HAWK signals, and rectangular rapid flash beacons (RRFB) were planned for 2010. Collision data were analyzed from 2004 to 2009, with the period from 2004 to 2007 serving as the pre-treatment phase, and the period from 2008 to 2009 representing the treatment implementation phase. During the implementation period, there was a 17.9 percent reduction in pedestrian crashes, a 20.1 percent reduction in pedestrian injuries, and a marginal (1.7 percent)

Table H-6. Crash trends before and during a citywide intervention in Detroit, Michigan.

Period	Pedestrian Crashes City of Detroit			Pedestrian Crashes Michigan (Exclusive of Detroit)		
	Crashes	Injuries	Fatalities	Crashes	Injuries	Fatalities
Before Intervention	576	464	29	1817	1772	107
During Intervention	473	371	30	1652	1616	88
Percent Reduction	17.9	20.1	-1.7	9.1	8.8	17.4

Source: Savolainen et al., 2011. (*3*)

increase in pedestrian fatalities, compared to statewide collision data. While the comprehensive program made determining specific program impacts difficult to analyze, the program has accompanied an improved pedestrian safety environment throughout the city (*3*).

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Conclusions

The primary source used to compile Appendix H was a UNC HSRC produced draft report of the *Evaluation of Pedestrian-Related Roadway Measures: A Summary of Available Research* by Mead, Zegeer, and Bushell[2]. Selected sections from this resource were extracted or adopted for use in this literature review. A summary is given below of the results of the literature review for the eight selected countermeasures:

Unsignalized Pedestrian Crosswalk Signs and Pavement Markings, Including Advanced Yield or Stop Markings and Signs

Many studies (roughly 30 identified) were found that evaluated pedestrian crosswalk signs, pavement markings, or advanced yield or stop markings and signs. The vast majority have been behavioral or observational studies. Only one study was able to develop a CMF for speed-limit reduction signs. Another study, in Los Angeles, found a crash effect of removing marked crosswalks at locations that did not meet their crosswalk policy. More research is definitely needed to better understand the safety effects of various types of signs and pavement markings for a variety of conditions.

High-Visibility Crosswalk Marking Patterns

Two studies were found that examined the crash effects of high-visibility crosswalk marking patterns, and two studies developed estimated CMFs. However, it is difficult to account for all confounding variables for such evaluations, and this is an issue of much interest to city traffic

[2]Mead, J., C. Zegeer, and M. Bushell (2013). Evaluation of Pedestrian-Related Roadway Measures: A Summary of Available Research. Chapel Hill, North Carolina: Federal Highway Administration.

engineers concerned with whether it is cost-effective to use high-visibility crosswalk marking patterns. More research is needed to determine safety effects of this treatment.

High-Intensity Activated Crosswalk (HAWK) Signals

Very few studies were found that examined HAWK signals; only one (Fitzpatrick and Park) of these studies developed CMFs and that study involved a limited number of sites, primarily from Tucson, Arizona. More work is needed to determine the safety effects of this treatment. Since this treatment is now in the 2009 MUTCD, and many city and state agencies have been installing or considering the installation of this measure, it would be valuable to better understand the crash effects in other cities and under a wide range of conditions.

Rectangular Rapid Flashing Beacons (RRFBs)

All six studies found on RRFBs were behavioral studies, but none developed CMFs. More research is needed to quantify the safety effects of this treatment, particularly since the RRFBs have become quite popular, and many are being installed in cities across the United States.

In-Pavement Warning Lights

Of the studies that were found related to in-pavement warning lights (IPWLs), none attempted to develop CMFs. Furthermore, there is evidence of malfunction and maintenance issues with some of these devices, which could cause difficulty in conducting a crash-based evaluation. However, there may also be reasons why CMF information would be of value for these devices if a suitable sample size of treatment locations could be found.

Pedestrian Refuge Areas

Several studies of pedestrian refuge areas have been identified, but only two developed CMFs, and these were from the mid-1990s, which had somewhat differing results. More work is needed to determine the safety effects of this treatment, particularly the promising nature of this treatment, combined with the large number of refuge islands that have been installed in recent years.

Curb Extensions

Of the four studies found on curb extensions, none developed CMFs. Curb extensions are a promising geometric treatment at unsignalized crossings, since they can result in improved sight distance for pedestrians, reduced speeds of oncoming and turning vehicles, and shorter crossing distance across the street for pedestrians. However, the CMF is not known for this treatment.

Raised Pedestrian Crossings

Only one study was found that examined raised pedestrian crossings, and no CMFs were developed. More work is needed to determine the safety effects of this treatment.

Needs for Further Research

While there were a few research studies that developed crash effects (CMFs) for these eight pedestrian crossing treatments, most of these studies used behavioral, speed, and/or conflict measures only and few CMF values were determined. In summary, regarding the need for evaluating these pedestrian treatments for NCHRP Project 17-56, there is clearly a need to better quantify the CMFs of the eight proposed treatments listed above under various traffic and roadway conditions (e.g., two-lane vs. multi-lane, high-speed vs. low speed, various area types, and road classes, etc.), to the extent possible.

Research studies reviewed as a part of this literature review are listed in the summary tables that follow.

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Summary Tables

Treatment 1. Unsignalized pedestrian crosswalk signs and pavement markings, including advanced yield or stop markings and signs.

	Study Title	Authors	Year	Summary	CMFs?	Application	Notes
Signs	The Effects of Innovative Pedestrian Signs at Unsignalized Locations: A Tale of Three Treatments	Huang et al.	2000	Study of in-street pedestrian signs "State Law - Yield to Pedestrians in Crosswalks in Your Half of the Road" installed in NY and Portland, OR.	No		
	Year 2 Field Evaluation of Experimental "In-Street" Yield to Pedestrian Signs	City of Madison Traffic Engineering Division	1999	Two year evaluation of in-street yield-to-pedestrian signs installed at various locations in Madison, WI.	No		

(continued on next page)

Treatment 1. (Continued).

	Study Title	Authors	Year	Summary	CMFs?	Application	Notes
	In-Street Yield to Pedestrian Sign Application in Cedar Rapids, Iowa	Kannel et al.	2000	Summarized results of placing in-street yield-to-pedestrian signs at three sites in Cedar Rapids, IA.	No		
	Methods to Reduce Traffic Speed in High-Pedestrian Rural Areas	Kamyab et al.	2003	Effects of installing removable pedestrian island and pedestrian crossing signs on a two-lane highway in rural Mahnomen County, MN.	No		
	Safety Evaluation of Yield-to-Pedestrian Channelizing Devices	Strong and Kumar	2006	Report summarized safety evaluation of in-roadway yield-to-pedestrian signs installed at 21 midblock and intersection sites in four PA cities.	No		
	Evaluation of Countermeasures: A Study on the Effect of Impactable Yield Signs Installed at Four Intersections in San Francisco	Banerjee and Ragland	2007	Video recordings to examine change in driver yielding rates as a result of impactable yield signs at three intersections in San Francisco.	No		
	In-Roadway "Yield to Pedestrian" Signs: Placement Distance and Motorist Yielding	Ellis et al.	2007	Studied effect of placing an in-roadway "Yield to Pedestrians" sign at different distances in advance of a crosswalk.	No		
	A Comparison of Gateway In-Street Sign Treatment to Other Driver Prompts to Increase Yielding to Pedestrians at Crosswalks	Bennett et al.	2014	Studied sites with gateway configuration of in-street signs in Lansing and Detroit, MI.	No		
	San Francisco Pedsafe II Project Outcomes and Lessons Learned	Hua et al.	2009	Evaluation of Pedsafe II project in San Francisco to study effectiveness of 13 countermeasures deployed at 29 sites throughout San Francisco, CA.	No		

Treatment 1. (Continued).

	Study Title	Authors	Year	Summary	CMFs?	Application	Notes
Other Signs	TCRP Report 112/NCHRP Report 562: Improving Pedestrian Safety at Unsignalized Crossings	Fitzpatrick et al.	2006	Some factors that influence driver yielding at sign locations may include speed and volume of roadway and whether motorists perceived yielding as a courtesy or the law.	No		
	Field Evaluation of Fluorescent Strong Yellow-Green Pedestrian Warning Signs	Clark et al.	1996	Evaluated performance of pedestrian warning signs that used the new design at sites in central NC.	No		Decrease in conflicts
	Use of Signs and Symbols to Increase the Efficacy of Pedestrian-Activated Flashing Beacons at Crosswalks	Van Houten et al.	1998	Evaluated the effects of two types of experimental signs on motorist yielding behavior.	No		Decrease in conflicts
	An Evaluation of High-Visibility Crosswalk Treatments - Clearwater, Florida	Nitzburg and Knoblauch	1999	Studied effectiveness of internally illuminated overhead crosswalk signs that were installed in conjunction with high-visibility crosswalks at two midblock crossings in Clearwater, FL.	No		
	The Effects of Innovative Pedestrian Signs at Unsignalized Locations: A Tale of Three Treatments	Huang et al.	2000	Evaluated two types of innovative pedestrian signs that were tested in Seattle and Tucson.	No		
	Advanced Yield Markings and Fluorescent Yellow-Green RA 4 Signs at Crosswalks with Uncontrolled Approaches	Van Houten et al.	2002	Studied effects of advance yield markings and fluorescent yellow-green RA 4 signs at 24 rural and urban crosswalks throughout Nova Scotia, Canada.	No		Decrease in conflicts
	San Francisco Pedsafe II Project Outcomes and Lessons Learned	Hua et al.	2009	Evaluation of Pedsafe II project in San Francisco to study effectiveness of 13 countermeasures deployed at 29 sites throughout San Francisco, CA.	No		

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Treatment 1. (Continued).

	Study Title	Authors	Year	Summary	CMFs?	Application	Notes
	Evaluation of SmartStud In-Pavement Crosswalk Lighting System and BlinkerSign Interim Report	Kipp and Fitch	2011	Described experience installing, evaluating, and maintaining SmartStud in-pavement crosswalk lighting system and BlinkerSign.	No		
	Safety Countermeasure and Crash Reduction in New York City - Experience and Lessons Learned	Chen et al.	2012	Evaluated the pedestrian safety impact of speed-limit reductions on roadway segments and at intersections.	Yes – Not currently in CMF Clearinghouse (to be reviewed)	At intersections, pedestrian crashes decreased by 41.49% at treatment sites and 15.58% at comparison sites.	
Marked Crosswalks	Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations: Executive Summary and Recommended Guidelines	Zegeer et al.	2002	Found no statistically significant difference in pedestrian crash risk for various types of crosswalk markings.	No		
	A Review of Pedestrian Safety Research in the United States and Abroad	Campbell et al.	2004	Summarized studies from many (Herms 1972, Gurnett 1974, Tobey et al. 1983, Gibby et al. 1994).	No		
	Pedestrian Accidents in Marked and Unmarked Crosswalks	Jones and Tomcheck	2000	Evaluated pedestrian crashes at crosswalks at unsignalized arterial intersections in Los Angeles to test the validity of the city's crosswalk policies.	Yes – Not in CMF Clearinghouse	73% reduction in pedestrian crashes after crosswalk markings were removed at the 104 sites combined with only one leg with previously marked crosswalks; considering both legs there was a 61% reduction in pedestrian crashes.	
Advanced Stop Lines	The Effects of Advance Stop Lines and Sign Prompts on Pedestrian Safety in Crosswalk on a Multilane Highway	Van Houten	1988	Used a combination of stop markings and "Stop Here for Pedestrian" signs at three Dartmouth, Nova Scotia, crosswalks to analyze the effect of the treatments on vehicle-pedestrian conflicts and yielding behavior.	No		
	Increasing the Percentage of Drivers Yielding to Pedestrians in Three Canadian Cities with a Multifaceted Safety Program	Malenfant and Van Houten	1989	Studied advance stop lines used with signs as a means of increasing motorist yielding at 34 crosswalks in three Canadian cities in Newfoundland and New Brunswick.	No		

Treatment 1. (Continued).

	Study Title	Authors	Year	Summary	CMFs?	Application	Notes
	The Influence of Signs Prompting Motorists to Yield Before Marked Crosswalks on Motor Vehicle-Pedestrian Conflicts at Crosswalks with Pedestrian-Activated Flashing Lights	Van Houten and Malenfant	1992	Continued evaluation of advance stop markings as used with a pedestrian warning sign.	No		Reduction in conflicts
	Rumble Strips and Pedestrian Safety	Cynecki et al.	1993	Studied effects of different types of advanced stop indicator.	No		
	Advance Yield Markings: Reducing Motor Vehicle-Pedestrian Conflicts at Multilane Crosswalks with Uncontrolled Approach	Van Houten et al.	2001	Studied effectiveness of advance yield markings used with symbol signs at three crosswalks in Nova Scotia, Canada, where yellow flashing beacons were already in place.	No		Reduction in conflicts
	Advanced Yield Markings and Fluorescent Yellow-Green RA 4 Signs at Crosswalks with Uncontrolled Approaches	Van Houten et al.	2002	Results of experiments that studied the effects of advance yield markings and fluorescent yellow-green RA 4 signs at 24 rural and urban crosswalks throughout Nova Scotia, Canada.	No		Reduction in conflicts
	Advanced Yield Markings and Pedestrian Safety: Analyses of Use with Danish Offsets and Median Refuge Islands	Nambisan et al.	2007	Examined driver and pedestrian behavior at unsignalized intersections with respect to combinations of Danish offset, advance yield markings, and high-visibility crosswalk markings.	No		
	Pedestrian Safety Engineering and ITS-Based Countermeasures Program for Reducing Pedestrian Fatalities, Injury Conflicts, and Other Surrogate Measures	Pecheux et al.	2009	Results of an evaluation of advance stop lines installed at one signalized and one unsignalized intersection in San Francisco.	No		

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Treatment 1. (Continued).

	Study Title	Authors	Year	Summary	CMFs?	Application	Notes
	Effect of Advanced Yield Markings and Symbolic Signs on Vehicle-Pedestrian Conflicts: A Field Evaluation	Samuel et al.	2013	Two experiments conducted in MA to determine the effectiveness of driver yielding behavior and ability to scan for pedestrians at advanced yield markings.	No		
	Build It and They Will Yield: Effects of Median and Curb Extension Installations on Motorist Yield Compliance	Hengel	2013	Single site study in CA of curb extension, pedestrian refuge island, and stop bar installation.	No		

Treatment 2. High-visibility crosswalk marking patterns.

Study Title	Authors	Year	Summary	CMFs?	Application	Notes
An Evaluation of High-Visibility Crosswalk Treatments - Clearwater, Florida	Nitzburg and Knoblauch	2001	Evaluated the effectiveness of high-visibility crosswalk markings used in conjunction with an illuminated overhead crosswalk sight at two sites in Clearwater, FL.	No		
Evaluation of School Traffic Safety Program Traffic Control Measure Effectiveness	Chicago DOT	2005	Results of an evaluation of experimental use of strong yellow/green crosswalk markings at over 100 Chicago elementary school zone crosswalks.	No		
An Empirical Bayesian Evaluation of the Safety Effects of High-Visibility School (Yellow) Crosswalks in San Francisco	Feldman et al.	2010	EB evaluation of safety outcomes of installing high-visibility crosswalks at 54 school sites in San Francisco, CA.	Yes – Not in CMF Clearinghouse	37% reduction in collisions	
Detection Distances to Crosswalk Markings: Transverse Lines, Continental Markings, and Bar Pairs	Fitzpatrick et al.	2011	Evaluated the relative visibility of three types of crosswalk markings, transverse lines, continental markings, and bar pair markings, under daytime and nighttime conditions.	No		

Treatment 2. (Continued).

Study Title	Authors	Year	Summary	CMFs?	Application	Notes
Safety Countermeasures and Crash Reduction in New York City - Experience and Lessons Learned	Chen et al.	2012	Considered the effectiveness of high-visibility crosswalks in increasing pedestrian safety at intersections.	Yes – Not currently in CMF Clearinghouse (to be reviewed)		Authors estimated a 48% reduction in pedestrian crashes. Reduction was in crash rates.
Evaluating the Effectiveness on Infrastructure-Based Countermeasures on Pedestrian Safety	Pulugurtha et al.	2012	Evaluated four different infrastructure based countermeasures installed individually or in combination with other countermeasures at eight sites in Las Vegas, NV.	No		

Treatment 3. High-intensity activated crosswalk (HAWK) signals.

Study Title	Authors	Year	Summary	CMFs?	Application	Notes
Improving Pedestrian Safety at Unsignalized Crossings	Fitzpatrick et al.	2006	Evaluated various midblock crossing treatments including PHB.	No		
Safety Effectiveness of the HAWK Pedestrian Crossing Treatment	Fitzpatrick and Park	2010	Evaluated safety effectiveness of PHB at 21 sites in Tucson, AZ.	Yes – In CMF Clearinghouse (3&4 star ratings)	29% reduction (total crashes), 69% reduction (ped crashes), 15% reduction (severe crashes)	
Pedestrian Crossings at Mid-Block Locations: A Comparative Study of Existing Signal Operations	Deng et al.	2013	Compared four midblock crossing signal types for safety and efficiency: pedestrian-activated (PA), pedestrian light controlled (PELICAN), high-intensity activated crosswalk (HAWK), and pedestrian user-friendly intelligent (PUFFIN).	No		

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Treatment 3. (Continued).

Study Title	Authors	Year	Summary	CMFs?	Application	Notes
Pedestrian and Motorists' Actions at Pedestrian Hybrid Beacon Sites: Findings from a Pilot Study. International Journal of Injury Control and Safety Promotion	Pulugurtha and Self et al.	2013	Researchers collected observational behavioral effects data from pedestrian crossings during weekday morning and evening peak times at five time points: before the installation, and at 1, three, 6, and 12 months following installation.	No	Increase in the percentage of yielding motorists, a decrease in the percentage of trapped pedestrians, and a decrease in pedestrian–vehicle conflicts at all three sites.	

Treatment 4. Rectangular rapid flashing beacons (RRFBs).

Study Title	Authors	Year	Summary	CMFs?	Application	Notes
Stutter-Flash Light Emitting-Diode Beacons to Increase Yielding to Pedestrians at Crosswalks	Van Houten et al.	2008	Studied effectiveness of RRFBs in increasing motorist yielding behavior.	No		Reduction in conflicts, not crashes
Pedestrian Safety Engineering and ITS-Based Countermeasures Program for Reducing Pedestrian Fatalities, Injury Conflicts, and Other Surrogate Measures: Final System Impact Report	Pecheux et al.	2009	Used various measures of effectiveness to assess the effect of RRFBs on pedestrian and driver behavior.	No		Reduction in conflicts, not crashes
San Francisco PedSafe II Project Outcomes and Lessons Learned	Hua et al.	2009	Evaluated safety effectiveness of flashing beacons activated by pedestrians and ones that automatically detected pedestrians using infrared technology.	No		Reduction in conflicts, not crashes
Evaluation of the Rectangular Rapid Flash Beacon at a Pinellas Trail Crossing in St. Petersburg, Florida	Hunter et al.	2009	Summarized effects of installing a pedestrian-activated RRFB at the location of one uncontrolled trail crossing.	No		

Treatment 4. (Continued).

Study Title	Authors	Year	Summary	CMFs?	Application	Notes
Effects of Yellow Rectangular Rapid-Flashing Beacons on Yielding at Multilane Uncontrolled Crosswalks	Shurbutt and Van Houten	2010	Reported on effects of installing a yellow RRFB at 22 multilane uncontrolled crosswalks in St Petersburg, FL, Washington, DC, and Mundelein, IL.	No		Reduction in conflicts, not crashes
Assessment of Driver Yielding Rates Pre- and Post-RRFB Installation, Bend, Oregon	Ross et al.	2011	Evaluated RRFB installation at two Bend, OR crosswalks.	No		
Improving Crosswalk Safety: Rectangular Rapid-Flashing Beacon (RRFB) Trial in Calgary.	Domarod et al.	2013	Observed driver yielding with staged crossings at six locations in Calgary, Canada.	No	The RRFBs were observed to increase yielding by an average of 15 percent, to nearly 100 percent motorist yielding at the majority of the study sites. Overall the average motorist yielding increased from 83 percent to 98 percent following the installation of the RRFB.	
Evaluating Driver and Pedestrian Behaviors at Enhanced Multi-lane Midblock Pedestrian Crossings: A Case Study in Portland, OR	Foster et al.	2014	Reported on motorist yielding and pedestrians' use of RRFBs when they were activated by the pedestrians versus not activated.	No	Site 1: Motorist yielding was 92% when beacons were activated and 75% when beacons were not activated. Site 2: Motorist yielding was 91% when the RRFBs were activated and 45% when not activated.	
Evaluation of Pedestrian and Bicycle Engineering Countermeasures: Rectangular Rapid-Flashing Beacons, HAWKs, Sharrows, Crosswalk Markings, and the Development of an Evaluation Methods Report.	Fitzpatrick et al.	2011	Report on driver yielding with staged crossings rates at multilane sites.	No	Driver yielding increased across all sites.	

Treatment 5. In-pavement warning lights.

Study Title	Authors	Year	Summary	CMFs?	Application	Notes
An Evaluation of Flashing Crosswalks in Gainesville and Lakeland	Huang	2000	Effects of in-pavement lighting on driver compliance and motorist yielding to pedestrians.	No		
Kirkland's Experience with In-Pavement Flashing Lights at Crosswalks	Godfrey and Mazella	1999	Effects of in-pavement lighting on driver compliance and motorist yielding to pedestrians.	No		

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Treatment 5. (Continued).

Study Title	Authors	Year	Summary	CMFs?	Application	Notes
An Evaluation of Crosswalk Warning Systems: Effects on Pedestrian and Vehicle Behavior	Hakkert et al.	2002	Studied the effectiveness of an in-pavement flashing light system that automatically detects the presence of pedestrians using infrared sensors (Israel).	No		
Evaluation of In-Pavement, Flashing Warning Lights on Pedestrian Crosswalk Safety	Van Derlofske et al.	2003	Results of a field evaluation of in-pavement flashing lights installed at two crosswalk sites at an uncontrolled intersection in Denville, NJ.	No		
An Evaluation of the Effectiveness of an In-Pavement Flashing Light System	Karkee et al.	2006	Summarized effectiveness of an in-pavement flashing light system installed at one uncontrolled crosswalk in the Las Vegas metropolitan area.	No		
Evaluation of SmartStud™ In-Pavement Crosswalk Lighting System and BlinkerSign®	Kipp and Fitch	2011	Observational study of in-pavement lights.	No	Found that while the system installed increased yielding and decreased approached speeds, it was removed due to multiple malfunctions and damage	

Treatment 6. Pedestrian refuge areas.

Study Title	Authors	Year	Summary	CMFs?	Application	Notes
Effects of Urban and Suburban Median Types on Both Vehicular and Pedestrian Safety	Bowman and Vecellio	1994	Determine effects of urban and suburban median types on the safety of vehicles and pedestrians.	Maybe		
Pedestrian Safety in Australia	Cairney	1999	Crash rates decrease with wider medians.	No		Reduction in crash rates, not crashes
The Road Safety Effectiveness of Wide Raised Medians	Claessen and Jones	1994	Investigated effects of replacing painted medians with wide raised medians.	Yes – Not in CMF Clearinghouse	Reduced pedestrian crashes by 23%	
The Effects of Traffic Calming Measures on Pedestrian and Motorist Behavior	Huang and Cynecki	2001	Evaluated a variety of traffic calming measures in several US cities.	No		

Treatment 6. (Continued).

Study Title	Authors	Year	Summary	CMFs?	Application	Notes
Pedestrian Refuge Island Safety Audit	Bacquie et al.	2001	Before-after study to evaluate the safety effectiveness of raised pedestrian refuge islands.	Yes – Not in CMF Clearinghouse	73% reduction in midblock pedestrian crashes with addition of islands (however, there was a 136% increase in total crashes)	
Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Intersections	Zegeer et al.	2002	Determine safety effects of marked vs. unmarked crosswalks on pedestrian crashes.	No		
Methods to Reduce Traffic Speed in High-Pedestrian Rural Areas	Kamyab et al.	2003	Effects of installing removable pedestrian island and pedestrian crossing signs on a two-lane highway in rural Mahnomen County, MN.	No		
Pedestrian Safety Through a Raised Median and Redesigned Intersections	King et al.	2003	Evaluated the effect of traffic calming measures involving signal, curb, sidewalk, and raised median installation and intersection redesign along a four-lane suburban road in NJ.	No		
Pedestrian Safety Engineering and ITS-Based Countermeasures Program for Reducing Pedestrian Fatalities, Injury Conflicts, and Other Surrogate Measures: Final System Impact Report	Pecheux et al.	2009	Results of an evaluation of median refuge islands installed at two signalized intersections in San Francisco, CA.	No		
Evaluating the Effectiveness of Infrastructure-Based Countermeasures on Pedestrian Safety	Pulugurtha et al.	2012	Evaluated four different infrastructure-based countermeasures including median refuge and Danish offset combined with high-visibility crosswalks at eight different sites in Las Vegas.	No		
Build It and They Will Yield: Effects of Median and Curb Extension Installations on Motorist Yield Compliance	Hengel	2013	Single site study in CA of curb extension, pedestrian refuge island, and stop bar installation.	No		

Treatment 7. Curb Extensions.

Study Title	Authors	Year	Summary	CMFs?	Application	Notes
Calming NYC Intersections	King	1999	Evaluated the effect of curb extensions on crashes at six locations in NYC.	No		
The Effects of Traffic Calming Measures on Pedestrian and Motorist Behavior	Huang and Cynecki	2001	Evaluated curb extensions at eight residential and arterial crosswalk locations in MA, WA, NC, and VA.	No		
Pedestrian Safety Impacts of Curb Extensions: A Case Study	Johnson	2005	Case study analyzed effect of curb extensions at one uncontrolled intersection in Albany, OR.	No		
Build It and They Will Yield: Effects of Median and Curb Extension Installations on Motorist Yield Compliance	Hengel	2013	Single site study in CA of curb extension, pedestrian refuge island, and stop bar installation.	No		

Treatment 8. Raised pedestrian crossings.

Study Title	Authors	Year	Summary	CMFs?	Application	Notes
The Effects of Traffic Calming Measures on Pedestrian and Motorist Behavior	Huang and Cynecki	2001	Looked at how various pedestrian safety countermeasures, including raised pedestrian crossings, affected the behavior of pedestrians and drivers at three sites in NC and MD. Also evaluated (before/after study) a raised crosswalk in Cambridge, MA	No		

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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